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Winter residency and activity patterns of channel catfish, *Ictalurus punctatus* (Rafinesque), and common carp, *Cyprinus carpio* L., in a thermal discharge canal

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Abstract Radiotelemetry was used to examine the behavioural responses of fish to dynamic environmental and operating conditions in a fossil-generating power station discharge canal on Lake Erie. A series of seven underwater antennas continuously monitored the movements of 10 common carp, *Cyprinus carpio* L., and 10 channel catfish, *Ictalurus punctatus* (Rafinesque), in the 550-m discharge canal between 23 December 1997 and 1 May 1998. Common carp residency values were higher (47.71 ± 8.51%) than those of channel catfish (10.15 ± 2.82%). While resident in the discharge canal, channel catfish spent more time in the upper reaches and were more active than carp. Carp spent more time in the lower reaches of the channel, and made more frequent movements between the canal and Lake Erie. Overall residency decreased significantly during the study period. Aside from significant negative correlations between common carp residency and daily mean influent temperature (r = –0.53), daily discharge mean (r = –0.30) and minimum water temperature (r = –0.47), and positive correlations to daily mean cooling water flow (r = 0.38), the activity and residency of tagged individuals were independent of environmental and operating conditions. There was no relationship between the total length of each fish, and any of the residency or activity indices. The implications of extended fish residency in heated discharges and the utility of radiotelemetry as a monitoring procedure are discussed.

KEYWORDS: activity, channel catfish, common carp, movement, telemetry, thermal effluent, winter.

Introduction

Concern for fish exposed to thermal pollution at facilities equipped with once-through cooling systems is based on the assumption that fish remain in the discharge water long enough to equilibrate their body temperature to the discharge temperature (Spigarelli, Romberg, Prepejchal & Thommes 1974). Despite this, very few studies examine the behaviour or residency of fish in relation to thermal discharges to determine whether, and to what extent, managers must consider the effects of thermal effluents on fish. The potential effects of residing in a thermal discharge channel include altered metabolic rates, feeding responses and

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reproductive potential, increased susceptibility to disease, and at worst, death from cold or heat shock (Coutant 1970; Spigarelli *et al*. 1974).

The Nanticoke thermal-generating power station (NTGS) on the north shore of Lake Erie is the location of a well-studied thermal discharge. Studies in and around the NTGS discharge have examined movements of numerous fish species (e.g. Kelso 1976; MacLean, Teleki & Polak 1982; McKinley, Griffiths, Kowalyk & McKenna 1996), although none were conducted in the winter months and only McKinley *et al*. (1996) monitored individual fish for extended periods of time.

During the winter of 1997, the behavioural response of fish exposed to fluctuating discharge temperatures in the NTGS discharge canal were examined. A fixed radiotelemetry system was used to continuously monitor movements of common carp, *Cyprinus carpio* L., and channel catfish, *Ictalurus punctatus* (Rafinesque), for several months to evaluate the distance fish penetrated and the duration of their residence in the discharge channel, and correlate activity and residency to environmental and operational conditions.

Materials and methods

Study site and plant operation

The NTGS (42° 48' N, 80° 04' W) is an eight-unit, 4000 MW (each unit = 500 MW) 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 which extend ∽ 550 m offshore. The maximum design cooling water flow is 154 m^3 s^{-1}, of which 88 m^3 s^{-1} is for condenser cooling and 66 m^3 s^{-1} is for the tempering of heated discharge water. The station discharges the heated effluent via a canal 550 m long, 15.25 m wide and 9.15 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 part of the way down the canal. Under normal generation demands, the NTGS operates as a peak load station, contributing power to the grid during periods of peak demand. This typically requires between six and eight units to operate during the early morning, mid-day and late afternoon periods. This creates fluctuating temperatures in the effluent discharge. Foster & Wheaton (1981) and Wiancko (1981) provided additional site descriptions and information on operating procedures

Transmitter implantation

Between 22 December 1997 and 22 January 1998, 10 channel catfish (Table 1) and 10 common carp (Table 2) were captured by angling from the discharge canal in low flow areas. Conventional fish capture techniques proved to be ineffective because of highly variable flow patterns. Several additional fish (three channel catfish) were captured using modified gill nets with 5-kg steel anchors and long ropes which were used to quickly lower the nets to the bottom. All nets were fished for less than 2 min to minimize handling stress. Prior to surgery, fish were held in a tank continuously supplied with out-fall channel discharge water.

