NOTE

RESPONSE OF SPORT FISHES TO THERMAL DISCHARGES INTO THE GREAT LAKES: IS SOMERSET STATION, LAKE ONTARIO, DIFFERENT?

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ABSTRACT. To assess potential thermal impacts of Somerset Generating Station on sport fishes, the frequencies and durations of encountering the thermal discharge at Somerset Station were determined by tagging 121 salmonines and 38 centrarchids with temperature-sensing radiotransmitters. Encounters of the Lake Ontario shoreline occupied by Somerset Station averaged 0.7 and 0.1 per fish for salmonines and centrarchids, respectively. Salmonines averaged 3.5 h at the station per encounter. Four centrarchids established residence areas in the lake near the station for 28-79 d; others averaged 3.3 d at the station. Salmonines and centrarchids occupied waters off Somerset Station on 6.7% and 16.0%, respectively, of the days they were tracked. No temperatures occupied by fish at the station exceeded critical thermal maxima for salmonines (20-25°C) or centrarchids (30-37°C). Salmonines occupied heated water >2°C above ambient lake temperatures on 1.3% of the 1,983 occasions when temperatures were recorded, while centrarchids averaged 0.1% of 1,773 observations. Rare encounters of and lack of attraction to the thermal discharge were attributed to characteristics of the discharge (600+ m offshore, small delta T, small volume/area), to unremarkable lake habitat (flat bottom, physically similar to other regions of southcentral Lake Ontario), and to the generally wide-ranging movements of fishes in Lake Ontario. Comparing results from Somerset Station with similar studies at other Great Lakes power stations suggests that discharge design and lake habitat importantly influence the extent of fish attraction to thermal discharges.

ADDITIONAL INDEX WORDS: Fish migration, thermal powerplants, water temperature, fish management.

INTRODUCTION

Fish may occupy a thermal discharge for several advantageous reasons: 1) discharge temperatures more closely approximate seasonally preferred temperatures than do ambient temperatures (Spigarelli et al. 1983, MacLean et al. 1982, Wyman 1981); 2) discharges attract and concentrate prey species (Janssen and Giesy 1984, Spigarelli et al. 1982); 3) discharge currents resemble natural, though warmed, tributaries and produce a positive rheotactic response in fish (MacLean et al. 1982, Johnsen and Hasler 1980); or 4) fish maintain energetically optimal temperatures in or near discharges (Spigarelli et al. 1983). However, thermal discharges may adversely affect aquatic organisms by changing the physiology or behavior of individuals, the abundance or reproduction of populations, or species diversity or trophic relations within communities (Spotila et al. 1979). Assessing the influence that a particular thermal discharge exerts on fish and the aquatic ecosystem depends on what species are found in the discharge area on a sustained basis, what species use the discharge area as a spawning, nursery, or feeding ground, and what species migrate or pass through the discharge area (Richards et al. 1977).

In Lake Ontario, sport fish are rarely found near power plant discharges in summer, but they are attracted to thermal discharges of some stations in winter and, to a lesser extent, in spring and fall (NYSEG 1986a; TII 1978; RGE 1977a,b). We

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studied the thermal histories of four salmonine species (brown trout, *Salmo trutta*; rainbow trout, *S. gairdneri*; chinook salmon, *Oncorhynchus tshawytscha*; coho salmon, *O. kisutch*) and two centrarchid species (smallmouth bass, *Micropterus dolomieu*; rock bass, *Ambloplites rupestris*) at Somerset Station from September 1984 to December 1986. Our objectives were to record temperatures occupied by radiotagged sport fish in and near the thermal discharge area and to determine how often and for how long fish occupied waters near the station. Movements and temperatures occupied by fish in Lake Ontario after they moved away from the station are reported elsewhere (Gerber and Haynes 1988; NYSEG 1987a, 1986d).

