thermal Tolerance

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Experimentally-derived upper thermal tolerances for redhorse suckers: revised 316(A) variance conditions at two generating facilities in Ohio

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Abstract

American Electric Power's Conseville Station and Muskingum River Plant, located on the Muskingum River in southeastern Ohio, utilize once-through cooling for seven (combined) generating units. Both facilities had approved 316(a) variances that required maintenance of a baseline fully-mixed downstream temperature of 31.6°C (88.9°F). Fish sampling conducted during critical conditions in Summer 1993 indicated the presence of thermally-sensitive redhorse suckers (*Moxostoma* sp.) at river temperatures > 32.2°C (90.0°F). Because the assumed upper tolerance limit for redhorse suckers (31.6°C) was extrapolated from field observations, we determined the actual thermal tolerance of suckers using fish collected locally. During September 1996 golden and shorthead redhorses were collected from the nearby Walhonding River. The short-term upper thermal tolerances were determined by the ultimate upper incipient lethal temperature (UUILT) and the critical thermal maximum (CTM) endpoints. For shorthead redhorse the calculated UUILT was 33.3°C (91.9°F), and the CTM was 35.1°C (95.2°F). For golden redhorse a similar CTM was obtained; however, a reliable UUILT could not be extrapolated due to procedural problems. The results of these tests played a role in Ohio EPA approving a higher fully-mixed downstream limit. This study demonstrates the value of obtaining thermal tolerances experimentally when assumed tolerance values are considered suspect. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Thermal tolerance; Redhorse suckers; Ultimate upper incipient lethal temperature (UUILT); Critical thermal maximum (CTM); Thermal variance

1. Introduction

American Electric Power (AEP) operates two once-through cooled generating facilities on the Muskingum River in southeastern Ohio (Fig. 1). Conesville Station consists of six generating units, three of which are once-through cooled (combined capacity of the three units = 415 MW). Conesville Station is located in the upper Muskingum River (formed at the confluence of the Walhonding and Tuscarawas Rivers) which is free-flowing. The facility is located at River Mile 103 (measured upstream from Marietta, OH); the 7 day once-in-ten-year low flow at Coshocton, OH is 14.1 m^3 s^{-1}. Downstream of Zanesville, the Muskingum River becomes impounded by a series of low-head dams until its confluence with the Ohio River at Marietta, OH. Muskingum River Plant, located at River Mile 30.3, consists of four once-through cooled generating units (combined capacity = 840 MW). The 7 day once-in-ten-year low flow at Beverly, OH (8 km downstream) is 24.4 m^3 s^{-1}.

Following extensive biological and water quality studies conducted in the 1970s and early 1980s, both

