THE EFFECTIVENESS OF A REMOTE PROFILE-WIRE SCREEN INTAKE MODULE IN REDUCING THE ENTRAINMENT OF FISH EGGS AND LARVAE

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ABSTRACT

The effectiveness of a remote, profile-wire screen intake module in reducing the numbers of entrained fish eggs and larvae below field densities was evaluated. The T-shaped module consisted of a cylinder 4.1 m in length and 0.9 m in diameter (the top of the T) with two sections of stainless steel profile-wire (1.0 mm slot width) separated by a support section of solid stainless steel pipe. The module was installed in a side channel of the Mississippi River (River Mile 530.6) at a depth of approximately 6 m (1 m above the bottom) with the screen slots oriented perpendicular to river flow. It was operated at a withdrawal rate of 0.25 to 0.28 m^3/sec (9 to 10 cfs). Species composition and abundance of fish eggs and larvae entrained at the module were contrasted with towed and fixed net collections taken concurrently. Six 24-hr sampling events were conducted during the period 24 May through 28 June 1979. The module was effective in reducing the numbers of eggs and larvae entrained below predicted (field) densities. Differences in effectiveness associated with species, larval size and time of sample collection were noted.

INTRODUCTION

The withdrawal of large volumes of water from surface sources that are of sufficient quality for human use has presented a continuing challenge to the engineer. Natural waters contain all means and matter of solid, suspended materials, the presence of which is often incompatible with the intended water use. For most of the history of hydraulic engineering, this problem has been principally one of screening; how to maintain a required quantity of flow while excluding unwanted solids that degrade water quality or threaten the integrity of the transport system. However, in recent years, the very magnitude of human water needs relative to available surface supplies and an increased concern by the general public for the well-being of aquatic communities inhabiting prospective sources has caused a shift in this emphasis. Today the engineer is called upon to meet the historical goals of providing adequate water quality and quantity while insuring that the diversion process is not detrimental to inhabitants of the source.

This revision in goals reached its zenith in the United States with the passage of Section 316(b) of Public Law 92-500, an Act that requires the installation or retrofitting of water intakes to reflect best available technology for the protection of aquatic life. Lacking a general consensus among and between water owners and water users about the definition of these terms and recognizing that both concepts are dynamic over time and space, regulatory emphasis in implementing the Act has most commonly and logically been restricted to a concern for maintaining the integrity of local fisheries, that segment of the aquatic community most dear to our pocketbooks and to our stomachs. Thus, the redefined goal for the hydraulic engineer of today is to provide an adequate quality and quantity of water for human use while insuring the protection and preservation of fisheries in the source waters. In a sense, the water users' responsibilities have been expanded through government mandate to include the consideration of ecological as well as engineering concerns, both at the intake and throughout the water body.

The response of the water users to this shift in regulatory emphasis has proceeded along two main paths. On the one hand, increased thought is being given to the quantitative dynamics and especially the resiliency of natural fish populations in an effort to assess what portions can be lost in the screening process without excessive or irreparable harm either to the fish population itself or to competitive human uses. On the other hand, elaborate and innovative attempts are being made to develop intake barriers that minimize the numbers of organisms sucked into or destroyed in the screening process.

Our study is among those seeking technological solutions to the problem. We have evaluated the operational characteristics of a relatively new application of an old technology, the fine-mesh, profile-wire screen. The apparatus, a full scale intake module, was tested in a river system where it was mounted in open water with the screen slots perpendicular to flow. Our specific interest has been the adequacy of this application to provide protection to the local fishery while meeting the qualitative and quantitative water needs of a closed-cycle power plant.

MATERIALS AND METHODS

STUDY LOCATIONS

All sampling was conducted in a side channel on the east side of Pool 13 of the Mississippi River at approximately River Mile 530 (several miles downstream of Savanna, Illinois). Previous studies at this location (Commonwealth Edison Co. 1975, 1976) and in Pool 14 immediately downstream (Commonwealth Edison Co. 1980), provided an extensive background on the seasonality of fish spawning activity and species composition of the egg and larval assemblage as a guide to study design.