**STUDY AREA**

Somerset Station is a 625 MWe coal-fired generating station located on the southcentral shore of Lake Ontario 38 km east of the Niagara River (Fig. 1). The cooling water discharge is designed so that heated water enters the lake from nine diffusers arising from the 9 m depth contour 670–790 m offshore (Fig. 1). Thermal effluent is discharged at a maximum of 20°C above ambient temperature, but rapid mixing with lake water decreases temperatures to approximately 1.7°C above ambient in a 7.3 ha area at the surface of Lake Ontario; differences decrease to less than 0.6°C at the surface within several hundred meters of the diffusers (NYSEG 1986b,c; Fig. 1). Temperatures more than 2°C above ambient exist only in small volume below the surface and above the diffusers, and the thermal plume is much smaller in winter than in summer (NYSEG 1986b,c; Fig. 1). Thus a different situation exists at Somerset Station than is characteristic for many older Great Lakes power plants: rather than encountering a heated tributary to the lake, fish encounter a rapidly diffused thermal discharge several hundred meters offshore and ambient water temperatures near shore (Fig. 1).

**METHODS**

Fish were captured by electrofishing in or near tributaries of Lake Ontario at Olcott and Pt. Breeze (Fig. 1), or by angling in the lake near Somerset Station. They were tagged with externally mounted, temperature-sensing radio transmitters (Haynes and Nettles 1983, Ross et al. 1979). Because the lake near the station was inaccessible for electrofishing and few fish were caught by angling in waters off the station, most fish (131/179) were transported from capture sites for release at the station.

Fish were tracked manually from the time of release until they moved out of range of four antennas (Fig. 1), usually <20 h for salmonines and 1–5 d for centrarchids. A three-site receiving system operated automatically by computer (Fig. 1) also recorded fish presence and temperatures occupied at the station every 15–25 min. Temperatures occupied by fish were compared with ambient water temperatures recorded every 30 min at the station’s water intake located at the 9 m depth contour and with two reference temperature transmitters located 1 m below the surface over 1 and 6 m depths (Fig. 1). To account for natural horizontal and vertical variations of temperature in nearshore regions of the lake (NYSEG 1986a, 1984), if temperatures recorded for fish at Somerset Station did not differ by more than 2°C from all three reference temperatures, fish were considered to be in ambient temperature water.

Statistical comparisons by multiway ANOVA (alpha = 0.05) of log-transformed data were made separately for salmonines and centrarchids using Stats Plus (1982). Analyses included encounters per fish of the section of shoreline occupied by the station, time spent at the station, temperatures occupied at the station, frequency of encountering the station, and frequency of encountering water >2°C above ambient. Because few differences in behavior were observed between coho and chinook salmon (NYSEG 1987a, 1986d; Haynes and Keleher 1986; Keleher et al. 1985), they were grouped as Pacific salmon. Details of analyses and results are reported in NYSEG (1987b).

**RESULTS**

The combined effects of capture, tagging, and transport were expected to fatigue fish; this delayed their movements away from the station and increased their overall frequency of encountering the station, but did not influence the frequency at which salmonines and centrarchids encountered the thermal discharge (Table 1). Including data for the hours or days transported fish remained at the station initially before moving elsewhere in Lake Ontario provides a maximum estimate of station impact, while data from subsequent encounters of the station provide a minimum estimate. These values are reported as ranges below.
FIG. 1. Map of Lake Ontario with existing electrical generating stations and details of Somerset Station showing water intake and fish discharge locations and typical winter and summer thermal plumes at the surface. Remote-1 is a tracking antenna not connected to the computer-controlled tracking system. Ref-S are surface temperature reference transmitters and Ref-B is a bottom temperature reference recorder. (N)GS is (Nuclear) Generating Station; UC is Under Construction.
TABLE 1. Encounters per fish of the station, time at station, temperature at station, frequency of encountering the station, and frequency of encountering heated water by species, season, and type of encounter.

