NOTES

Effectiveness of Fine Mesh Cylindrical Wedge-Wire Screens in Reducing Entrainment of Lake Michigan Ichthyoplankton

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Samples of ichthyoplankton entrained through 2.0-mm and 9.5-mm-slot opening cylindrical wedge-wire screens and through an open pipe (control) were collected in June, July, and August 1979, 1067 m off the southeast shore of Lake Michigan at a depth of 10.7 m. Screens were designed for a flow rate of 1.9 m^3 min^{-1} at 15.2 cm s^{-1} through slot velocity. Ambient composition and density of ichthyoplankton weie determined by net tows. Rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), and yellow perch (*Perca flavescens*) larvae were common in both entrainment and tow collections. Eggs were found almost exclusively in entrainment collections. Ambient larval fish densities were about 11 times greater than those found in entrainment collections. Total entrainments through either screen and the open pipe were not statistically significant. Larval avoidance and, to a lesser extent, screen exclusion were responsible for the low entrainment. We estimated that about 90% of native fish larvae at the site avoided pumping.

Key words: Lake Michigan, fish larvae, fish eggs, ichthyoplankton, entrainment, power plants, avoidance

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Des échantillons d'ichtyoplancton entraînés à travers des écrans cylindriques de fil métallique cunéiforme à ouvertures en fentes de 2,0 mm et 9,5 mm et à travers un conduit libre (témoin) ont été recueillis en juin, juillet et août 1979, à 1067 m au large de la rive sud-est du lac Michigan, à une profondeur de 10,7 m. Les écrans ont été conçus pour une vitesse d'écoulement de 1,9 m^3 min^{-1} à une vitesse à travers les fentes de 15,2 cm s^{-1}. Des prises au filet à plancton ont servi à déterminer la composition et la densité ambiantes de l'ichtyoplancton. Les larves d'éperlan arc-en-ciel (*Osmerus mordax*), de gaspareau (*Alosa pseudoharengus*) et de perchaude (*Perca flavescens*) sont communes dans les collections à la fois par entraînement et par filet. On a trouvé des oeufs presque exclusivement dans les collections par entraînement. La densité des larves de poissons dans l'environnement est d'environ 11 fois supérieure à celle trouvée dans les collections par entraînement. Il n'y a pas de différence significative d'entraînement total soit à travers les écrans, soit dans le conduit libre. L'évitement par les larves et, à un degré moindre, l'exclusion par les écrans sont responsables du faible entraînement. Nous estimons qu'environ 90% des larves de poissons indigènes au site évitent d'être aspirées par les pompes.

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PROMULGATION of the 1972 Federal Water Pollution Control Act (FWPCA) emphasized monitoring and identification of ichthyoplankton potentially entrained at power-generating stations. Entrainment occurs when small organisms pass through traveling screens of power plant intakes. Entrainable organisms include plankton, macroinvertebrates, and fish eggs and larvae. Fish larvae and egg entrainment may have greater potential impact on aquatic systems because of the relatively lower reproduction rates of fish as compared to other aquatic organisms (Jude et al. 1978).

Various intake alternatives are used to minimize entrainment. Reduction of water intake volume via closed-cycle cooling systems is an alternative to open-cycle cooling. Although the risk for ichthyoplankton entrainment is less, closed-cycle cooling systems may have other adverse environmental effects, such as destruction of surrounding vegetation due to cooling tower drift (Rochow 1978) and discharge of concentrated contaminants to the aquatic environment (Reynolds 1980).

The J. H. Campbell Plant, Unit No. 3, is located on the southeastern shore of Lake Michigan. The 1067 m (3500 ft) offshore intake is constructed of cylindrical wedge-wire screens with 9.5-mm (3/8-in) square slot openings and a maximum through slot velocity of 15.2 cm·s^{-1} (0.5 fps). The screens provide uniform velocity fields at relatively low approach velocities (Cook 1978). Laboratory tests indicated that entrainment of fish larvae was reduced with small-mesh flat or cylindrical wedge-wire screens (Tomljanovich et al. 1978; Hansen et al. 1978). Reduction was attributed to larval avoidance induced by water velocity through the screens (Heuer and Tomljanovich 1978). To minimize entrainment, the Campbell Plant intake design allows retrofitting with 2.0-mm mesh screens in place of the 9.5-mm screens, if the finer mesh is proven biologically advantageous.