DESCRIPTION OF THE PROTOTYPE INTAKE MODULE

The test module was a T-shaped device constructed entirely of stainless steel (Figure 1). The upper branch of the T consisted of two cylindrical sections of helically wound profile-wire screen, each 1.2 m long and 0.9 m in diameter separated by a manifold of solid pipe section of equal diameter. Deflection cones were mounted on the outside ends of each screen section. Total length of the upper branch of the T was 4.1 m. Slot width of the screen sections was 1.0 mm with a total open screen area of approximately 40% or 1.4 m. The design through-slot velocity was 12.2 cm/sec or slightly less than 0.4 ft/sec.

The module was situated in the approximate center of the side channel at a depth of 6.1 m (normal river stage). River velocities at the module location ranged from 0.37 to 0.81 m/sec during the testing period. The screen sections (upper branch of the T) were raised approximately 0.9 m above the bottom

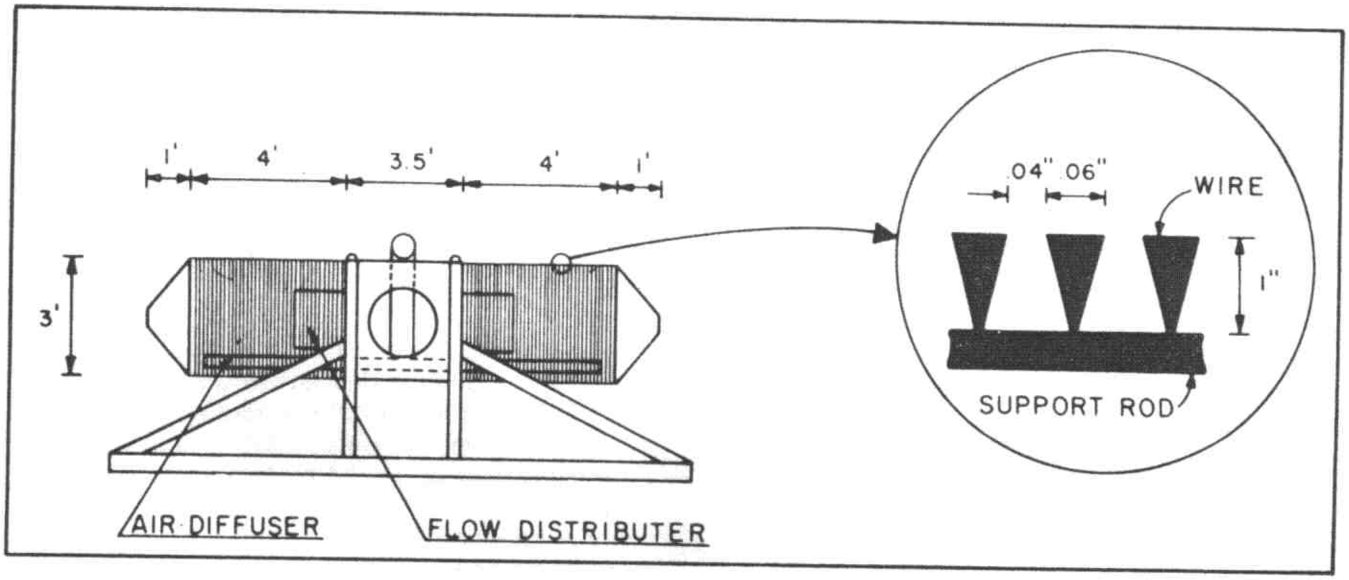

Figure 1. Test module with wire detail (University of Iowa, Institute of Hydraulic Research)

and oriented with the long axis parallel to river current flow (making the screen slots perpendicular to river flow). The central manifold connected to an intake pipe 36 cm in diameter and 49 m long that led to a pumphouse on the adjacent shore.

A propeller-type irrigation pump was used to draw water through the module at a maximum rate of 0.25 to 0.28 m^3/sec (9 to 10cfs). A manometer located in the pumphouse was used to measure back pressure of the system as an indication of clogging. The module was cleaned every 24 hours either by backflushing (reversing flow in the system) or by an air-burst system.

Following installation of the module in the river, it was subjected to a 12-month period of hydraulic testing by the University of Iowa Institute of Hydraulic Research (Commonwealth Edison Company, in preparation).