<table>
<thead>
<tr>
<th>Group</th>
<th>Encounters/Fish</th>
<th>Time at Station</th>
<th>Temperature at Station (°C)</th>
<th>Frequency of Encounter (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>x ± SD</td>
<td>n</td>
<td>x ± SD</td>
</tr>
<tr>
<td>Salmonines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown Trout</td>
<td>35</td>
<td>0.6 ± 0.8</td>
<td>28</td>
<td>5.0 ± 5.5h</td>
</tr>
<tr>
<td>Rainbow Trout</td>
<td>37</td>
<td>1.0 ± 1.2</td>
<td>54</td>
<td>4.5 ± 4.0h</td>
</tr>
<tr>
<td>Pacific Salmon</td>
<td>32</td>
<td>0.5 ± 0.7</td>
<td>39</td>
<td>6.1 ± 8.8h</td>
</tr>
<tr>
<td>P Value</td>
<td>&gt;0.5</td>
<td>&gt;0.5</td>
<td>0.008</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall</td>
<td>75</td>
<td>0.8 ± 1.0</td>
<td>86</td>
<td>4.0 ± 4.0h</td>
</tr>
<tr>
<td>Spring</td>
<td>29</td>
<td>0.5 ± 0.8</td>
<td>35</td>
<td>8.0 ± 9.3h</td>
</tr>
<tr>
<td>P Value</td>
<td>0.320</td>
<td>0.071</td>
<td>&lt;0.001</td>
<td>&gt;0.087</td>
</tr>
<tr>
<td>Encounter</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>Not Applicable</td>
<td>72</td>
<td>6.7 ± 7.3h</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Subsequent</td>
<td>Not Applicable</td>
<td>49</td>
<td>2.9 ± 3.2h</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>P Value</td>
<td>–</td>
<td>0.026</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Centrarchids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smallmouth</td>
<td>18</td>
<td>0.2 ± 0.6</td>
<td>22</td>
<td>10.6 ± 20.1d</td>
</tr>
<tr>
<td>Rock Bass</td>
<td>12</td>
<td>0.1 ± 0.3</td>
<td>13</td>
<td>8.0 ± 15.9d</td>
</tr>
<tr>
<td>P Value</td>
<td>&gt;0.5</td>
<td>0.249</td>
<td>&gt;0.5</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Encounter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>Not Applicable</td>
<td>30</td>
<td>6.5 ± 12.2d</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Subsequent</td>
<td>Not Applicable</td>
<td>5</td>
<td>28.6 ± 36.1d</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>P Value</td>
<td>–</td>
<td>0.011(b)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

(a) Species x season interaction significant, P = 0.003; differences among species and between seasons are an artifact of a sampling anomaly for brown trout in spring 1985 - see text for explanation.
(b) Species x encounter interaction significant, p = 0.034; see text for explanation of influence of resident fish on calculations.

**Salmonines**

Encounters of waters off Somerset Station were infrequent and brief. Excluding initial releases of fish transported to the station, 42% (51/121) encountered waters there on 79 occasions, or an average of 0.7 (79/121) encounters per fish. Time spent at the station averaged 6.7 h initially and 2.9 h subsequently (Table 1); only two fish remained more than 13 h on subsequent encounters. Salmonines encountered the station on 4.3-9.4% of the 2,430 days they were tracked in the lake, or one encounter every 10.6-23.3 d.

Salmonines occupied elevated temperatures on 1.3% (initially) and 2.6% (subsequently) of 1,983 observations. At these rates they would be expected to accumulate a day of heated water exposure once every 815-896 d. Since the average life span of a stocked salmonine in Lake Ontario is 550-1,100 d, these figures translate to an estimated accumulation of 0.6 to 1.4 d of heated water >2°C above ambient during a lifetime. Temperatures occupied at the station averaged 11.2°C (Table 1), and were not different from temperatures occupied elsewhere in Lake Ontario (10.7 ± 3.7°C; P > 0.3; t-test; NYSEP 1987b). Temperatures >20°C were occupied on 25 occasions, but only one was >35°C above ambient.

Few differences in behavior were observed among species and between seasons. Although average temperatures differed among species (brown trout > Pacific salmon; Table 1), a difference of only 1°C is unlikely to be meaningful ecologically. Salmonines occupied warmer temperatures at the station in fall than spring (Table 1), because nearshore temperatures of Lake Ontario were warmer in the fall. Frequencies of encountering heated water appeared to be higher for brown trout and in the spring (Table 1). This occurred because inadequate reference temperature records
in spring 1985, when only brown trout were tracked, suggested that brown trout frequently occupied the thermal discharge. In fact, they occupied the very warmest lake waters closest to shore, as confirmed by manual tracking, and there were no power plant-related differences in encountering heated water among salmonines by species or season.