Therefore, this study was initiated to investigate the effectiveness of 2.0-mm and 9.5-mm cylindrical wedge-wire intake screens in reducing ichthyoplankton entrainment at the proposed location of the plant intake. Furthermore, we determined the ambient composition and abundance of fish eggs and larvae at the intake location and evaluated the diurnal differences in entrainment.

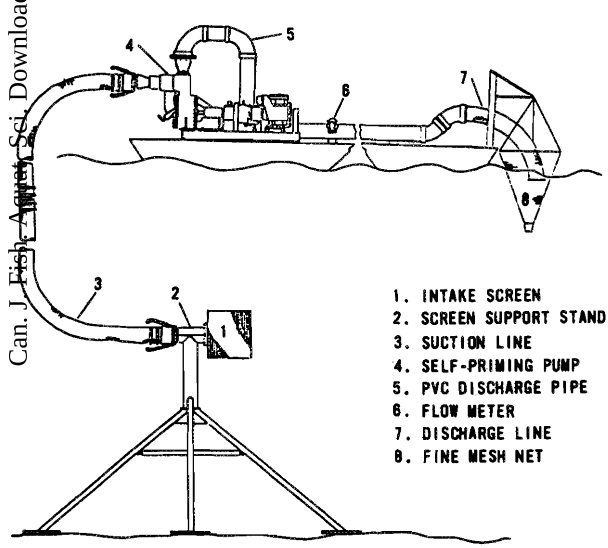

FIG. 1. Sampling equipment used in collecting entrainment samples.

Materials and methods — The wedge-wire screens were constructed of stainless steel with a solid stainless steel end plate at one end. On the open end, a flange with mounting bolts was welded to its base for attachment to the screen support stand. The screen structure and form were described by Cook (1978). Each test was designed for a flow rate of 1.9 m^3·min^{-1} at the 15.2-cm·s^{-1} (0.5 fps) maximum through slot velocity for the duration of the study. Design specification of the test screens and the control, each giving a total open area of 0.27 m^2, were as follows:

Screen slot size (mm)	Diameter (mm)	Length (mm)
2.0	457	368
9.5	384	300
Open pipe (control)	152	—

In conjunction with entrainment collections, duplicate 5-min net tows were taken at the same depth as the screens both day and night to define ambient composition and densities of ichthyoplankton species. Tows were made with a 0.5-m-mouth diameter, 351-μm-mesh net equipped with a Rogosha flow meter. Water was pumped through the screens and open pipe with a gasoline-powered 16-hp Briggs and Stratton engine, an Eaton hydrostatic transmission, and a Marlow self-priming centrifugal pump (1.9 m^3·min^{-1}). Pumps were bolted to the middle of an 8.8-m (25 ft) pontoon. The pontoon was replaced halfway through the study with a 12.2-m barge to withstand rougher lake conditions. Flexible 152-mm (6-in) diameter intake and discharge hoses were attached to each pump. A cumulative reading flow meter was mounted on each discharge hose to measure water volume pumped. Discharge water was filtered through a 1.0-m-mouth diameter, 351-μm Nitex plankton net suspended in the water from the side of the working platform. Screens and open pipe were located 2.3 m off lake bottom using a steel support stand (Fig. 1).

Entrainment and tow data are presented as number of larvae or eggs/1000 m^3 (D) of water filtered using the formula:

$$D = \left(\frac{\Sigma N}{\Sigma V}\right) \cdot 1000$$

where:

N = total number collected, and
V = total water volume filtered in m^3.

TABLE 1. Summary of water volume sampled and total ichthyoplankton densities (no./1000 m³) entrained and collected in tows during the day (D) and night (N) in June, July, and August 1979 from Lake Michigan near the J. H. Campbell Plant.