SAMPLING APPARATUS

Fish eggs and larvae entrained at the intake module were collected in a flow reduction trough located downstream of the pump. This device allowed the rapid screening of substantial volumes of water with a minimum of damage to the screened organisms (McGroddy and Wyman 1977). There was no indication that organisms collected in the flow reduction trough were damaged by passage through the pump.

To collect a sample, the intake flow was diverted to the flow reduction trough by means of a valved T located in the discharge line. A measured flow was screened through 331 mesh netting mounted across the trough for a period sufficient to allow screening of a sample volume ranging from 25 to 75 m^3. At the end of a sampling period, flow was rediverted to the river and the trough allowed to drain. Any organisms entrained and trapped in the trough were washed into a collection box, removed and preserved in 10% buffered formalin containing rose bengal.

Estimates of egg and larval densities in the open river were obtained with both fixed position nets and towed nets. The fixed nets were of a cylinder-cone design (Tranter and Smith 1968), 0.75 m in diameter and 4 m long with a mesh size of 3.0. Paired propeller-type flowmeters were mounted in the net mouth and on a bracket to the side to allow calculation of volumes sampled and an evaluation of clogging.

The fixed nets were mounted to anchor-float arrays similar to those of Weinstein (1979), located near the center of the side channel and adjacent to the intake module. The nets were set from a boat to fish at a depth of 1 m above the bottom, the approximate centerline depth of the test module. Water velocities at the mouth of the net were monitored during deployment using a direct readout current meter. The nets were removed from the water when velocities fell below 85% of that recorded 1 min after deployment or when about 100 m^3 of water had been filtered. During periods of high detrital loads or algal blooms, it was necessary to make multiple sets (as many as three), the contents of which were combined to obtain a total sample volume of 100 m^3. Sample preservation was as for the test module samples.

Towed nets identical in design and mesh size to the fixed nets were employed. The nets were attached to a 3-point bridle and deployed from a boat. A propeller-type flow meter was mounted in the net mouth to allow calculation of volumes filtered. Tows were made against the current at a speed of approximately 0.75 m/sec over water. The nets were fished at about the same depth as the test module but immediately downstream to avoid the contamination of the fixed net and module samples. About 100 m^3 of water was filtered for each sample.

SAMPLING PROCEDURES

Six sampling events were conducted between 24 May and 28 June 1979. Each event consisted of two (day and night) sampling series during a continuous 24-hr period. Three replicate samples were collected with each gear type during each of the 12 sampling series for a total of 108 samples (six events x two series x three gear types x three replicates = 108 total samples).

A similar procedure was followed for each sampling event. First, the test module was backwashed to clear the screens. Flow from the test module was then diverted to the flow reduction trough. While the first of the test module samples was being accumulated, single fixed and tow net samples were collected. This sequence was repeated twice for a total of three replicates per gear type. The entire series was then repeated about 12 hr later to complete the sampling event.

LABORATORY PROCEDURES

All samples were manually sorted to remove the fish eggs and larvae from associated detritus. Specimens were identified to the lowest positive taxon. In addition, each larva was measured to the nearest 1 mm of total length. Numbers of eggs and larvae collected per sample were converted to densities (No./100 m^3) on the basis of sample volumes obtained in the field. A factorial analysis of variance of log-transformed densities was employed to evaluate differences between gear types by date and time of day.

RESULTS

EGGS

Eggs were present in the river throughout the study period. Almost all were freshwater drum. Individual sample densities ranged from zero to 1100/100 m^3. Series mean estimates of river densities (fixed and tow net catches only) ranged from 3 to 511 eggs/100 m^3 with the greatest catches occurring in June (Figure 2).

