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Evaluation of a Hidrostal Pump Fish Return System

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ABSTRACT

We tested the effectiveness of a Hidrostal pump and filtered mercury vapor light system for attracting, concentrating, and transporting fish commonly impinged on water intake structures of thermal electric generating stations on the Great Lakes. In general, the Hidrostal pump effectively transported test fish with relatively low mortality rates. Mortality varied among fish species, with rainbow trout (*Salmo gairdneri*) significantly hardier than yellow perch (*Perca flavescens*) and alewife (*Alosa pseudoharengus*). Mortality also generally increased at higher pumping speeds, while mortality of yellow perch was greater in a long transport loop than in a short transport loop. In tests of fish attraction and capture, the addition of a filtered mercury vapor light significantly increased the efficiency of fish capture of the Hidrostal pump transport system. Other directive cues (bubble curtains, strobe lights, and electric fields) did not significantly improve the efficiency of the Hidrostal pump-mercury vapor light system. Capture efficiency varied significantly among fish species and increased with duration of the test period.

The electrical industry is the largest single user of water in developed regions of the world (Langford 1983) and, in the United States, the thermal electric industry constitutes the largest industrial user of water (ASCE 1982). The principal use of water in both nuclear and fossil-fueled thermal electric generating stations is for condenser cooling either in 'once-through' cooling processes or as 'make-up' water for closed cooling systems. By and large, this demand for water is met by diverting natural surface waters that also serve as habitat for a variety of aquatic organisms (Hanson et al. 1977).

The capture of aquatic organisms in the cooling water current is among the principal environmental effects of thermal electric generating stations (Hanson et al. 1977). A variety of modifications in the design of intake structures are available to reduce the capture of aquatic organisms (Sharma et al. 1981; ASCE 1982). Despite these modifications, however, fish still may become entrained in the intake water current and impinged on the intake screens (Langford 1983). This condition may be particularly acute when retrofit changes are applied to existing problem stations.

Fish return or bypass systems offer an alternative in that they permit entrained fish to return to the natural environment prior to impingement. An effective return system requires an efficient means of attracting and concentrating fish within the water intake channel and a mechanism for transporting fish back to their original waters without appreciable damage to the fish.

A variety of pumping systems are available for transporting fish; however, many either produce excessive mortality or have low hydraulic efficiencies (see review by ASCE 1982). The Hidrostal pump that uses a one-piece, screw-centrifugal impeller has been used successfully in transferring fish from a vessel to processing plant in a number of locations and has been suggested for the transfer of live fish from intakes (Taft et al. 1981; ASCE 1982).

There remains, however, the problem of attracting and concentrating fish in the vicinity of the pump intake. Potential mechanisms for attracting and concentrating fish include lights, water currents, electric fields, and olfactory lures (Langford 1983). The strong currents encountered in water intake channels largely preclude the use of currents and olfactory cues in directing fish within the intake channel of operating stations. Light may be used either to attract or repel fish depending on light intensity, wavelength, species, and physiological condition of the fish involved (Ben-Yami 1976; Hadderingh 1982; Langford 1983). In our own research in both the

