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Winter Residency of Smallmouth Bass in a Thermal Discharge Canal: Implications for Tempering Pump Operation

Steven J. Cooke,[1] Christopher M. Bunt, and R. Scott McKinley*

Waterloo Biotelemetry Institute, Department of Biology, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

Abstract.—The behavior of smallmouth bass *Micropterus dolomieu* was studied in the Nanticoke Thermal Generating Station discharge canal on Lake Erie during the winter to examine the effects of thermal tempering pump operation. A series of seven fixed underwater antennas continuously monitored movements of 20 radio-tagged fish from January 7 until March 15, 1998. Fish were released at the head of the discharge canal, upstream from the eight tempering pumps where they were captured. Most fish spent the entire study within 25 m of the release site. Small-scale movements occurred when fish moved back and forth from the most upstream tempering pump (which was not operational during the study) to an adjacent eddy. Five fish moved greater distances throughout the length of the discharge canal, with most of their time spent in areas that provided velocity refuges and cover (e.g., large rip-rap and oil-boom structures); their movements appeared to be independent of environmental conditions. The benefits of the thermal tempering pumps for smallmouth bass in the discharge canal in winter appear to be minimal because the majority of their time was spent upstream of pump influence. The design and operation of power plant cooling systems should consider the tradeoffs between the actual mitigative effects of tempering pump operation and the increased fish impingement and entrainment associated with such operating conditions.

Heated discharges from power plants alter the nearshore ecology of aquatic systems (Coutant 1970; Benda and Proffitt 1973; Reutter and Herdendorf 1976). Studies have repeatedly documented the attraction of fish to heated discharges during cold months (Benda and Proffitt 1973). In addition, numerous laboratory studies have been conducted to determine the effects of heat and cold shock on fish (e.g., Reutter and Herdendorf 1976; Wilde 1988). However, Sawyko and Smythe (1983) suggested that the application of laboratory results should not be generalized and related to field locations for which relevant parameters may be unknown.

Smallmouth bass *Micropterus dolomieu* are an important game fish species in North America. Lake Erie has long been renowned for the quality of its smallmouth bass fishery, particularly in the vicinity of the Nanticoke Thermal Generating Station (NTGS; MacGregor and Witzel 1987). Fish may be attracted to the NTGS outfall largely because of variable temperature (MacGregor and Witzel 1987) and, in particular, flow (MacLean et al. 1982). These factors and prey abundance have been cited most often as the cause of fish invasions into thermal discharges (e.g., Moore et al. 1973).

During the winter months, smallmouth bass associated with the thermal plume at the NTGS on Lake Erie could potentially experience rapid changes in temperature related to peaking discharges. Cold shock can influence the behavior and enzymatic processes in fish resulting in stress and sometimes death (Fry 1971). The thermal effluent from the station is regulated by limits on the temperature rise (ΔT) across the station and maximum effluent temperature (T_{max}). To reduce the temperature differential between intake and discharge waters, normal operating procedure involves the use of one thermal-tempering pump for every two cooling-water pumps in operation (Foster and Wheaton 1981). Eight tempering pumps shunt ambient intake water directly to the heated discharge stream to meet the prescribed limits. The original limits, $\Delta T = 8.3°C$ and $T_{max} = 32.2°C$, were conditionally increased to 12.5°C and 35.0°C, respectively, in 1983. This has enabled the station to operate using only three or four tempering pumps.

Since 1983, NTGS has conducted a range of biological studies to assess the implications of current and further reductions in tempering pump operations. The primary considerations are the benefits of reduced intake volume and, therefore, reduced fish entrainment and impingement versus the possible negative effects of more extreme thermal fluctuations on fish species (e.g., smallmouth bass) in the discharge. This field study was con-

* Corresponding author: smckinle@sciborg.uwaterloo.ca
[1] Present address: Center for Aquatic Ecology, Illinois Natural History Survey, Champaign, Illinois 61820, USA.

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TABLE 1.—Length, weight, and tagging data for smallmouth bass implanted with radio transmitters.