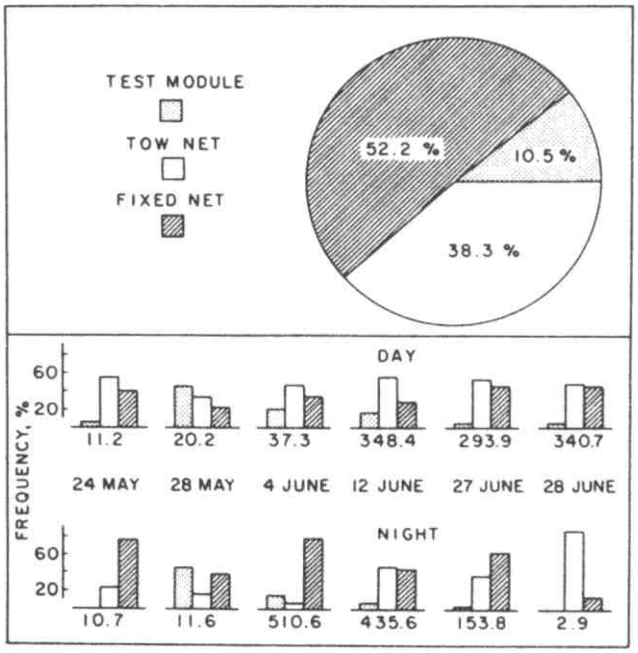

Figure 2. Relative catches of freshwater drum eggs

The test module was quite effective in reducing entrainment of drum eggs below expected (field) densities. Catch by the module was lower than that by either net type for nine of the 12 sampling series. The catch by the module was greater than that of both net types only on 28 May, a period of relatively low egg densities.

The fixed net took a greater proportion of the total catch than did the towed net (52% vs. 38%). However, this difference was not statistically significant and can, for the most part, be attributed to a single series (4 June, night) when the fixed net collections averaged 940 eggs/100 m^3 vs. 81/100 m^3 for the towed net samples.

LARVAE

Species Occurrence

Seventeen taxa of larvae were collected by the three sampling gears and the composition of the samples taken with the test module was generally similar to that for the net samples (Table 1). Four taxa (*Catostominae*, largemouth bass, *Etheostoma* spp. and *Stizostedion* spp.) occurred only in the net collections, on infrequent occasions and at very low densities (rare). Eight taxa (gizzard shad, mooneye, minnows, *Ictiobinae*, temperate basses, sunfish, *Percina* spp. and yellow perch) were consistently present in the samples for all three gear types but always at low to moderate densities (common). The remaining five taxa (*Clupeidae*, carp, emerald shiners, crappies and freshwater drum) were consistently present and exhibited obvious density peaks (abundant or very abundant). No taxon or life stage was collected only by the module.

Table 1. Fish larvae collected.

Species	Abundance	Module	Nets
Gizzard shad (*Dorosoma cepedianum*)	Common	Y[1]	Y
Herrings (*Clupeidae*)	Abundant	L[1]	L
Mooneye (*Hiodon tergisus*)	Common	Y	Y,L
Carp (*Cyprinus carpio*)	Very abundant	Y,L	Y,L
Emerald shiner (*Notropis atherinoides*)	Very abundant	Y,L	Y,L
Minnows other than above (*Cyprinidae*)	Common	Y,L	Y,L
Suckers (*Ictiobinae*)	Common	Y,L	Y,L
Suckers (*Catostominae*)	Rare	0	L
Temperate basses (*Morone* spp.)	Common	Y,L	Y,L
Sunfish (*Lepomis* spp.)	Common	Y,L	Y,L
Largemouth bass (*Micropterus salmoides*)	Rare	0	L
Crappies (*Pomoxis* spp.)	Abundant	Y,L	Y,L
Darters (*Etheostoma* spp.)	Rare	0	L
Darters (*Percina* spp.)	Common	Y	Y,L
Yellow perch (*Perca flavescens*)	Common	L	Y,L
Walleye/sauger (*Stizostedion* spp.)	Rare	0	Y
Freshwater drum (*Aplodinotus grunniens*)	Very abundant	Y,L	Y,L

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[1] Y — Yolk sac larvae, L — Larvae

Species Abundance

Densities of larvae collected by the three gear types were evaluated only for the five very abundant taxa with emphasis on the periods of peak abundance. Four of the five (*Clupeidae*, carp, emerald shiner and freshwater drum) responded positively to the module in that entrained collections contained fewer organisms (lower densities) than did field (net) collections. The fifth taxon, crappies, displayed little or no response to the module with entrained densities approximating field values.