Table 1. Summary of the characteristics of channel catfish implanted with radio transmitters to study movement and activity in the Nanticoke thermal-generating power station discharge canal

		Length (mm)				Index		
Code	Weight (g)	Total (mm)	FL (mm)	Date tagged	Number of days monitored	Residency	Lake activity	Canal activity
41	476	1430	521	23/12/97	128	1.71	1	6.67
55	524	2386	583	23/12/97	128	26.90	5	3.11
58	482	1700	522	23/12/97	128	1.80	1	2.33
59	420	903	470	23/12/97	116*	6.070	11	6.07
56	480	1750	520	23/12/97	128	18.35	1	18.35
42	622	4480	674	07/01/98	113	18.00	1	0.01
43	622	4130	670	07/01/98	113	0.96	1	3.00
44	521	2077	569	07/01/98†	113	14.30	2	0.78
45	625	4240	684	07/01/98†	113	1.70	1	7.00
46	478	1540	510	07/01/98†	113	11.69	1	3.14

*Angled on 19 April 1998.

The fish were anaesthetized using a 65 p.p.m. induction bath of clove oil and ethanol (Anderson, McKinley & Colavecchia 1997). Fish lost equilibrium after several minutes, and were then measured [i.e. total length (TL) and (FL) to the nearest millimetre] and weighed (in grams) before being placed ventral side up in foam padding on a surgery table. A maintenance dose of anaesthetic (30 p.p.m.) in oxygenated water continuously irrigated the gills. A small incision (30 mm) was made slightly dorsal to the ventral midline of the fish.

Table 2. Summary of the characteristics of common carp implanted with radio transmitters to study movement and activity in the Nanticoke thermal-generating power station discharge canal

		Length (mm)				Index		
Code	Weight (g)	Total (mm)	FL (mm)	Date tagged	Number of days monitored	Residency	Lake activity	Canal activity
49	1894	553	490	23/12/97	128	24.9	13	2.49
52	1158	420	383	23/12/97	128	89.54	2	1.53
47	1562	485	437	15/01/98	106	23.19	19	1.21
48	3047	605	546	15/01/98	106	46.98	11	1.55
50	2446	543	480	15/01/98	106	64.2	3	1.63
51	3671	630	565	22/01/98	98	58.36	7	1.29
53	3190	613	562	22/01/98	98	90.24	9	1.72
54	3399	615	560	22/01/98	98	18.58	8	1.14
57	1228	436	398	22/01/98	98	27.36	17	1.27
40	1970	516	460	22/01/98	98	33.82	28	0.83

Several scales were removed from common carp in the area of the incision to facilitate suturing. Coded radio transmitters (Model MCFT-3 A, Lotek Engineering Inc.) weighing 16.0 g in air, 7.0 g in water and measuring 16 × 50 mm were inserted into the coelomic cavity. A 16.5-gauge hypodermic needle was then pushed through the body cavity and the antenna wire was passed through to the outside. The incision was closed using five independent sutures of 2/0 non-absorbable braided silk (Ethicon Inc.). The entire procedure took less than 6 min. The fish were then returned to the holding tank and allowed to recover for several hours prior to release at site of capture.