Fish number	Total length (mm)	Fork length (mm)	Weight (g)	Date tagged (1998)	Number of days monitored	Hours downstream of tempering pumps
1	336	310	560	Jan 07	65	0
2	264	254	234	Jan 15	58	0
3	216	207	153	Jan 21	52	0
4	260	252	285	Jan 21	52	0
5	241	229	195	Jan 21	52	24
6	242	231	204	Jan 21	52	0
7	284	270	360	Jan 21	52	94
8	296	283	372	Jan 21	52	0
9	270	258	312	Jan 22	51	0
10	250	240	221	Jan 22	51	0
11	255	242	230	Jan 22	51	0
12	272	259	275	Jan 22	51	0
13	255	243	285	Jan 22	51	0
14	222	209	154	Jan 22	51	2
15	233	228	182	Jan 22	51	0
16	238	229	212	Jan 22	51	0
17	240	229	184	Jan 22	51	0
18	272	260	305	Jan 28	45	126
19	293	279	326	Jan 28	45	28
20	240	230	256	Jan 28	45	0

ducted to monitor winter movements and residency patterns of smallmouth bass in and around the NTGS thermal discharge and to relate those findings to the importance of tempering pump operation during the winter.

Study Site

The NTGS, located at 42°48′N, 80°04′W, is an 8-unit, 4,000 MW (500 MW each) coal-fired station situated on the north shore of Lake Erie. The station uses a once-through condenser cooling-water system, taking water from Lake Erie via two submerged intakes that extend approximately 550 m offshore. The maximum cooling water flow is 154 m^3/s, of which 88 m^3/s is for condenser cooling and 66 m^3/s is for the tempering of heated discharge water. The station discharges the heated effluent into a canal 550 m long, 15 m wide, and 9 m deep. The canal was blasted out of bedrock and is relatively homogeneous throughout, except for rip-rap near the mouth of the canal and a series of oil-boom structures located approximately halfway down the canal. Under normal generation demands, NTGS operates as a peak load station, contributing power to the grid during periods of peak energy demand. This typically requires operation of 6 to 8 units during the early morning, midday, and late afternoon periods, creating fluctuating water temperatures in the discharge canal. Additional site descriptions and information on operating procedures are provided by Foster and Wheaton (1981) and Wiancko (1981).

Methods

Transmitter implantation.—Between January 7 and January 28, 1998, 20 smallmouth bass were captured from the discharge canal, near tempering pump 1 (Table 1; Figure 1). Six fish were angled, and the remaining fish were captured in a modified hoop net. Despite significant angling and netting efforts, we were unable to locate fish elsewhere in the canal, except on one occasion when a smallmouth bass was visually observed near antenna 3 (Figure 1). Fish were held in a tank continuously supplied with water from the outfall canal discharge for 24 h before surgery. This period allowed swim bladders to normalize following capture in deep water (>4 m).

Fish were anesthetized in a 60 mg/L induction a bath of eugenol and ethanol (1:10) (Anderson et al. 1997). Fish lost equilibrium after several minutes and were then measured (mm) for total length (TL) and fork length (FL) and weighed (g) before being placed ventral side up in foam padding on a surgery table. A maintenance dose of anesthetic

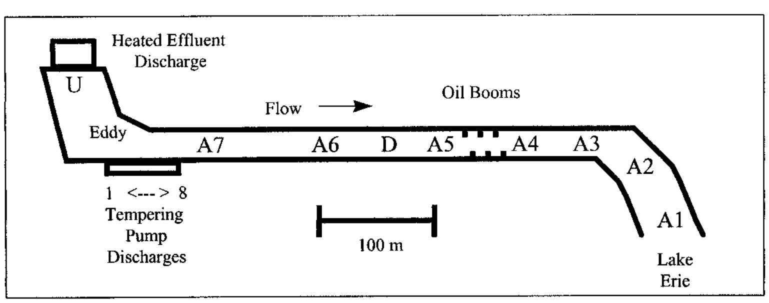

FIGURE 1.—Schematic overhead view of discharge canal. Antennas (A) are denoted by number. Water temperatures were monitored upstream (U) and downstream (D) of the tempering pump discharges.

(30 ppm) in oxygenated water continuously irrigated the gills.