		Screen mesh size (mm)							
		2.0		9.5		Open pipe		Tows	
Month		D	N	D	N	D	N	D	N
June 1979	Total larvae	2.2	33.7	1.4	14.1	14.5	58.5	64.6	61.4
	Total eggs	122.5	58.1	56.6	60.0	83.2	21.1	0.0	0.0
	Sample volume (m³)	1331.1	861.1	1 395.5	849.3	829.5	615.2	263.2	130.3
July 1979	Total larvae	4.3	20.0	4.5	23.8	1.9	8.3	144.1	233.0
	Total eggs	20.6	162.2	65.2	420.8	6.4	30.4	7.0	5.1
	Sample volume (m³)	8694.9	7876.9	8 189.4	8020.9	7 791.1	8289.4	430.2	587.4
August 1979	Total larvae	1.8	16.0	4.4	26.0	4.9	56.8	75.3	230.6
	Total eggs	0.2	0.0	1.0	0.7	23.5	0.0	0.0	0.0
	Sample volume (m³)	9727.8	8178.0	11 519.0	9809.9	10 380.9	8484.7	863.6	698.1
Cumulative	Total larvae	10.2		13.8		18.3		149.4	
	Total eggs	45.6		102.0		17.3		2.4	
	Sample volume (m³)	36 669.8		39 784.9		36 390.9		2972.7	

Sampling was conducted as frequently as possible to estimate entrainment rates of fish larvae for the test intake system for this electric generating plant. The study was conducted during periods of peak larval abundance in the study area as determined by Jude et al. (1978, 1979) to ensure the generation of sufficient data to determine true differences between collections from the two test screens, open pipe and tow nets. In June 1979, five days and three nights were sampled for 3 h each. Because of the low larval densities in the area, the sampling efforts in early July 1979 were doubled to 6 h each, then in late July and August to 9 h. However, weather conditions and equipment failures controlled the sampling frequency and duration. The cumulative water filtered through the 2.0-mm, 9.5-mm, open pipe and tows, respectively, are given in Table 1.

Statistical analysis — A 2 × 3 factorial analysis of variance (ANOVA) where time (day and night) and screen slot size were main effects was used to test for significance (Gill 1978). Because of the major assumptions required in the ANOVA models, data were normalized and were tested for normality using the Kolmorgorv–Smirnov test of goodness of fit. Although transformation of the number of larvae collected using ln $(y + 1)$ normalized the data to an acceptable level ($\alpha > 0.01$), larval densities could not be normalized. Therefore, analysis of covariance (ANCOVA) was employed to test for significance.

Results — Rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*), yellow perch (*Perca flavescens*) and minnow larvae were the predominant species in both entrainment and tow samples (Table 2). Total larvae collected in the tow samples during the study were approximately 14, 11 and 8 times more than those entrained through the 2.0-mm and 9.5-mm screens and open pipe, respectively (Table 1). Analysis of covariance for July and August data combined indicated that there was no statistically significant difference [illegible]rough the two screens and the open pipe (Table 3). Similarities in entrainment densities among the 2.0-mm and 9.5-mm cylindrical wedge-wire screens and open pipe may be a function of screen design (Cook 1978) and a behavioral response of fish larvae.

Diurnal variations in egg and larval entrainment were evident throughout the study (Table 1). Fish larvae entrainment through the screens and open pipe were significantly ($P < 0.01$) higher at night (Table 3). Tow collections, however, had similar day–night densities in June and were higher at night during July and August.

Overall average larvae entrainment through both the 2.0-mm and 9.5-mm screens was 12.5 larvae/1000 m³ and 18.3 larvae/1000 m³ in the open pipe (Table 1). In June and August, open pipe entrainment densities were generally two to five times greater than screen entrainment densities, whereas in July the reverse was true (Table 2).

Fish eggs were found almost exclusively in entrainment samples with a maximum of 241 eggs/1000 m³ (Table 2) in July through the 9.5-mm screen. This may be attributed to the presence of the screens which promoted local spawning. Furthermore, eggs were collected in the tow samples only during July and averaged 5.9/1000 m³ (Table 2).

Among the major taxa collected, rainbow smelt entrainment was highest in June while maximum entrainment of alewife larvae occurred in August. Entrainment of these two predominant species through the screens and open pipe was generally lower than densities collected in tows. Larvae of the minnow family were collected in only entrainment samples in June and were entrained and collected in tows in July and August. In June and July, minnow entrainment generally exceeded ambient concentrations; however, in August, entrain-

TABLE 2. Comparison of predominant ichthyoplankton densities (no./1000 m³) entrained through the 2.0-mm, 9.5-mm, and open pipe and collected in tows during June, July, and August 1979 from Lake Michigan near the J. H. Campbell Plant. (Daytime and Nighttime combined.)