Centrarchids

Despite spending days at the station, rather than hours like salmonines, centrarchids rarely encountered waters near the station after leaving initially and almost never occupied the thermal discharge. Excluding initial releases of transported fish, 7% (4/58) encountered the station on three occasions. Including resident fish, centrarchids occupied waters near the station on 16.7–39.8% of the 856 days they were tracked, or one encounter every 2.5–6.0 days.

Excluding long-term residents from calculations, centrarchids spent 3.5 ± 3.3 days at the station, but four fish established residences near the station for 28–79 days. Since three fish became residents during subsequent encounters of the station, days spent at the station during subsequent encounters were high (Table 1). One smallmouth bass resided for weeks near the fish return port at the 6 m contour (Fig. 1). This was a site of rapid currents, prey fish returning to the lake after impingement on traveling screens inside the power station, and a substantial concentration of conspecifics observed by divers (W. Heitzenrater, Beak Consultants, Akron, NY, personal communication).

Centrarchids occupied the thermal plume on 0.1% of the 1,773 occasions when temperatures were recorded. They would be expected to accumulate a day of heated water exposure once every 2,500 days or 1 day in a 7-year lifespan. Temperatures occupied at the station averaged 13.0°C; none exceeded 25°C.

DISCUSSION

Salmonines

Whether or not salmonines encountered the offshore thermal discharge at Somerset Station was a chance result of the direction a fish moved away from the station after its initial release or the distance a fish swam offshore during a return encounter. Most fish swam inshore of the thermal plume. To encounter a temperature >2°C above ambient, a fish had to swim through a heated volume approximately 300 m wide by 400 m long by 6 m thick located 670 m offshore (Fig. 1). Salmonines were either closer to shore as they sought warmest waters in spring or spawning tributaries in fall, or they were much farther offshore in pelagic waters in summer and winter (Nettles et al. 1987, Haynes et al. 1986, Haynes and Keleher 1986, Keleher et al. 1985).

Temperatures occupied by individual salmonines were variable at Somerset Station and in the open waters of Lake Ontario (NYSEG 1987a, 1986d), reflecting natural variability among individuals and changing seasonal water temperatures. Critical maxima or lethal temperatures have been determined for rainbow trout (24–30°C), brown trout (22.5–30.5°C), and Pacific salmon (22–24°C) (Kaya 1978, Spotila et al. 1979, Lee and Rinne 1980, Brett 1952), but salmonines generally avoid temperatures > 20–22°C (Reynolds and Casterlin 1979, Coutant 1977, Cherry et al. 1975, Brett 1952). At Point Beach Station on Lake Michigan, abundant salmonine catches by anglers dropped sharply as water temperatures rose above 20–21°C (Spigarelli and Thomas 1976), suggesting that fish left thermally impacted areas when temperatures exceeded preferenda. For salmonines at Somerset Station no recorded temperatures exceeded 22°C; thus, even on the rare and brief occasions when fish were exposed to the thermal discharge, it is unlikely they experienced dangerous temperatures.

Salmonines moved away from Point Beach and Somerset Stations a few days or hours after release and some returned to the stations on one or more occasions (Romberg et al. 1974, Spigarelli et al. 1983). Despite being seasonally abundant at some power plants (Tesar and Jude 1985; Jude et al. 1981, 1979), individual salmonines are basically transients that do not spend prolonged periods at power plants or exposed to dangerously heated water (Spigarelli et al. 1983, Romberg et al. 1974). For example, internal temperatures of salmonines caught by anglers in the thermal discharge and plume at Point Beach Station were consistently lower than discharge temperatures (Spigarelli et al. 1974). Because of the lag time between entering thermally impacted waters and the warming of body temperatures to dangerous levels, large sport fish can occupy heated water for many minutes before internal body temperatures rise (Spigarelli et al. 1977, 1974).
Centrarchids