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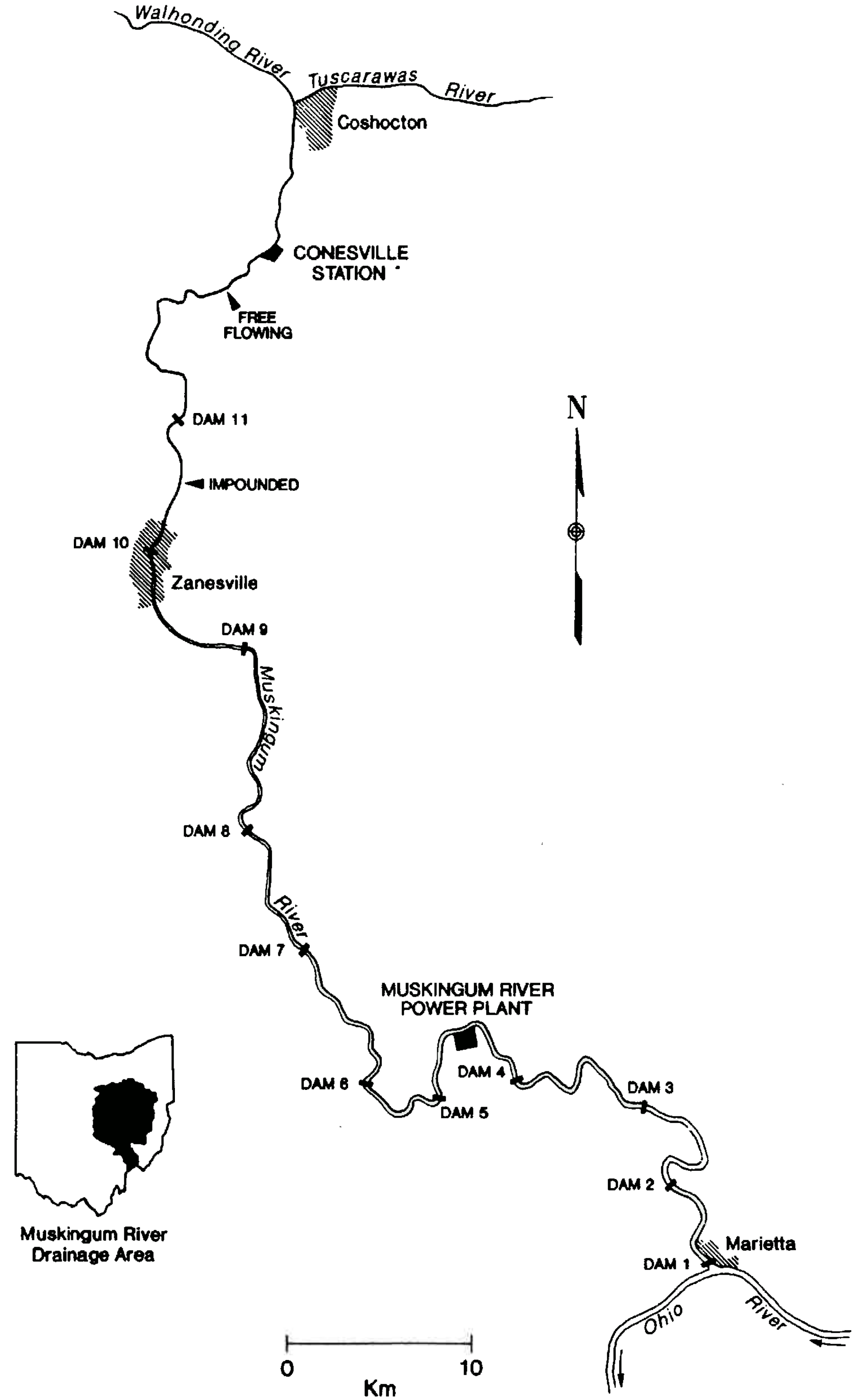

Fig. 1. Location of Conesville Station and Muskingum River Plant.

facilities were granted approved 316(a) thermal discharge variances by Ohio EPA in 1985. The variances were defined as upper-end heat rejection rates. Biological studies conducted by both AEP and Ohio EPA during extreme low-flow, high temperature conditions in Summer 1988 indicated a temporary reduction in Index of Biotic Integrity (IBI) and Modified Index of well-being (MIwb) scores downstream of each facility, caused largely by thermal avoidance of sensitive fish species. Follow-up biological studies conducted from 1989–1991 showed that the fish community had fully recovered from adverse effects observed in 1988 (EA, 1991a, b). Ohio EPA, however, revoked the 316(a) variances at both facilities during the 1990 NPDES permit renewal, citing that the originally-approved variance could not ensure protection of sensitive aquatic life during critical conditions. A subsequent settlement of the permits allowed AEP to submit updated 316(a) demonstrations that would serve as the basis for any newly approved variances (EA, 1991a, b). Until a new variance was approved, the facilities were required to maintain a fully-mixed downstream temperature of ≤31.6°C (88.9°F).

AEP's strategy to seek re-approved variances was to: 1) conduct instream fish sampling during low-flow, high temperature conditions to assess the response of sensitive species *in situ*; and 2) evaluate the technical basis of assumed upper thermal tolerance values for sensitive species. A favorable low flow, high temperature period occurred during August and September 1993. Instream fish sampling (night time DC-pulsed electrofishing using Ohio EPA methodologies) was conducted at established upstream and downstream zones. At Muskingum River Plant two species of redhorse suckers were collected at sites having measured water temperatures between 32–33°C (90–91°F). Redhorse suckers were found in moderate abundance downstream of Conesville Station, however measured downstream temperatures did not exceed 28.0°C (82.4°F).