Ichthyoplankton	June				July				August			
	2.0	9.5	Open pipe	Tows	2.0	9.5	Open pipe	Tows	2.0	9.5	Open pipe	Tows
Larvae												
Minnow,[a] Cyprinidae	12.8	1.8	26.3	0.0	6.9	9.6	1.3	1.0	0.1	0.0	0.1	1.3
Rainbow smelt, *Osmerus mordax*	0.5	4.0	0.7	43.2	0.3	0.1	0.5	4.9	0.2	0.6	3.2	9.6
Yellow perch, *Perca flavescens*	0.5	0.0	1.4	10.2	1.0	1.2	0.3	79.6	0.0	0.0	0.0	0.0
Alewife, *Alosa pseudoharengus*	0.0	0.0	2.1	7.6	0.8	0.8	1.7	96.3	3.5	8.0	12.4	130.6
Carp, *Cyprinus carpio*	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Whitefish, *Coregonus* sp.	0.0	0.0	0.0	2.5	0.2	0.2	0.3	3.9	0.0	0.0	0.0	0.0
Herring or smelt,[b] *Alosa* or *Osmerus*	0.0	0.0	0.0	0.0	0.9	0.9	0.4	2.0	4.4	5.5	11.8	2.5
Total larvae[c]	14.6	6.2	33.2	63.5	11.8	14.1	5.2	189.7	8.3	14.4	28.2	144.7
Total eggs	97.2	57.9	56.8	0.0	87.9	241.1	18.8	5.9	0.1	0.9	12.9	0.0

[a]Minnow family (excluding carp or goldfish) — primarily specimens in prolarval through mid-postlarval stage. Myomere counts and some morphometric characteristics allowed tentative identifications as ~80% spottail shiner; 10% golden shiner; remainder emerald shiner, bluntnose minnow, fathead minnow, pugnose minnow, or undeterminable. However, positive identifications were not made as accepted morphometric characteristics and pigmentation patterns were not present in specimens through those early developmental stages.

[b]Herring or smelt specimen in mutilated condition. Unable to separate into Clupeidae or Osmeridae — myomeres indistinct, gut stripped.

[c]Total larvae include predominant larvae, sparsely collected larvae, and unidentified remains.

TABLE 3. Analysis of covariance for total larvae entrained (July and August combined).

Source of variation	Sum of squares	Degrees of freedom	Mean square	F statistic	Significance level (α)
Sample volume	0.002557	1	0.002557	0.00	0.960
Day	11.620250	1	11.620250	11.34	0.001
Month	4.006810	1	4.006810	3.91	0.053
Day × month	7.376918	1	7.376918	7.20	0.009
Error	61.457356	60	1.024290	—	—

ment through the screens and open pipe was lower. Highest densities of yellow perch larvae were found in July tow samples.

Fish larvae collected during 1977 and 1978 at the 8.0-m depth, 100-m offshore (Jude et al. 1978, 1979) were similar in composition and abundance to larvae collected during this study. Therefore, data generated in the present investigation are reliably representative of the potential impact of these screens on ichthyoplankton populations in the areas.

Discussion — Since entrainment through the screens and open pipe was consistently lower for most species than ambient concentrations, larval avoidance responses to the low velocity currents from pumping may be as effective or more effective than exclusion (Table 4). Tow sampling which is an active collecting method, was indicative of larval presence and was used to ascertain the size of the larval pool from which entrainment was derived. Pumping, on the other hand, is a stationary collecting method that best represents the entrainment losses that potentially occur as a result of water withdrawal by power-generating facilities. About 90% of most larvae occurring in the test area were excluded or avoided entrainment (Table 4).