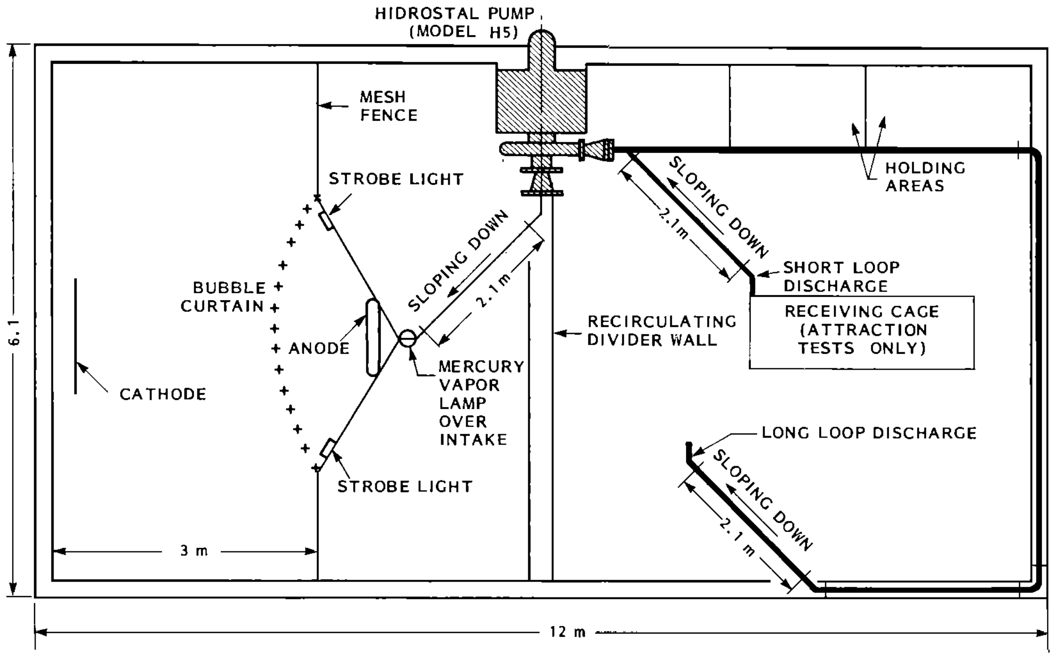

Figure 1. General layout of Hidrostal pump test pool.

laboratory and in the field, we have found that filtered, mercury vapor lights are often very effective in attracting and concentrating fish (Patrick and Vascotto 1981; Haymes et al. 1984). Accordingly, filtered mercury vapor lighting was used as the primary fish attractant in the present study. Strobe lights, electric fields, and bubble curtains also have been reported to be useful for directing fish movement (Vibert 1967; Patrick et al. 1982; Stewart 1982; Langford 1983) and were used intermittently as additional cues for guiding fish to the pump intake.

In this study, we first determined the mortality for a number of fish species transported through a Hidrostal pump under a range of operating conditions. We then tested the effectiveness of filtered mercury vapor lighting and other directive cues (strobe lighting, electric fields, and bubble curtains) in increasing the capture of free-swimming fish by the Hidrostal transport system. A number of species of native and introduced Great Lakes fish were used in these tests, particularly yellow perch (*Perca flavescens*), rainbow trout (*Salmo gairdneri*), rainbow smelt (*Osmerus mordax*), and alewife (*Alosa pseudoharengus*). The last two species, in particular, are representative of the midwater, pelagic Great Lakes fishes that constitute the majority of fish impinged on water intake structures of Ontario Hydro thermal generating stations on the Great Lakes.

Materials and Methods

The Hidrostal pump (model H5F) used for all tests is designed for free passage of solid objects up to approximately 10 cm in diameter. The pump consists of an enclosed, screw-type impeller driven by a 10-hp electric motor controlled by a variable speed drive over an operational range of 400–1,200 RPM (revolutions per minute).

Tests were conducted in a rectangular concrete pool (12 × 6.1 m) divided into two equal areas (Fig. 1). The pool was supplied with dechlorinated Toronto water and maintained at a depth of approximately 1 m. The Hidrostal pump was mounted on the divider wall, with intake and discharge pipes (25 cm diameter) extending into each area (Fig. 1). Water pumped through the pump to the discharge side of the pool returned to the intake side through screened openings within the divider wall.

In tests of transport mortality, a screened cage of approximately 2-cm^2 mesh was placed around the pump intake to restrict fish to this area. Fish passing through the pump were discharged to the receiving pool through either short or long transport loops. The short loop was 2.1 m long with one 45° bend, while the long loop was approximately 15.5 m from pump to discharge, with two 45° and two 90° bends.

The intake side of the pool was modified for tests of attraction, concentration, and capture of free-swimming fish (Fig. 1). A wire-mesh fence extended perpendicularly to the side walls of the intake side of the test pool, then angled to the pump intake. A mercury vapor light (250 W clear mercury bulb) equipped with blue plastic filters was placed immediately behind the pump intake. The anode (1-m diameter circle of tubular aluminum (6 mm in diameter)) of an electrofisher encircled the pump intake, while the cathode (three 2-m corrugated galvanized tubes (5 cm in diameter)) was placed parallel to the back wall of the pool approximately 3 m from the anode. Two Tandy strobe lights were attached to the angled walls of the "fence" approximately 1.5 m from the intake and directed towards the intake. The pump intake was surrounded by a 3-m length of porous hose (5 cm in diameter) filled with glass beads. The hose was connected to a source of compressed air and generated the bubble curtain.