Next, we evaluated the existing Ohio EPA thermal effects database and criteria (the criteria were established in the 1978 Water Quality Standards revision). The thermal effects database was outdated (i.e., there was no thermal effects information published after 1977), even though the established criteria represented a comprehensive review of known thermal tolerance data and ecological requirements. An updated thermal effects database was compiled for those species known to occur in the Muskingum River, using published and unpublished information (e.g., Wismer and Christie, 1987; Hokanson, 1990).

There was little available information on experimentally-derived upper thermal tolerance values for redhorse suckers. Cherry et al. (1977) reported Upper Incipient Lethal Temperature (UILT) values as a function of acclimation temperature for northern hog sucker (*Hypentelium nigricans*), an ecologically-related species. The derived UILT values ranged from 30–34°C (86–93°F) within a range of acclimation temperatures (21–33°C; 70–91°F). In a study published after this project, Walsh et al. (1998) reported the physiological tolerances of robust redhorse (*Moxostoma robustum*) to temperature, salinity, pH and hypoxia. This species, however, is found only in southeastern Atlantic Coast drainage basins. Because of uncertainty regarding the true temperature tolerance of suckers residing in the Muskingum River, we conducted thermal bioassays to determine the upper thermal tolerances for two common species.

2. Methods

Upper thermal tolerance testing of golden redhorse (*Moxostoma erythrurum*) and shorthead redhorse (*Moxostoma macrolepidotum*) was conducted at Conesville Station during August and September, 1996. A trailer equipped with thermal exposure chambers and water quality monitoring equipment served as the test facility. Both species were collected from the nearby Walhonding River (major tributary of the Muskingum River) in early September. The Walhonding River has documented good water quality and exceptional aquatic life (Ohio EPA, 1996). We initially attempted to capture suckers using large seines. Too few suckers were collected in the target size range by seining, however, so boat-mounted DC-pulsed electrofishing was employed after obtaining approval from Ohio EPA.

The target size for both species was 200–300 mm total length (TL), but we used fish within the range 153–350 TL (large juveniles and small adults). Within 10–20 min of capture, fish were transferred from the boat's live well to aerated containers on shore. Fish were then transported to the test trailer at Conseville Station. Upon arrival, fish were transferred to two 2500 l acclimation pools (separate pools for each species). Water temperature in the pools was within 1°C of the temperature measured in the Walholding River. Each pool received water (pumped from the Muskingum River) on a flow-through basis at the renewal rate of 20 l min^{-1}. The fish in both pools were acclimated to a temperature ranging between 20.6–23.8°C (69.1–74.8°F) for 7 days prior to testing. A more precise control of acclimation temperature was not possible due to the large volume of water.

Shorthead redhorse mortality was low (15%) during acclimation. Due to a high rain event (causing a blockage of feed water into the golden redhorse tank), significant mortality (47%) occurred in this pool during acclimation. Although no further mortalities were observed, the stress upon surviving fish may have lowered their thermal resistance.

After the acclimation period, fish of both species were randomly distributed into a series of temperature-controlled tanks (180 l capacity). Two replicate and one control tank were established for each species. Ten to twelve fish were added to each replicate and each control tank. The temperature in each tank was controlled using a series of heaters and temperature controllers which allowed regulation of water temperature within 0.5°C of the target temperature. The temperature of the control tanks was 22.5°C (72.7°F) throughout the exposure period, with deviations being less than 0.5°C. Temperatures in each replicate tank were increased 1°C day^{-1} in increments of 0.5°C 12 h^{-1}. This slow rate of increase allows fish to acclimate to each successively higher temperature and allows a more accurate estimate of the UUILT (Hokanson and Koenst, 1986). The temperature at which each fish died was recorded.

The determination of UUILT values in this study deviated from traditional procedures. Historically, the UILT endpoint was determined by exposing test organisms to an abrupt temperature change. In this study, the UUILT was determined using the slow heating method as used by Hokanson and Koenst (1986) and recommended by Kilgour and McCauley (1986).

After complete mortality in the test groups had been reached, the remaining control fish for each species were exposed to a rapid temperature increase (3–5°C h^{-1}) to determine the critical thermal maximum (CTM). The CTM was calculated as the arithmetic mean of the temperatures at which each individual fish died. Because death is typically not the endpoint used for CTM determinations, the CTM endpoint used in this study is actually a lethal thermal maximum as defined by Becker and Genoway (1979).