Telemetry system

A fixed system consisting of seven sequentially scanned underwater antennas monitored fish movements in the out-fall canal (Fig. 1). The receiver (SRX-400, Lotek Engineering Inc.) equipped with code log discrimination software (W 17, Lotek Engineering Inc.) was programmed to scan each of the seven antennas for 5 s before cycling to the next antenna. The antennas consisted of RG 58 c/u cable with the shielding removed 5 cm from the end. An ASP-8 switcher box (Lotek Engineering Inc.) was used to facilitate the switching between the seven antennas. Since all fish codes were on the same frequency, the entire scanning period for all fish at all seven antennas only took 35 s. Antennas were secured on the bottom of the channel with receiver sensitivity adjusted so that the reception cells served as movement check points. Reception cells were carefully mapped to ensure that the reception cells covered the entire cross-sectional area of the channel. Fish were occasionally able to move past a single antenna without detection, depending upon the sequential scanning cycle. Data were downloaded on a weekly basis to ensure proper system configuration. Data were sorted by code, date and time, and then the results for each fish were summarized.

Additional telemetric observations were collected using a portable receiver (SRX-400), and either a two-element yagi antenna or an underwater dip antenna to verify the fixed system results. Anecdotal information was collected throughout the study by angling, netting and through visual observations. The relative depth of the fish was determined using power strength records from the fixed and manual tracking.

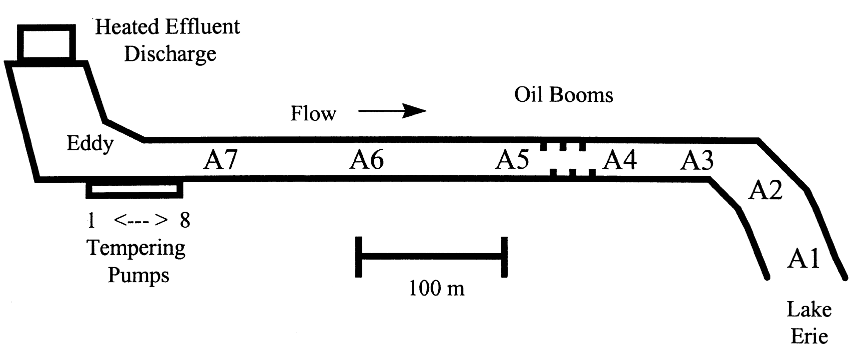

Figure 1. Map illustrating the configuration of the discharge canal and the locations of the antenna reception cells.

Data analysis

Descriptive statistics were calculated for effluent water temperature on a daily basis from measurements collected every 0.5 h from a station located midway along the discharge canal (i.e. maximum, minimum, mean, median, range, SEM, standard deviation and variation). The other environmental and operational variables collected were mean daily influent temperature (°C), station net capacity (%), condenser cooling flow ($m^3\ s^{-1}$) and station load ($MW\ h^{-1}$).

The duration of time individual fish spent in the discharge canal was expressed as a residency index and was represented by the percentage of time from release until 30 April 1998 during which the fish was resident in the canal. Similar indices were calculated for canal activity (the number of movements per day between adjacent antennas when in the discharge canal) and lake activity (the number of times the fish enter/or exit the canal on a given day). For each index, daily values were calculated for each fish, as was an average value for the study period for each fish and an average value for all fish of each species on a daily basis.

To determine if there were species-specific differences in the residency index values, in and out values, and activity indexes of channel catfish and common carp, data were first tested for normality using a Lilliefors test and were examined to determine if variance was homogeneous using an *F*-test. If the data were normal and variances were homogeneous, then the data were analysed using a *t*-test; otherwise, data were analysed using a Mann–Whitney *U*-test. The Wald–Wolfowitz runs test was used to detect serial patterns in daily residency and activity indexes. The cut-off point for this test was based upon the median residency index and activity index values.

To determine if significant differences existed in activity or residency for common carp and channel catfish when daily water temperature fluctuations were above the mean daily range, the residency and activity indexes were determined for each species and then analysed individually using the Wilcoxon signed rank tests. Correlations between residency values, activity indices, and environmental and operational variables were computed using Spearman rank correlations for non-parametric data. To determine if the residency index, in and out index, or activity index were correlated to fish length for each species, a Spearman rank correlation was used after distributions were analysed for normality and homogeneity of variances as mentioned above. All tests were considered significant at $P = 0.05$ and all means are presented with the standard error.