Current velocities within 30 cm in front of the pump intake varied with pump speed from roughly 12 cm/second at 450 RPM to approximately 30 cm/second at 1,200 RPM. Beyond 60 cm from the pump intake, currents were consistently less than 5 cm/second.

The filtered mercury vapor light produced light that was predominantly in the blue-violet region (410–450 nanometers) of the visible spectrum. Light intensities directly in front of the intake were approximately 1.0 microeinsteins per square meter per second and decreased to less than 0.02 microeinsteins per square meter per second within 2 m of the intake. (Light intensity was measured with a Radiometer, Model L1-185A photometer.) Strobe lights were operated at a frequency of >200 flashes per minute with a flash peak duration of <100 microseconds. When the strobe lights were operated in conjunction with the mercury vapor light, light intensities in this same 2-m zone were 0.03 microeinsteins per square meter per second or greater.

The electrofisher (Smith Root Type V1-A) was operated at 168 V with square-wave DC pulses of 1 millisecond duration; electrical stimuli were applied intermittently with a 2-second pulse followed by a 2-second pause. This produced an electric field of 15–20 microamp/30 cm between electrodes.

Rainbow trout were obtained from a commercial hatchery (Shamrock Springs Trout Farm, Erin, Ontario). All other fish were collected from local waters using seines, dip nets, or trap nets. Fish were maintained in holding pools of approximately 10,000 liters that were supplied with dechlorinated Toronto water. Water temperature varied seasonally from 10 to 18 C. Fish were held for at least 1 week prior to testing and normally used within the next 3 weeks. Rainbow trout, yellow perch, and alewife were fed commercial trout diet, earthworms, and a mixture of Tetramin diet and oatmeal, respectively. Rainbow smelt would not accept artificial diets and were not fed during the holding period. In mortality tests, a natural photoperiod was maintained (10–14 hours of light and 14–10 hours of dark); while in attraction tests, photoperiod was controlled at 16 hours of light and 8 hours of darkness.

Test Procedures

Transport Mortality

After the Hidrostal pump was primed and operating at the test speed, a group of fish (normally 25 fish/test) was transferred to the retaining cage over the intake and forced through the intake. After fish passed through the pump to the receiving pool, they were collected by seine, transferred to holding cages within the pool, and the mortality was recorded after 24 and 48 hours. Fish were visually examined for external injury at the end of this interval. For each test, an equivalent number of control fish were subjected to the same handling as the experimental fish but were not passed through the pump. Mortality of these controls was less than 12% in all tests, with an average mortality of less than 4%. Accordingly, results were not corrected for mortality of control fish.

Rainbow trout 12–20 cm long (TL) and yellow perch 10–20 cm long were tested with both long and short transport loops while alewife (10–15 cm TL) were tested only with the long transport loop. Limited additional tests also were performed using rainbow smelt (8–12 cm TL), juvenile gizzard shad (*Dorosoma cepedianum*) 10–20 cm long (TL), white sucker (*Catostomus commersoni*) 15–40 cm long (TL), and brown bull-

Table 1. Average percent mortality (±SE) of fish passed through the Hidrostal pump transport system at various pumping speeds (RPM).

	Short transport loop				Long transport loop		
Species	450	600	950	1,150	450	600	950
Rainbow trout	0	0.8 ± 0.8	0.8 ± 0.8	0	0	0	1.6 ± 1.0
Yellow perch	0.8 ± 0.8	4.0 ± 1.8	6.4 ± 2.0	11.2 ± 3.4	3.2 ± 1.5	12.0 ± 6.2	28.8 ± 7.5
Alewife					4.8 ± 1.5	8.8 ± 3.9	22.4 ± 5.9

head (*Ictalurus nebulosus*) 20–30 cm long (TL). Pump speeds of 450, 600, 950, and 1,150 RPM were tested with the short transport loop. The highest speed (1,150 RPM) could not be attained with the long transport loop and only test speeds of 450, 600, and 950 RPM were used with this loop. Five replicate tests with 25 fish per test were conducted at each trial but, for rainbow trout and yellow perch, a single series of tests was conducted at a higher density (100 fish/test).