Two slightly different transmitters were used for this study. Each transmitter (Lotek Engineering Inc, Newmarket, Ontario) was cylindrical, but one weighed 3.7 in water, the other 1.9 g. A 15-mm incision was made slightly dorsal to the ventral midline, just posterior to the pelvic girdle. The transmitter was then gently inserted into the coelomic cavity. A 16.5-gauge hypodermic needle was then pushed through the body cavity wall, using the shielded-needle technique, and the antenna wire was passed through to the outside. The incision was closed using three or four independent sutures of 3/0 nonabsorbable braided silk (Ethicon, Inc.). The entire procedure took less than 5 min. Fish were then returned to the holding tank, where they were allowed to recover for several hours before release at site of capture.

Water temperature monitoring.—Temperature in the canal was monitored every half hour throughout the study at two locations in the canal (Figure 1). Additional spot temperatures were taken at locations where fish were telemetrically located.

Tracking and observations.—A fixed system consisting of seven sequentially scanned underwater antennas monitored fish movements in the outfall canal (Figure 1). The receiver was set to scan and record the presence of transmitters at each antenna for a 5-s interval before scanning subsequent antennas. This system facilitated the monitoring of each antenna every 35 s. Antennas were secured on the bottom of the canal, and receiver sensitivity was adjusted so that the reception cells served as movement checkpoints. Reception cells were carefully mapped to ensure they covered the entire cross-sectional area of the canal. Fish locations were accurate to within approximately 5 m. Several times each week, fish locations were verified using a manual tracking receiver and a hand-held 2-element yagi antenna or a dip antenna (coaxial receiving element) for greater resolution. The study was terminated after 60 d (on March 13), just before the predicted transmitter battery expiry.

To further verify telemetric observations, videographic observations were also conducted. A color camera (Deep Sea Power and Light Inc.) in a water-tight housing was used in areas of the discharge canal that were identified, using telemetry, as frequently occupied. Although videographic footage was not quantified, it was useful for documenting feeding and aggregation behavior of untagged conspecifics. Additional information was collected by angling and netting during the entire duration of the study.

Analysis.—For both the location above the tempering pumps and the location below the tempering pumps, we investigated four water temperature characteristics: daily water temperature fluctuation, mean daily water temperature, minimum daily water temperature, and maximum daily water temperature. To assess differences in daily water temperature characteristics above and below the tempering pumps we used the Wilcoxon test. To compare the mean water temperature characteristics on days when there was no smallmouth bass movement below the tempering pumps with the mean water temperature characteristic on days when smallmouth bass did move below the water tempering pumps, we used the Mann–Whitney *U*-test. A set of tests were conducted for both the location above the tempering pumps and the location below the tempering pumps. For each combination of water temperature characteristic and location (above and below the tempering pumps), we calculated the Pearson's correlation coefficient between the water temperature characteristic and the number of smallmouth bass below the tempering pumps. We also calculated the Pearson's correlation coefficient between number of fish downstream from the tempering pumps and the net-station capacity factor, which serves as a measure of relative station output and ranges from 0 through 100. We used *t*-tests to determine whether the correlation coefficients were significantly different from zero. All tests were conducted using SYSTAT and were considered significant at $\alpha = 0.05$.

Results

Three radio-tagged fish were recaptured by angling during the study. Each fish was carefully examined and immediately released. Inspection of the incision and antenna exit wound revealed that the fish had healed quickly, and there was no evidence of any negative tagging effects.

During the study, no radio-tagged fish departed the discharge canal. The furthest downstream that fish ventured was to A2 (Figure 1), which was 375 m from head of canal and 350 m from the fish release site. The majority of time was spent upstream of the antenna array in an area that was thermally unaffected by the tempering pumps. During the study the three most upstream tempering pumps were not operational. The water upstream of the operational tempering pumps was on average 2.7 ± 0.3°C warmer than areas down-