Because they occupied the benthos < 6–10 m deep (Gerber and Haynes 1988, MacLean et al. 1982, Emery 1973), at Somerset Station centrarchids were inshore of the thermal discharge. Reports vary on centrarchid responses to other thermal discharges. Smallmouth bass were collected from the thermal discharge at Point Beach Station, but not from nearby control areas in Lake Michigan (Romberg et al. 1974). At Nanticoke Station on Lake Erie, they were reported to swim up discharge canals when lake temperatures were cold (MacLean et al. 1982). Seasonal abundance of smallmouth bass caught by angling increased near thermal discharges in one study (Shuter et al. 1985). Griffiths (1979) reported that at Pickering Station, which has a nearshore discharge on Lake Ontario, radiotagged smallmouth bass maintained residence in the thermal plume for up to 3 months in summer and early fall; they moved out of the warmest waters available only when temperatures exceeded 30°C. However, MacLean et al. (1982) reported no long-term residency of plume areas at Nanticoke Station with a nearshore discharge; most tagged smallmouth and rock bass left the area within 24 h after release, results more similar to those at Somerset Station. At Nanticoke Station, basses appeared to be influenced more by currents and turbulence than temperature (MacLean et al. 1982). Partially consistent with Griffiths (1979) and MacLean et al. (1982), the four centrarchids that established residence near Somerset Station occupied areas of current and prey, not thermal, resources.

Preferred temperatures for smallmouth and rock bass determined in the laboratory range from 26–31°C (Griffiths 1979, Reynolds and Casterlin 1978, Coutant 1977, Cherry et al. 1975), but temperatures occupied in the field are usually much lower, 20–22°C, in summer (Gerber and Haynes 1988, Coutant 1977, Barans and Tubb 1973, Hallam 1959, Ferguson 1958). The critical thermal maximum for smallmouth acclimated to a typical field temperature (23.3°C) was 36.3°C (Reutter and Herdendorf 1976). Smallmouth bass occupying thermal plumes at power plants in the southern U.S. are caught at temperatures approaching their critical thermal maxima (Gammon 1973, Churchill and Wojtalik 1969), but northern waters, even with a thermal discharge, rarely approach lethal or preferred (laboratory) temperatures for centrarchids (Coutant 1977). Thus, centrarchids are not particularly attracted to thermal discharges in northern waters (MacLean et al. 1982, Neill and Magnuson 1974). Because no temperatures recorded for centrarchids at Somerset Station exceeded 25°C, the maximum nearshore surface temperature observed in Lake Ontario in summer (NYSEG 1986a, 1984), it is unlikely that they were exposed to dangerous water temperatures.

Responses of Fish to Great Lakes Power Plants

Bioacoustic, netting, and impingement studies at other Great Lakes power stations (Table 2) have quantified the abundance, distribution, and composition of fish communities at power plants and nearby control sites. Most fish detected in standard surveys are prey species, particularly alewives (Alosa pseudoharengus) and rainbow smelt (Osmerus mordax). Adult and juvenile representatives of important salmonine, centrarchid, esocid, percid, and icthyid sport fishes are far less abundant, usually averaging < 0.1% of total community abundance (NYSEG 1986a, 1984; TII 1978; RGE 1977a, b; Tesar et al. 1985; Jude et al. 1981, 1979). These results suggest that sport fish sampled at power plants are caught roughly in proportion to their lakewide abundances, but few studies have focused primarily on adult sport fish (Romberg et al. 1974, Spigarelli et al. 1983).