Fish Concentration and Attraction

Fish were tested without directive cues (pump alone), with the mercury vapor light alone, and in combination with electrofisher, strobe lights, and bubble curtain. Tests of 3 hours' duration were conducted with both rainbow smelt and alewife but only rainbow smelt were available for the 16-hour tests. At least two replicate trials of each treatment were conducted, with the order of treatments within a replicate randomized.

For each test, a group of 25 rainbow smelt or alewife (10–15 cm TL) were introduced to the intake side of the test pool at least 6 hours before the test. The Hidrostal pump was primed and operated at a speed of 600 RPM for all tests and was operated either for 3 hours (0900–1200) or 16 hours (1700–0900 the next day). During this period, the scheduled treatment was applied to the pool. The pump and attractants were shut off at the end of the test and fish in the receiving cage were counted.

In tests employing the mercury vapor light, the light was used continuously for the duration of the test. Other treatments (strobe lights, electrofisher, and bubble curtain) were tested only in conjunction with the mercury vapor light because preliminary tests indicated these treatments by themselves were not effective in increasing the passage of fish through the pump. These other treatments were applied intermittently for 3-minute intervals, commencing at 57 minutes after the test started and subsequently repeated every 15 minutes in the 3-hour tests; every 60 minutes for the 16-hour tests.

The results were analyzed using the appropriate analysis of variance model. Data were transformed using the square-root transformation to comply with assumptions of normality and equivalence of variance—as indicated by residual and normal probability plots. Cell means were compared using the least significant difference method if the F-ratio was significant ($P < 0.05$). In all statistical tests, the 95% level of probability was used as the criterion of statistical significance.

Results

Transport Mortality

Transport mortality generally increased at the higher pump speeds (Table 1). However, there were significant differences in patterns of survival among species. Rainbow trout were much more hardy than yellow perch and alewife and had low average mortality (<2%) in all tests. Accordingly, for rainbow trout, neither pump speed nor length of transport system significantly affected mortality, but among both yellow perch and alewife, transport mortality increased significantly with pump speed. With the long transport loop, mortality was not significantly different between yellow perch and alewife at the same test speed. Mortality of yellow perch at a specific pump speed in the long transport system was more than 3 times greater than mortality at the same speed in the short transport loop.

Transport mortality did not appear to increase at higher fish densities. In tests using 100 fish/test, there was no mortality of rainbow trout at any test speed with either transport system, while mortality of yellow perch in the short transport loop was less than 15% at all test speeds. In additional tests with other fish using the short trans-

Table 2. Percent capture (±SE) of fish by the Hidrostal pump transport system operated at 3 and 16 hours duration with different treatments. Number of replicates in parentheses.

Treatment	Rainbow smelt (3 hours)	Rainbow smelt (16 hours)	Alewife (3 hours)
No attractants	4.0 ± 1.6 (4)	24 ± 4 (2)	6.7 ± 3.5 (3)
Mercury vapor light (MVL)	19 ± 3 (4)	54 ± 2 (2)	61 ± 8 (3)
MVL + strobe lights (STR)	21 ± 5 (3)		47 ± 20 (3)
MVL + electrofisher (ELC)	34 ± 2 (2)		57 ± 15 (3)
MVL + bubble curtain (BC)	14 ± 6 (2)	68 ± 0 (2)	68 ± 11 (3)
MVL + STR + ELC	34 ± 2 (2)		73 ± 9 (3)
MVL ± STR + BC	24 ± 16 (2)	40 ± 4 (2)	41 ± 3 (3)
MVL + ELC + BC			47 ± 9
MVL + STR + ELC + BC			60 ± 8

port loop, mortality of rainbow smelt at 450 RPM was less than 5%. No mortality was observed among gizzard shad tested at 600 RPM or white sucker and brown bullhead tested at 950 RPM.

Injuries were observed among 10–20% of the surviving fish. These injuries appeared to result from impact and abrasion with the pump and transport system. Hemorrhage and loss of scales were the most frequently observed injuries. Over the range of lengths we employed, the injury did not appear to be related to size of the fish because the average length of injured fish was not significantly different from the mean length of fish tested. As with mortality, the incidence of injury appeared to increase with pump speed and was greatest in the long transport system.