3. Results and discussion

3.1. Ultimate upper incipient lethal temperature

Golden redhorse proved difficult to test during the UUILT trial. Although none of the control fish died during the experiment, fish in all tanks were quite agitated by confinement. Three fish actually jumped out of one of the replicate tanks during the first 5 days of the test despite a mesh tank cover that enclosed most of the exposure chamber opening. All of the golden redhorse died at water temperatures between 27.0 and 30.6°C (80.6–87.1°F), suggesting an upper thermal tolerance of around 28.5°C (83.3°F).

Testing of shorthead redhorse was less problematic. In the first replicate, the calculated UUILT was 34.4°C (93.9°F). The calculated UUILT for the second replicate was 31.5°C (88.7°F) (Fig. 2). The average UUILT was 33.3°C (91.9°F). This value is higher than the assumed upper thermal tolerance of 30.8°C (87.4°F) for redhorse suckers, which was based on field observations made during studies in the Wabash River in the early 1970s (Gammon, 1973).

3.2. Critical thermal maximum

Following completion of the UUILT experiment, CTM trials were conducted using control fish. During the golden redhorse CTM test, the temperature was increased from 21.1 to 37.1°C (70.0–98.8°F) during a 3.3 h period (average heating rate of 4.8°C h^{-1}). The calculated CTM for this species was 35.4°C (95.7°F). For shorthead redhorse, the CTM trial was begun at a temperature of 19.9°C (67.8°F). The test was terminated after an exposure period of 4.9 h, during which the final temperature was 36.3°C (97.3°F; average heating rate of 3.4°C h^{-1}). A CTM value of 35.1°C (95.2°F) was obtained for shorthead redhorse (Fig. 3).

Although an experimentally-derived UUILT for golden redhorse was obtained, we considered this value unreliable, for several reasons. First, golden redhorse were observed to experience stress that was unrelated to temperature increase. Although the UUILT test could have been repeated from the start, the successful completion of the CTM test (and other pragmatic factors) argued against this. Secondly, the collection of this species at measured water temperatures higher than 30°C (86°F), at locations on the Muskingum River and elsewhere, cast further doubt on the reliability of a UUILT value around 28–29°C (82–84°F) for this species. Third, the similar CTM values for both species suggest a true UUILT for golden redhorse that approximates the derived UUILT for shorthead redhorse.

Upper thermal tolerances reported for other round-bodied sucker species are similar to the tolerance parameters determined in this study. As mentioned above, previously published reported UILT values for northern hog sucker ranged between 30 and 34°C (Cherry et al., 1977). Walsh et al. (1998) reported mean critical thermal maxima of 34.9°C (94.8°F) and 37.2°C (99.0°F) for robust redhorse acclimated to 20°C and 30°C, respectively. The seemingly higher upper thermal tolerance for robust redhorse (a southern species) is not unexpected. Temperature-preference relationships are known to be related to the amplitude of annual thermal-cycles during a species' recent evolutionary history (Johnson and Kelsch, 1998). In summary, all of the above factors were considered adequate justification for considering the calculated UUILT value for golden redhorse as unreliable.

The experimentally derived upper thermal tolerances for the two redhorse species were used to address