Clupeidae. Clupeid larvae were present on all sampling dates. Presumably most if not all of these larvae were gizzard shad although skipjack herring (*Alosa chrysochloris*) have also been reported to occur in Pool 13 (Smith 1979). Observed densities ranged from zero to 22 larvae/100 m^3. Night catches were slightly greater than day catches ($\bar{x} = 3.5$ Larvae/100 m^3 vs. 2.8/100 m^3). However, the difference was not significant. The mean field density (fixed and tow net samples) was 3.2 larvae/100 m^3. A distinct peak in abundance occurred on 12 June when the mean field density was 13.6 larvae/100 m^3. The larvae ranged from 3.0 to 14.9 mm in length with the majority being 4.0 to 5.9 mm long. Length frequency distributions were similar for day and night catches.

The module was quite effective in reducing catches of clupeid larvae from predicted (field) densities. Entrained larvae made up only 7% of the total in comparison to 47.5% for the fixed nets and 45.5% for the towed nets (Figure 3). Larvae entrained by the module ranged in length from 3.0 to 7.9 mm in length while those collected in nets were as large as 14.9 mm (Figure 4).

Emerald Shiner. Emerald shiner larvae were present throughout June. Field densities ranged from zero to 64 larvae/100 m^3 with a mean of 5.1 larvae/100 m^3. Most of the larvae were collected on 12 June. Night densities were slightly (but not significantly) greater than day catches (6.0 vs. 4.2 larvae/100 m^3). Larvae ranged in length from 2.0 to 10.9 mm with most being less than 6.0 mm long.

Entrained densities made up only 10.5% of the total catch with fixed and tow net catches being approximately equivalent (48.2% and 41.3% respectively, Figure 5). The largest emerald shiner larva taken was collected by the module (one larva, 10.9 mm long). However, no other entrained larvae exceeded 5.9 mm in length while low numbers of net collected larvae were taken in the 6.0 to 9.9 mm range (Figure 6).

Carp. Carp larvae were present on all sampling dates with individual sample densities ranging from zero to 31 larvae/100 m^3. The mean field density was 6.6 larvae/100 m^3. No clearly defined peak in abundance was noted. Densities were slightly greater