Results

Residency

Channel catfish were resident in the canal at the beginning of the study, but the proportion of tagged individuals in the discharge canal declined quickly, and by day 40, no tagged fish were in the discharge canal (Fig. 2). Several fish returned for brief periods of time. Common carp were resident in the NTGS discharge canal for the majority of the winter of 1997–1998, although the number of tagged individuals residing in the canal decreased throughout the study (Fig. 2). During the study, the average individual residency index values were significantly greater for common carp ($n = 10$) than channel catfish ($n = 10$; $P < 0.05$). The mean common

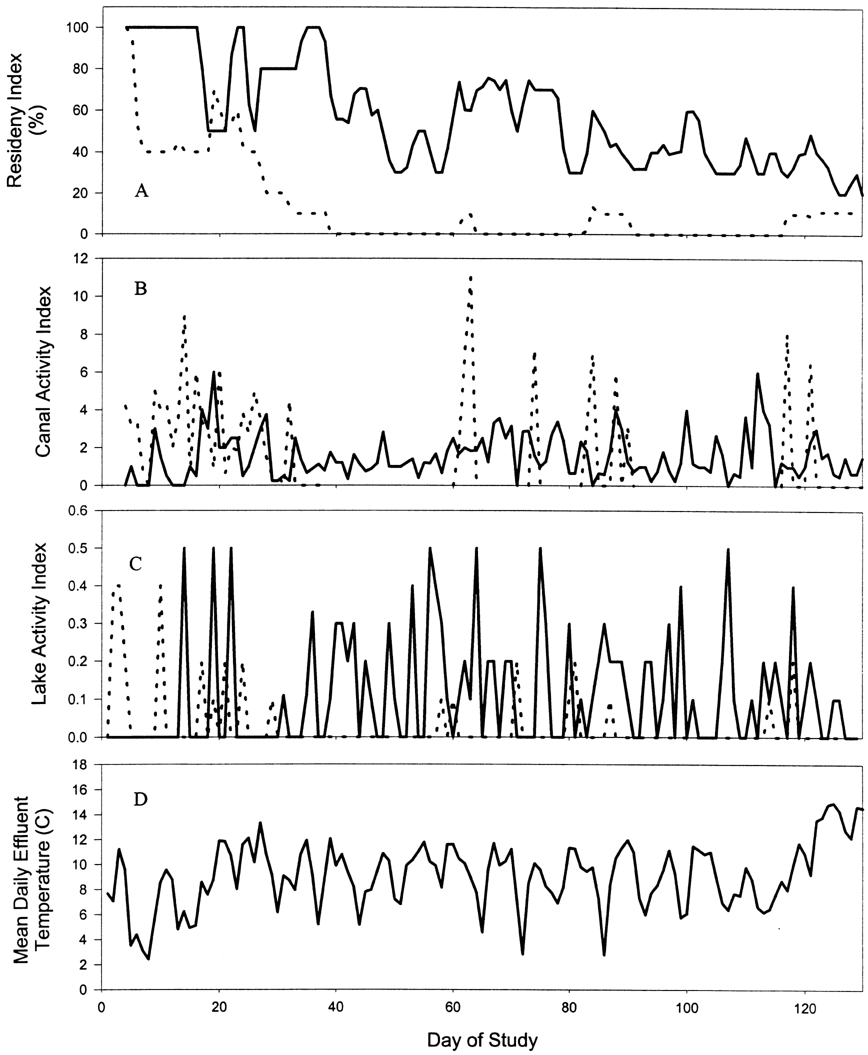

Figure 2. Series of graphs illustrating the changes in common carp (solid trace) and channel catfish (dashed trace) (A) residency, (B) canal activity and (C) and lake activity during the study period; (D) the daily mean discharge water temperatures illustrate the fluctuating environmental and operating conditions in the discharge canal.

carp residency values were 47.71 ± 8.51%, compared with values of 10.15 ± 2.82% for channel catfish. The daily residence index values were not ordered randomly ($P < 0.05$) for channel catfish (z = –9.875) or common carp (z = –8.397).