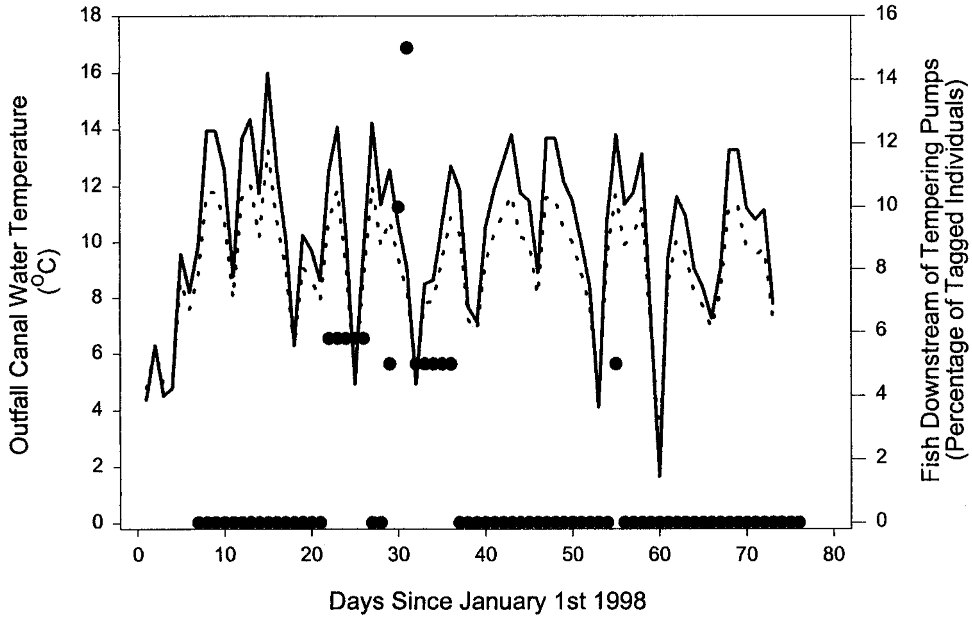

FIGURE 2.—Outfall canal mean daily temperatures upstream of tempering pumps (solid line), mean daily temperatures downstream of tempering pumps (broken line), and percentages of fish downstream of the tempering pumps (solid circles).

stream of A7 (Figure 1) during station operation (Wilcoxon's test; $P < 0.05$). The daily upstream minimum temperatures were significantly higher than downstream of the tempering pumps (Wilcoxon's test; $P < 0.05$), the mean difference being 0.35 ± 0.03°C. Maximum daily temperatures were also consistently higher upstream of the pumps than downstream (Wilcoxon test; $P < 0.05$), the mean difference being 2.32 ± 0.20°C. Mean daily water fluctuations were significantly higher above (8.8 ± 0.21°C) the tempering pumps than below (6.98 ± 0.13°C; Wilcoxon's test; $P < 0.05$).

Only five of the radio-tagged fish moved downstream of the tempering pumps, but all quickly returned to areas upstream. The longest period a fish was absent from the area upstream of A7 was 126 h (Table 1). There were no clear temperature changes that prompted fish to move downstream (Figure 2). For every combination of water temperature characteristic and location in the discharge canal (upstream and downstream of the tempering pumps), the mean of the water temperature characteristic during days when all of the fish were upstream from A7 was not significantly different from the mean of the water temperature characteristic during days when some of the fish were downstream from A7 (*U*-tests; $P > 0.05$). Movement of fish below A7 was not significantly correlated with mean daily water temperature characteristic, both upstream and downstream of A7 (Peason's correlation; $P > 0.05$). Fish movement was also independent of net station capacity (Pearson's correlation; $P > 0.05$), and mean station capacity did not differ on days when fish were upstream compared with days when fish were downstream of the tempering pumps (*U*-test; $P > 0.05$).

The majority of fish were concentrated near the three most upstream tempering pumps that were nonoperational during the monitoring period. Most movements during the study were localized. Fish occasionally moved among the nonoperational tempering pump discharge locations and the adjacent eddy; a distance of less than 25 m. Visual, netting, and angling observations indicated that smallmouth bass congregated in large numbers in these small areas within the discharge canal. Telemetry data supported this observation because radio-tagged individuals were found almost exclusively in these areas, except when several fish made short excursions downstream from the tempering pumps. During the study, no smallmouth bass larger than the biggest tagged individual (336 mm total length) were caught or observed in the discharge canal. Similarly, no age-0 fish were observed. The areas where smallmouth bass were observed served as velocity refuges, and were more spatially complex than the otherwise homogeneous discharge canal.