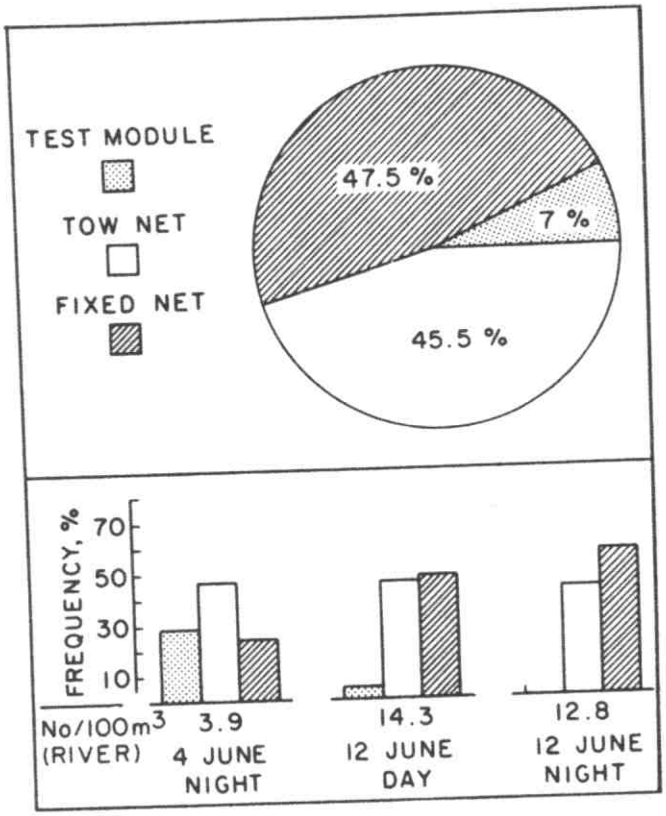

Figure 3. Relative catches of clupeid larvae

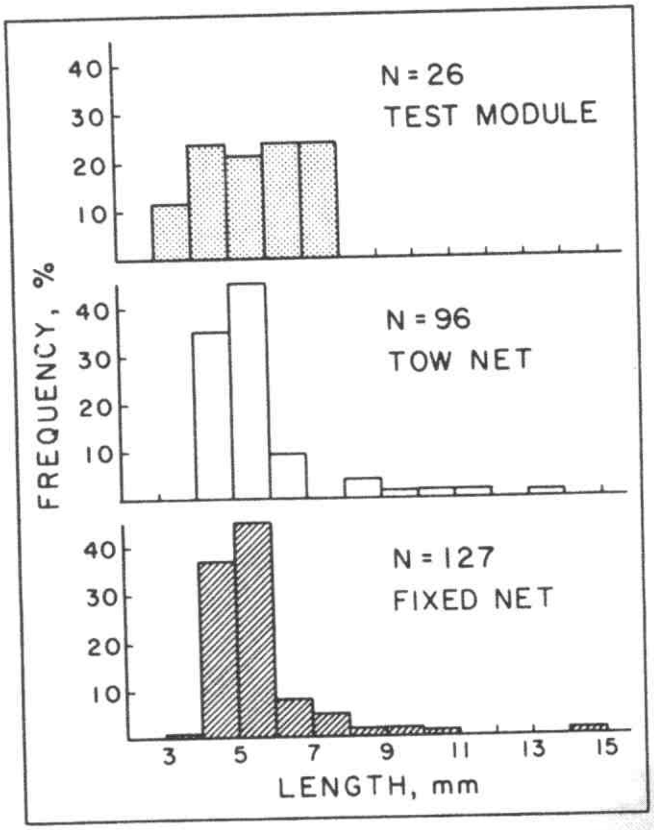

Figure 4. Length frequency distributions for clupeid larvae collected from a side channel of pool 13, Mississippi River