Water temperature fluctuations which were greater than the mean (5.8 °C) had no significant influence ($P > 0.05$) on the time that channel catfish or common carp spent in the discharge canal during the 129-day study period. There were no significant correlations ($P > 0.05$) between channel catfish residency and the environmental/operational variables; however, significant correlations did exist for common carp residency. Common carp daily residency

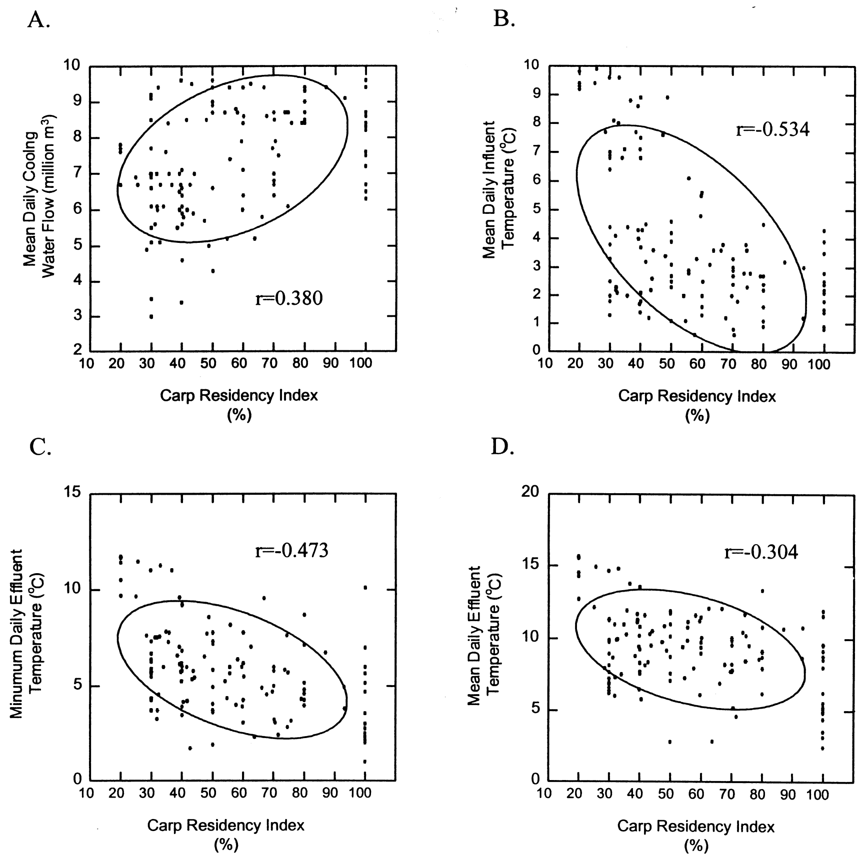

Figure 3. Correlations between carp residency, and (A) mean daily cooling water flow, (B) mean daily influent temperature, and (C) minimum and (D) mean daily effluent temperature. The ellipsoids represent 95% confidence limits.

was negatively correlated (n = 129; $P < 0.05$) with mean daily influent water temperature (r = –0.534), and minimum and mean daily effluent temperature (r = –0.473; r = –0.304), and positively correlated ($P < 0.05$) with mean condenser cooling flows (r = 0.380) (Fig. 3). There was no relationship between total length of fish and the residency index for channel catfish (n = 10; $P > 0.05$) and common carp (n = 10; $P > 0.05$).

At the conclusion of the monitoring period, two radiotagged common carp were still in the discharge canal, while there was only one channel catfish. One radiotagged channel catfish was recaptured by an angler on 19 April 1998, 500 m upstream in Nanticoke Creek, a small tributary of Lake Erie. Nanticoke Creek is only 2 km west of NTGS and is a known spawning location of channel catfish.