In the region near the nonoperational tempering pumps (tempering pumps 1, 2, and 3), smallmouth bass were observed feeding on rainbow smelt *Osmerus mordax,* emerald shiners *Notropis atherinoides,* and alewives *Alosa pseudoharengus.* Smallmouth bass were always observed near the bottom of the canal, which was consistent with signal-strength data recorded by the telemetry receiver. Other species observed in the discharge canal at the same time as smallmouth bass included rainbow trout *Oncorhynchus mykiss,* common carp *Cyprinus carpio,* largemouth bass *M. salmoides,* channel catfish *Ictalurus punctatus,* mooneyes *Hiodon tergisus,* gizzard shad *Dorosoma cepedianum,* freshwater drum *Aplodinotus grunniens,* rock bass *Ambloplites rupestris,* and longnose gars *Lepisosteus osseus.*

Discussion

Water temperature is one of the most important environmental variables affecting smallmouth bass because it influences geographic range, migrations, spawning date, success of egg incubation, growth, responses during the winter, and habitat selection (Armour 1993). Thermal effluent canals provide an opportunity to study the in situ behavioral response of fish to a variable thermal environment. Our study suggests that fish continued to occupy the discharge canal despite dramatic temperature fluctuations during the winter.

Few studies of thermal effluent canals have included an assessment of the habitat selection process. With many factors involved, habitat selection is undoubtedly a complicated process that involves balancing the values of several interacting and competing variables (Bevelhimer 1996). In field studies, physical cover has clearly been identified as a major factor in habitat selection by smallmouth bass (Probst et al. 1984; Sechnick et al. 1986; Todd and Rabeni 1989). Few researchers have considered temperature or food availability as factors that also affect habitat selection by smallmouth bass (see Hubert and Lackey 1980; Bevelhimer 1996).

Energetic efficiency is optimized in habitats where temperature and other characteristics minimize costs of metabolism and activity and maximize food conversion efficiency (Bevelhimer 1996). Several studies (Peterson and Myhr 1979; Hubert and Lackey 1980; Bevelhimer 1990, 1996) have suggested that the preference for an optimal temperature is often overridden by a stronger preference for another variable, such as physical structure or food availability.

Bevelhimer (1996) studied the relative importance of temperature, food, and physical structure to habitat choice by smallmouth bass. Laboratory studies revealed that the presence of food and cover significantly affected the temperature selected by smallmouth bass. The author suggests that even when temperature is not a primary consideration in habitat selection, its effects are often mediated through other behavioral responses. This may help to explain the presence of smallmouth bass in the discharge canal in a variable thermal environment, upstream of the region affected by the tempering pumps.

An alternative interpretation that may also help to explain the presence of smallmouth bass upstream from the tempering pumps is final preferred temperature selection. The water temperature downstream of the tempering pumps is always lower than the final preferred temperature for smallmouth bass compared with the region upstream that was always as close or closer to the final preferred temperature than any other part of the canal. Barans and Tubb (1973) report that adult smallmouth bass would probably aggregate during all seasons near the above ambient temperatures they observed. It is also likely that winter temperature selection, even after 2–3 d of acclimation to elevated temperatures represents the final preferred temperature regardless of previous thermal history (Fry 1947).

All of the fish that were implanted with radiotransmitters for our study were captured upstream of antenna 7. We cannot determine if fish captured downstream would have behaved differently. As indicated earlier, there was no evidence that smallmouth bass were concentrated in other areas of the discharge canal during the study.

Summer telemetric studies at NTGS by McKinley et al. (1996) reported that tagged nest-guarding male smallmouth bass remained in the discharge canal during the spawning period despite temperature fluctuations of up to 16°C. MacLean et al. (1982) also conducted a study to examine the response of smallmouth bass movement patterns to the NTGS discharge. The authors report that there was no long-term residency in the plume, and only several fish made short-term forays into the discharge canal. However, sample sizes were small, and fish were tracked primarily in the summer months. In addition, the fish used for their study were captured in Lake Erie, and not in the discharge canal that may have altered their behavior.