Attraction and Concentration

The Hidrostal pump by itself, without directive cues, was not effective in capturing fish. For both rainbow smelt and alewife, capture efficiency increased significantly when the pump was operated in conjunction with the filtered mercury vapor light and other directive cues (Table 2). Capture efficiency within treatments was quite variable, however, and no significant differences in capture efficiency were apparent among tests employing the mercury vapor light alone or in conjunction with other directive cues. The general pattern of response was similar for both species, but the efficiency of capture of alewife was significantly greater than that of rainbow smelt. Capture efficiency also was significantly affected by the duration of the experiment, with greater numbers of rainbow smelt captured in the 16-hour (overnight) tests than in tests of 3 hours.

Discussion

The Hidrostal pump used in conjunction with filtered, mercury vapor lighting was useful in attracting, concentrating, and transporting fish. However, both attraction and transport mortality varied significantly among species. Field applications of the system would thus be expected to require a degree of fine tuning to adapt to site-specific conditions.

The increased mortality of yellow perch and alewife at higher pump speeds indicates that pump speed should be maintained as low as is practicable in field applications. With pump speeds at or below 600 RPM, mortality generally was less than 10%. This mortality was similar to the range of 5–20% reported for a number of other fish-return pumps (Taft et al. 1981; ASCE 1982). The present tests were conducted with a relatively small capacity Hidrostal pump but larger models (>30 cm diameter) are available. In these larger models, the ratio of contact surface to water pumped should decrease, thus reducing the probability of impact and abrasion from the impeller and walls of the transport system.

The significant increase in mortality of yellow perch with the longer transport system may indicate that fish return systems should be designed to be as short as possible. However, in addition to increased length, the long transport loop also included two right-angle bends that were not included in the short transport loop. Right-angle bends are likely to increase injury and abrasion of transported fish, and recent recommendations for return systems suggest that bypass systems should be designed with transition angles of 45° or less (ASCE 1982). Further research is required to separate the effects of system length and transport angles on overall mortality.

The differences in transport mortality among test species likely reflected the actions and interactions of a number of factors. Extensive scale loss was often observed in moribund fish and it is possible that rainbow trout with relatively small scales were less susceptible to abrasion than yellow perch and alewife which have relatively large scales. In addition, both alewife and yellow perch were captured from the wild, while rainbow trout were hatchery-reared and differences in mortality may also correspond to the increased susceptibility to stress of wild fish (Wedemeyer et al. 1977). Interestingly, mortality rates did not differ significantly between alewife and yellow perch although the yellow perch frequently are considered to be hardier than clupeids (ASCE 1982). The present study did not investigate the effects of temperature on mortality or the susceptibility of transported fish to predation. Both of these factors could be important in field operations and thus merit further investigation.

The increase in capture efficiency noted when the Hidrostal pump was used in conjunction with the filtered mercury vapor light is consistent with previous observations that mercury vapor lights are effective in attracting fish in both field and laboratory tests (Patrick and Vascotto 1981; Haymes et al. 1984). Additional directive cues (strobe lights, electrofisher, and bubble curtain) did not increase the capture efficiency of the Hidrostal pump-mercury vapor light system; thus, these other treatments may not be required for fish return systems.

The inability to discriminate among tests employing the mercury vapor light in combination with other treatments appears to derive, in part, from the high variability among replicate trials (Table 2). This variability may have resulted from the tendency for both rainbow smelt and alewife to swim in schools (Emery 1973). Fish in a school tend to respond as a unit (Partridge and Pitcher 1980), so that capture becomes a group response with either many or few fish captured in a given trial.

The increased capture efficiency of rainbow smelt in 16-hour (overnight) tests relative to 3-hour tests indicates that the filtered mercury vapor light should be employed continuously in field operations. These results are consistent with previous observations in our laboratories that the number of fish approaching a mercury vapor light increased with duration of exposure to the light source (Patrick and Vascotto 1981; Patrick 1982). Sequentially operated lights may effectively lead fish (Wickham 1973) and, in field operations, we have had some success in using a series of filtered, mercury vapor lights in sequence to lead fish (Haymes 1983). Thus, the sequential use of distant lights to direct fish towards the continuous light over the fish return intake may prove useful.

The observed differences in capture efficiency of rainbow smelt and alewife emphasize the need for site-specific fine tuning of any return system in response to local and seasonal variation in species of fish that are impinged. These differences are in accord with apparent differences observed in the response of these species to filtered mercury vapor light previously observed in our laboratory (Patrick 1982).

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