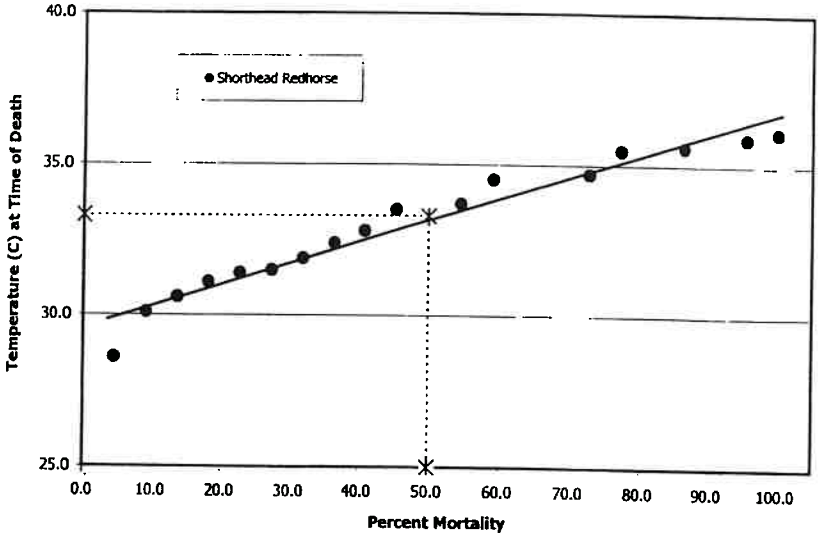

Fig. 2. Plot of temperature at time of death vs total percent mortality for shorthead redhorse (both replicates combined) using the slow-heat method. Mean UUILT=33.3°C (91.9°F).

requested changes to the existing 316(a) variance for both facilities. The 316(a) variance is incorporated into the facilities' thermal management plan, a detailed set of requirements specified in the waste-water permits. The principal requirement is maintenance of specific downstream temperatures during summer and fall months. River conditions and combined unit generation are monitored on a real-time basis, which is necessary to ensure compliance with the requirements.

From an allowable generation standpoint, the most important condition in the thermal management plan is the baseline not-to-exceed fully mixed river temperature. After compiling the results of recently published thermal tolerance data and information obtained from this study, AEP argued that a less stringent baseline not-to-exceed temperature would be protective of all species that would be expected to occur in the Muskingum River. Ohio EPA agreed that the technical basis for revising this temperature had changed, and approved a new baseline fully-mixed temperature change from 31.6°C (88.9°F) to 32.8°C (91.0°F). The allowable 'excursion' above the baseline fully-mixed temperature was retained, which required maintenance of a fully-mixed temperature no higher than 33.9°C (93.0°F) for a total of up to 287 h of plant operation.

Changes to the 316(a) variances and thermal management plans will allow the facilities the opportunity to maximize generation during critical demand periods.

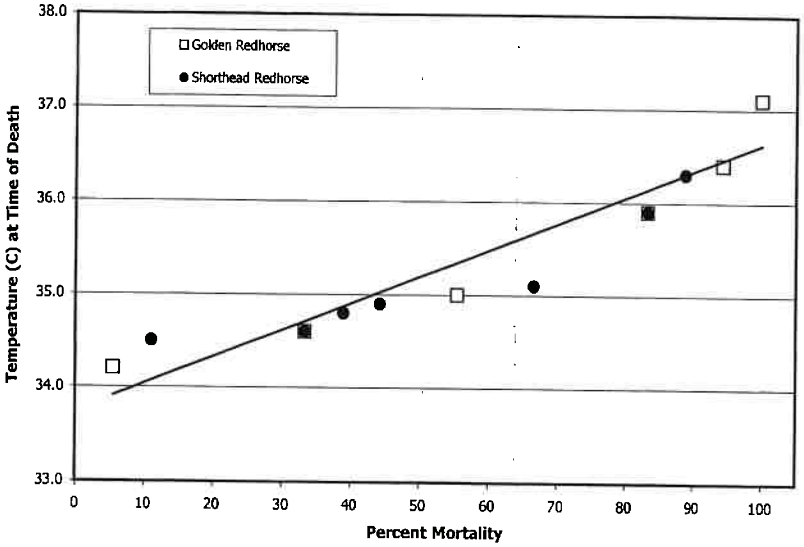

Fig. 3. Plot of temperature at time of death vs total percent mortality for golden and shorthead redhorse (both replicates combined) using the rapid temperature increase method. Mean UUILT=35.3°C (95.5°F).

Although this is desirable from a business perspective, it is worth noting that the changes would not have been allowed unless adequate protection of sensitive species and biological communities could be demonstrated.

4. Conclusion

Our study demonstrated the value of deriving thermal tolerances for fish species whose assumed thermal tolerances are considered suspect. This does not imply that the technical basis for existing temperature criteria are flawed simply because they were derived several years ago. Rather, there must be sound technical reasons to question the validity of a water quality criterion. Thermal testing is one option that can be used to evaluate the accuracy of an established temperature criterion. Clearly, the cost associated with such a project must be evaluated in light of the projected economic benefit of favorable results.

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