Winter residency studies in the vicinity of thermal plumes are relatively rare. Wrenn (1976) captured a single smallmouth bass from a reservoir, implanted a radio transmitter, and displaced the fish upstream of a long heated discharge input in a river in November 1972. The fish remained in the river upstream of the discharge for 34 d before entering the heated effluent, which it traversed within 24 h, before returning to the lake from which it was initially captured. It must be noted that the fish was not caught from the discharge area and its behavior was probably altered by the displacement and thermal history.

Ross and Winter (1981) studied winter movements and home ranges of yellow perch *Perca flavescens*, northern pike *Esox lucius*, walleyes *Stizostedion vitreum*, and largemouth bass. Although spatial distributions differed among species, only largemouth bass confined their movements to heated-water areas. Contrary to these findings, Clugston (1973) found largemouth bass moved in and out of a thermal discharge. However, temperature differences between the discharge plume and ambient lake conditions were not as extreme as those described by Ross and Winter (1981) and our study. Tranquilli et al. (1981) used radiotelemetry to monitor the behavior of largemouth bass in Lake Sangchris, Illinois, over several years. Winter activity patterns of largemouth bass were higher in heated areas than in unheated control areas, apparently because of elevated temperatures and circulation water around the cooling loop. Again, the temperature fluctuations experienced by fish in Lake Sangchris were not as extreme and were more stable than the operating regime at the NTGS.

Although several other winter studies have been conducted using other methods, such as netting, angler surveys, scuba-diving, acoustic surveys, or electrofishing (e.g., Neill and Magnuson 1974; Romberg et al. 1974; Minns et al. 1978; Shuter et al. 1985), only telemetry studies provide the opportunity to monitor long-term movements and residency of individual fish. In addition, the use of a fixed antenna array allowed us to monitor movements continuously during the study, which is impractical using conventional manual tracking.

Management Implications

We documented long-term winter residency of smallmouth bass in a thermal discharge canal. In general, fish movements were restricted to a linear distance of 25 m, and the several temporary downstream excursions in areas affected by the tempering pumps were, at most, for 5 d. Fish continued to reside in the warmest parts of the discharge canal despite dramatic temperature changes. Perhaps the negative effects of living in a thermally fluctuating environment are mitigated by the increased abundance of forage fish associated with thermal discharges. Evidence for such hypotheses can be gained through the coupling of several assessment and observational techniques and, where appropriate, laboratory studies. Even within a relatively homogenous discharge canal, fish spent the majority of their time in one of several areas that provided velocity refuges, cover, and presumably high food availability, in addition to being nearer to the final preferred temperature of smallmouth bass.

The benefits of tempering the effluent for smallmouth bass present in the canal during the winter were minimal because the majority of their time was spent upstream of the operational tempering pumps, where water temperatures were highest and fluctuations were more extreme than elsewhere in the discharge canal. Tempering pumps are probably most effective at minimizing thermal impact on smallmouth bass during the summer, when discharge temperatures are greater than the final preferred temperature of smallmouth bass. Habitat suitability during the fall or spring, when temperatures are intermediate, provides managers with a more difficult challenge of deciding when to temper. Seasonal tempering exemptions during the winter may therefore be an appropriate strategy for realizing financial savings, which could be directed towards increased tempering during summer periods to keep the daily maximum temperatures within the zone of thermal tolerance.

The design and operation of power plant cooling water systems should also consider the tradeoffs between the increased potential for impingement, entrapment, and entrainment associated with tempering pump operation versus the mitigative effects this has on the water temperature and the questionable benefits to organisms in and around the discharge canal. Up to 40% of the water volume drawn through the intakes at Nanticoke is used for tempering (Foster and Wheaton 1981). If the regulated water volume for tempering was reduced, it should reduce entrainment of fish by the tempering pumps, entrapment of fish in the forebay, and impingement of fish on traveling screens (Kelso and Milburn 1979; Foster and Wheaton 1981).

The results of this study further emphasize the need for in situ studies that take into account many conditions that are difficult to replicate in laboratory studies. Additional studies investigating the behavior and physiology of fish exposed to different tempering operations in different seasons are required to further understand whether the mitigative strategies of tempering have any benefits for abating thermal pollution during other seasons, for other life stages, and for different species.

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