Results common to many fish surveys at Great Lakes power plants include: 1) high variability of fish abundance within and among seasons, species, and stations; 2) no or few consistent differences in fish densities and species diversity between thermally impacted and control sites; 3) decreased fish density with increased distance from shore and occupancy of water < 5 m deep by most fish sampled; 4) greater abundance of fish nearshore at night than day; (5) greater fish abundance near shore associated with upwelling and storm events; and 6) orientation or to clustering of fish near current or substrate structure associated with power plant operation and location as much or more than association with thermal structure. One or more of these results has been reported in each of NYSEG (1986a, 1984), Tesar et al. (1985), Tesar and Jude (1985), Reutter and Herdendorf (1984), Wyman and Dischel (1984), Spigarelli et al. (1982), Wyman (1981), Jude et al. (1981, 1979), Minns et al. (1978), TII (1978), RGE (1977a, b), Kelso and Minns (1975), Neill and Magnuson (1974), and Everest (1973). Given the array of factors that appear to influence fish near power plants, and the
TABLE 2. Thermal discharge and substrate characteristics of generating stations on the Great Lakes where fish ecology has been studied.

<table>
<thead>
<tr>
<th>Station</th>
<th>Fuel</th>
<th>Power (MWe)</th>
<th>Substrate</th>
<th>Discharge Characteristics</th>
<th>ΔT(C°)</th>
<th>Vol. (m³/s)</th>
<th>Vel. (m/s)</th>
<th>Area (ha)</th>
<th>References</th>
</tr>
</thead>
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<td>Lake Ontario</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>FitzPatrick</td>
<td>Nuc.</td>
<td>821</td>
<td>Bedrock/rubble</td>
<td>Offshore (11 m)</td>
<td>17.5</td>
<td>22</td>
<td>4.3</td>
<td>No Data</td>
<td>TII 1978</td>
</tr>
<tr>
<td>Ginna</td>
<td>Nuc.</td>
<td>490</td>
<td>Bedrock/rubble</td>
<td>Offshore</td>
<td>11.1</td>
<td>25</td>
<td>1.1</td>
<td>61</td>
<td>RGE 1977a</td>
</tr>
<tr>
<td>Hearn</td>
<td>Coal</td>
<td>1,200</td>
<td>Sand/gravel</td>
<td>Offshore</td>
<td>14.0</td>
<td>47</td>
<td>No Data</td>
<td>200</td>
<td>Everest 1973</td>
</tr>
<tr>
<td>Lakeview</td>
<td>Coal</td>
<td>2,400</td>
<td>Sand/gravel</td>
<td>Offshore</td>
<td>14.0</td>
<td>98</td>
<td>No Data</td>
<td>180</td>
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</tr>
<tr>
<td>Lennox</td>
<td>Oil</td>
<td>2,200</td>
<td>No Data</td>
<td>Offshore</td>
<td>10.6</td>
<td>93</td>
<td>2.0</td>
<td>300</td>
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<td>610</td>
<td>Bedrock/rubble</td>
<td>Offshore (5 m)</td>
<td>17.3</td>
<td>16</td>
<td>1.2</td>
<td>No Data</td>
<td>TII 1978</td>
</tr>
<tr>
<td>Oswego</td>
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<td>890</td>
<td>Rubble</td>
<td>Offshore (12 m)</td>
<td>15.0</td>
<td>18</td>
<td>5.1</td>
<td>750</td>
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<tr>
<td>Pickering</td>
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<td>2,100</td>
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<td>98</td>
<td>2.0</td>
<td>500</td>
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<td>Russell</td>
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<td>Cobble/gravel</td>
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<td>1.0</td>
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<td>Somersct</td>
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<td>625</td>
<td>Flat bedrock</td>
<td>Offshore (9 m)</td>
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<td>12</td>
<td>5.2</td>
<td>(4)</td>
<td>Tuttle, pers. comm. (5)</td>
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<td>Lake Erie</td>
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<td>Acme</td>
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<td>Tributary</td>
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<td>No Data</td>
<td>Reutter and Herndon 1984</td>
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<td>623</td>
<td>Bay sediment</td>
<td>Onshore</td>
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<td>29</td>
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<td>No Data</td>
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<td>Davis-Bessie</td>
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<td>Flat bottom</td>
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<td>Reutter and Herndon 1984</td>
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<td>Coal</td>
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<td>Flat bottom</td>
<td>Offshore</td>
<td>8.3</td>
<td>87</td>
<td>0.8</td>
<td>180</td>
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<tr>
<td>Bruce A</td>
<td>Nuc.</td>
<td>3,000</td>
<td>Boulder/gravel</td>
<td>Onshore</td>
<td>9.5</td>
<td>135</td>
<td>No Data</td>
<td>160</td>
<td>Shuter et al. 1985</td>
</tr>
<tr>
<td>Lake Michigan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.C. Cook</td>
<td>Nuc.</td>
<td>2,200</td>
<td>Sand</td>
<td>Offshore (6 m)</td>
<td>10.5</td>
<td>105</td>
<td>4.0</td>
<td>228</td>
<td>Rossmann 1986</td>
</tr>
<tr>
<td>J.H. Campbell</td>
<td>Coal</td>
<td>1,350</td>
<td>Sand</td>
<td>Offshore (8 m)</td>
<td>8.7</td>
<td>38</td>
<td>No Data</td>
<td>7(4)</td>
<td>Winnell and Jude 1981, Consumers Power Co. 1982</td>
</tr>
<tr>
<td>Pt. Beach</td>
<td>Nuc.</td>
<td>1,000</td>
<td>No Data</td>
<td>Offshore (2)</td>
<td>10.7(3)</td>
<td>45(3)</td>
<td>0.3-0.9</td>
<td>10-100</td>
<td>Spiagerelli and Thommes 1976</td>
</tr>
<tr>
<td>Waukeegan</td>
<td>Coal</td>
<td>1,100</td>
<td>No Data</td>
<td>Offshore</td>
<td>7.0</td>
<td>55</td>
<td>2.0</td>
<td>No Data</td>
<td>Spiagerelli et al. 1982</td>
</tr>
<tr>
<td>Zion</td>
<td>Nuc.</td>
<td>2,200</td>
<td>No Data</td>
<td>Offshore</td>
<td>11.0</td>
<td>49</td>
<td>2.9</td>
<td>No Data</td>
<td>Spiagerelli et al. 1982</td>
</tr>
</tbody>
</table>