Activity

While in the canal, channel catfish were consistently located on the bottom of the water column in deep water areas (> 6 m), whereas common carp were often located in shallow areas (< 1 m) of low velocity in aggregations with untagged conspecifics. Channel catfish undertook frequent movements within the canal and rarely spent extended periods of time in one location. While resident in the canal, the average individual activity index was significantly higher ($P < 0.05$) for channel catfish (5.04 ± 1.66; $n = 10$) than common carp (1.47 ± 0.14; $n = 10$). The daily canal and lake activity index values were not ordered randomly ($P < 0.05$) for channel catfish or common carp, indicating that there were distinct patterns of activity (Fig. 2).

Channel catfish were more active during periods when water temperature fluctuations were minimal. Activity levels were significantly lower ($n = 129$; $P < 0.05$) for channel catfish during periods when water temperature fluctuations were higher than the daily average fluctuation in water temperature (5.8 °C). No significant differences in activity were observed for common carp ($n = 129$; $P > 0.05$). There were no significant correlations between channel catfish or common carp activity and the environmental/operational variables. There was no relationship between total length of fish, and canal or lake activity indices for channel catfish ($n = 10$; $P > 0.05$) and common carp ($n = 10$; $P > 0.05$).

While resident in the discharge canal, common carp spent significantly more ($P > 0.05$) time in the lower reaches of the canal than did channel catfish. Although more active while within the canal, channel catfish activity was generally restricted to the upper reaches of the canal. Consistent with this, the average individual lake activity values were significantly greater ($P < 0.05$) for common carp 11.7 ± 2.50 ($n = 10$) than channel catfish 2.5 ± 1.02 ($n = 10$), indicating that common carp made more movement between the lake and canal than channel catfish.

Discussion

Fish movements and activity patterns

The present study represents one of the first attempts to monitor the long-term residency of fish captured in a discharge canal using a fixed radiotelemetry system. The results indicate that common carp appear to reside in the discharge canal for a significant portion of the winter. During winter at the J. M. Stuart electric generating station on the Ohio River, Yoder & Gammon (1976) similarly found that carp preferred the heated effluent and backwater areas relative to the ambient river reference sites.

Contrary to the findings of the present investigation, several reports have suggested that few common carp reside in the warmer discharge environment during the winter, although none of these studies were based on radiotelemetry. For example, Romberg, Spigarelli, Prepejchal & Thommes (1974) found that carp at a thermal discharge on Lake Michigan appeared in large schools during May, and were observed routinely swimming into and out of the discharge flume through temperature gradients as much as 10 °C. Neill & Magnuson (1974) also reported that common carp were absent from samples in the out-fall area of a power plant on Lake Monona, Wisconsin, USA, during their winter sampling period, despite being present at other times of the year.

In the present study, radiotagged common carp were found to aggregate with large numbers of untagged conspecifics in the discharge channel. Although there are apparently no reports of large winter aggregations of common carp in other thermal discharges, Johnsen & Hasler (1977) used ultrasonic telemetry to locate large winter aggregations of carp in Lake Mendota, Wisconsin, USA, a system unaffected by a large thermal effluent. In addition, the apparent congregations of common carp in heated effluent out-falls in the USSR led to attempts to rear these fish in floating cages (Coutant 1970). The consistent presence of common carp at the entrance to the NTGS discharge canal, as well as at several areas of lower velocity, suggested that these fish reside within, and therefore, are subject to continual exposure to fluctuating discharge temperatures.

Conditions which were correlated to high common carp residency included high flows, with low minimum and mean daily water temperatures, and low lake temperatures. The low lake temperatures may have permitted fish to move freely into discharge waters which were usually low during times of increased residency. Fish were apparently attracted by the discharge during periods of higher flow, perhaps reacting rheotacticly to the flows. Several authors (Minns, Kelso & Hyatt 1978; MacLean *et al*. 1982) suggested that the fish presence at out-falls of thermal generating stations may be a consequence of the turbulence regime and/or topographical irregularities, and not the plume of elevated temperatures. Carp remained quite stationary within the channel with their movements frequently being less than would be detectable by the fixed telemetry system.