Jude et al. (1978, 1979) mathematically related larval body depth to estimate the percentage of Lake Michigan larvae that would potentially be excluded by various screen sizes. Assuming no avoidance to screens or velocity patterns around them, Jude et al. (1978) postulated that a 2.0-mm opening screen would exclude 7.2, 60.5, 60, and 100% of alewife larvae in July, August, September, and October, respectively. Estimates of exclusion assumed that larvae pass through the screen head first. In 1979, the same authors, in their second similar assessment of exclusion percentage of larvae collected from Lake Michigan, indicated that 2.0-mm-mesh-size screens would not exclude alewife,

TABLE 4. Estimates of exclusion or entrainment (−) percentages of predominant ichthyoplankton entrained through 2.0 mm, 9.5 mm, and open pipe at 15.2 cm·s^{-1} (0.5 fps) pumping velocity relative to ambient larval concentrations (calculated from Table 2).[a]

	June			July			August		
Species	2.0	9.5	Open	2.0	9.5	Open	2.0	9.5	Open
Minnow f.	−1277[b,c]	−178	−2630	−602	−882	−337	91	96	91
Rainbow smelt	99	91	98	94	98	90	98	94	66
Yellow perch	95	100[d]	86	99	98	100	nd	nd	nd
Alewife	100	100	73	99	99	98	97	94	91
Carp or goldfish	nd	−45	nd	nd	nd	nd	nd	nd	27
Whitefish sp.	100	100	100	95	95	92	nd	nd	5
Herring or smelt	nd	nd	nd	54	56	78	−70	−114	−359
Total larvae	77	90	48	94	93	97	94	90	80
Total eggs	−9716	−5788	−5676	−1390	−3987	−218	−11	−89	−1293

[a]nd represents no ambient or entrainment data.
[b]Negative sign denotes the percentage increase of ichthyoplankton entrainment above ambient concentration.
[c]Ambient concentration of 0.00 was substituted with a value of one to allow calculations.
[d]By inspection, the zero entrainment value indicates total exclusion.

carp (*Cyprinus carpio*), spottail shiner (*Notropis hudsonius*), and yellow perch during the summer months. However, about 24% of the rainbow smelt larvae could be excluded in July and 100% were excluded in August. Therefore, mathematical predictions of larval exclusion by screens are not consistent and tend to be unrealistically conservative since avoidance behavior is ignored. Hansen et al. (1978) estimated that up to 97.5% of potentially entrainable striped bass larvae could avoid entrapment through cylindrical wedge-wire screens, although most aquaria-held larvae were eventually entrained within 1 min of exposure. Restrained larvae may not be able to escape the continuous influence and stress of pumping. In a natural environment, restriction in space is eliminated and velocity fields are limited; thus, avoidance can occur.

Fish larvae avoidance is a function of larval ability to sense structures visually, to detect velocity gradients around screens and then swim away to escape entrainment (Heuer and Tomljanovich 1978). Therefore, avoidance is partly a sensory and partly a muscular function and potentially eliminates or substantially reduces both impingement and entrainment. Distant touch orientation through lateral line organs involves the localization and identification of stationary or moving objects particularly when visual orientation is limited (Lowenstein 1957). Visual detection of screens was practically curtailed during nights as indicated by the higher rates of entrainment in the present study. Alewife, rainbow smelt, and yellow perch usually spawn close to shore. As eggs hatch and larvae begin feeding and growing, they gradually move offshore. This movement is induced by various biotic and/or abiotic factors (Jude et al. 1978, 1979). Offshore movement of growing larvae is associated with stronger muscular systems and relatively more developed sensory perception (Disler and Smirnov 1977).

Entrainment of minnows in June and July was greater than the ambient concentration. However, the reverse was true in August. During August, minnow larvae were large enough to detect sensorially and then avoid both screens and currents emanating from pumping. Larval exclusion by screens could be effective with passively moving organisms.

In view of the present findings, siting of an intake in an area where ichthyoplankton abundance is low and larvae are old enough to possess a strong muscular system and relatively developed sensory perception is as important for minimizing ichthyoplankton entrainment as designing an intake to utilize avoidance behavior and/or to exclude entrainable ichthyoplankton regardless of the screen-mesh size. Intakes located offshore or away from spawning beds will be associated with low entrainment. Furthermore, impact assessment should simulate real operation conditions in which pump samplings are used, rather than tow nets.

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