(1) values = lake depths where thermal discharge structure located.
(2) Discharge released from surface flumes 46m offshore.
(3) 4.4°C; 25 m³/s in winter.
(4) Uses high velocity diffusers.
(5) L.R. Tuttle, Jr., NY State Electric and Gas Corp., Binghamton, NY.
major differences in operation and habitat characteristics among stations, it is difficult to establish that presence or absence of fish near a power station is primarily a response to a thermal discharge.

Any attraction of fish to thermal discharges in the Great Lakes depends largely on seasonal lake temperatures, species abundance near shore, and species thermal preferenda (Spigarelli et al. 1983, Spigarelli and Thommes 1976, Romberg et al. 1974, Neill and Magnuson 1974), but differing discharge design and lake habitat characteristics (Table 2) also may play important roles. Currents and complex substrates are known to attract and concentrate fish in lakes with and without thermal discharges (MacLean et al. 1982, Johnsen and Hasler 1980, Johnson and Stein 1979). Sport fish may remain longer and spend more time in heated water at stations with onshore, high volume/current, low delta T discharges, and structured substrates than at stations with offshore, low volume, high delta T discharges and unstructured substrates (Table 2). For example, salmonines spent 5–216 h at Point Beach Station and 9–21% of their time in heated water (Spigarelli et al. 1983, Romberg et al. 1974). Salmonines averaged < 7 h at Somerset Station and < 3% of observations were in heated water. In contrast with Point Beach Station, and despite great initial effort by anglers, a productive fishery does not exist at Somerset Station (NYSEG 1986e). Important seasonal fisheries do occur on Lake Ontario at Russell and Ginna Stations (Fig. 1), which have onshore discharges and considerable substrate structure (Table 2).

Evidence presented here suggests that individual Great Lakes power plants have substantially different potentials for attracting sport fish, apparently related to plant design and lake habitat characteristics. These differences have important implications for the siting and design of any future power plants on the Great Lakes.

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REFERENCES


RESPONSES OF SPORT FISHES TO THERMAL DISCHARGES