Studies on channel catfish movements and residency are scarce, with winter reports almost non-existent. Channel catfish residency or activity was not correlated to any of the environmental variables studied. However, these fish were less common during the later portion of the study in the discharge canal. When present, common carp were active and would often explore the entire length of the canal, swimming repeatedly upstream and downstream.

Dryer & Benson (1957) also found that channel catfish concentrated in a heated discharge harbour on Kentucky Lake, Tennessee, USA, during both winter and spring, although the study was not based on the behaviour of individual fish. Yoder & Gammon (1976) collected channel catfish in D-nets in the summer and autumn, and by electric fishing in the winter in the effluent canal of the J. M. Stuart electric generating station on the Ohio River. Winter electric fishing catches of channel catfish were highest during one collecion period in February, after a brief rise in water level and a rise in temperature, when the above authors captured many large adults, which may indicate an early spring response at a temperature of ≈ 10 °C.

Channel catfish spawn in Lake Erie in late spring, usually in warm, turbid tributaries (Scott & Crossman 1973). An angler recapture of a channel catfish in a nearby river suggests that these fish were exploring spawning areas. The several channel catfish which returned in late April may have also been exploring potential spawning areas.

Study limitations and conclusions

When employing a fixed telemetry system, data can only be obtained when fish are in or move past an antenna reception cell. When fish move beyond the range of detection, or in this case, out into the lake, it was not possible to pinpoint their location. In the present study, it was not possible to locate most fish (i.e. no channel catfish and only a few common carp in shallow water) after the animals left the discharge canal because of impaired propagation of radio signals in deep water. Therefore, it was not possible to determine whether the fish had entirely left the discharge affected area (plume). Within the NTGS discharge canal, fish are exposed to the most extreme variations in temperature and flow resulting from plant operation.

If fish are able to reside in these conditions, then the animals would also probably be able to reside in the plume. Although this was a limitation, it was possible to monitor movements and activity on a continual basis throughout the study period, which would be almost impossible using conventional manual tracking. The technique used permitted documentation of extended winter residency of individual fish, and showed to what extent fish residency and activity was related to fluctuating flows and thermal conditions.

Neill & Magnuson (1974) cautioned that the generally accepted notion (Coutant 1970) that fish are attracted to the warmed water of power plants during cooler months and repulsed by thermal extremes in the summer may be based upon studies with a common deficiency, i.e. a lack of suitable reference sites with which the discharge area could be compared. Although the objective of the above studies was primarily to examine fish distributions, these were often based upon the relative abundance or presence/absence of these species in catches, and as such, data insufficient to assess residency behaviour of individual fish.

Similarly, previous studies of fish residency based upon mark and recapture had difficulties in interpreting movements since the movement history between mark and recapture was unknown (see Tranquilli, McNurney & Kocher 1981). The findings are generally contradictory to previous research which has suggested that fish may enter discharge canals on a temporal scale usually of the order of minutes or hours, or for which residency was unknown. These previous studies were based upon residence-time calculations derived from internal body temperature measurements (e.g. Spigarelli *et al*. 1974) and did not allow for the continuous monitoring of the behaviour of individual fish over a large spatial and temporal scale. Managers and regulators must consider the potential extended residency of some fish species when attempting to assess the impacts of different heated effluents on the biota.

In situ studies on the physiological effects of temperature fluctuations on fish such as common carp and channel catfish which reside in thermally altered waters for extended periods of time still require further attention. Further assessments of activity and movement at a finer resolution than possible with conventional coded telemetry are still required. The advent of physiological telemetry will allow researchers to monitor the physiological response of fish in the field to fluctuating environmental conditions (Lucas, Johnstone & Priede 1993) instead of relying on laboratory studies which do not incorporate site-specific characteristics.

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