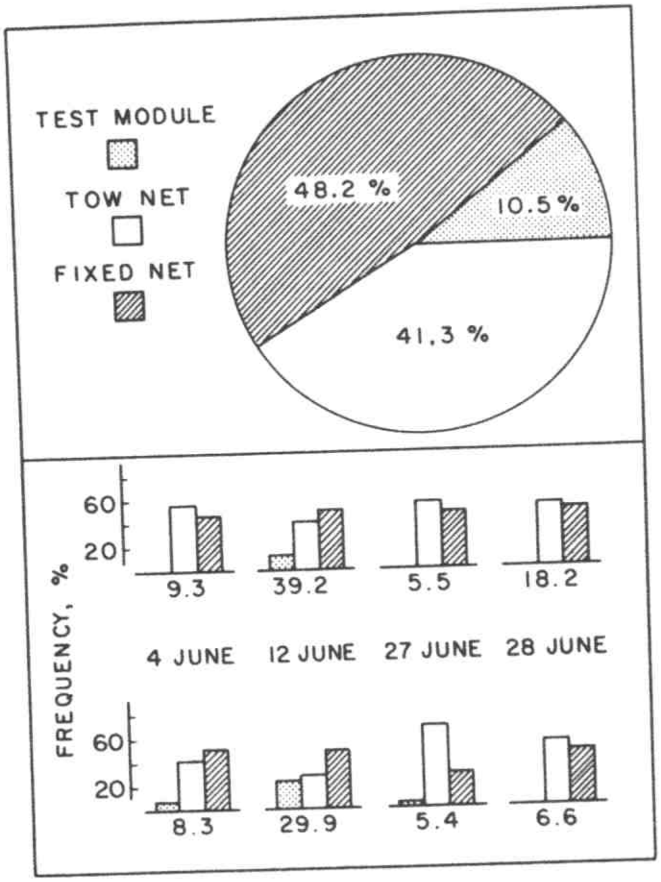

Figure 5. Relative catches of emerald shiner larvae

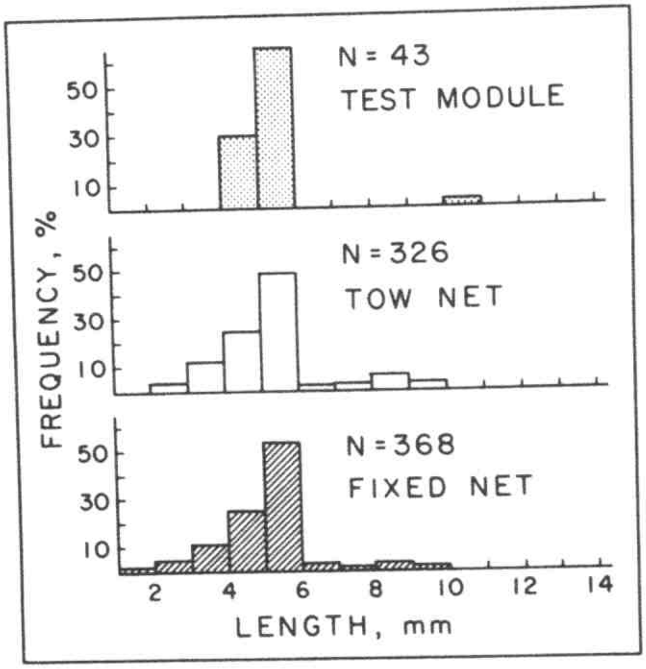

Figure 6. Length frequency distributions for emerald shiner larvae collected from pool 13, Mississippi River

during the day than at night (7.4 vs. 5.9 larvae/100 m^3). The larvae ranged in length from 4.5 to 19.5 mm with the majority being 5.0 to 7.9 mm long.

Entrained densities were substantially lower than those collected with the fixed and tow nets (Figure 7). Larvae were totally excluded by the module on four of the 12 sampling occasions at field densities as high as 25 larvae/100 m^3. The entrained larvae ranged from 5.0 to 7.9 mm in length (Figure 8).

Freshwater Drum. Drum were by far the most abundant species of larvae taken. They were present in the samples throughout June at individual sample densities ranging from zero to 178 larvae/100 m^3. The mean field density for the period of occurrence was 16.0 larvae/100 m^3. A distinct peak in abundance occurred on 12 June (day) when the average density was 126.4 larvae/100 m^3. Drum larvae were slightly more abundant during the day than at night ($\bar{x}$ = 17.4 vs. 14.5 larvae/100 m^3). However, the difference was not significant. Drum larvae ranged in length from 2.5 to 19.5 mm. Most were 4.0 to 6.9 mm long.

Entrainment of drum larvae by the module was much lower than expected on the basis of field densities. Only 4.4% of the total larvae collected were taken in the module samples as opposed to 50% in the fixed net and 45.6 in the tow net samples (Figure 9). Performance of the module was consistent throughout the period of larval occurrence and between day and night. The maximum size drum larva entrained at the module was 7.9 mm long with most being 3.0 to 5.9 mm (Figure 10).

Crappies. Crappie larvae were present in the samples on all dates. Densities ranged from zero to 29 larvae/100 m^3 with a mean field density of 2.4

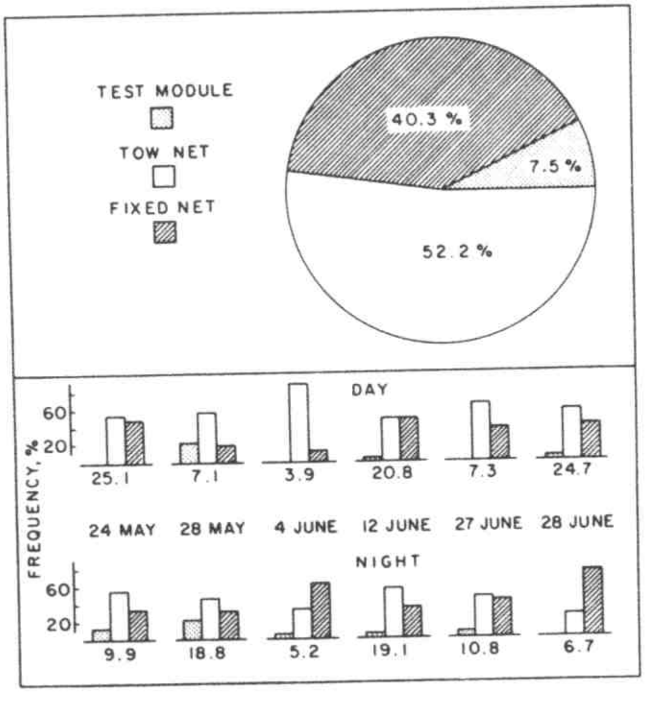

Figure 7. Relative catches of carp larvae

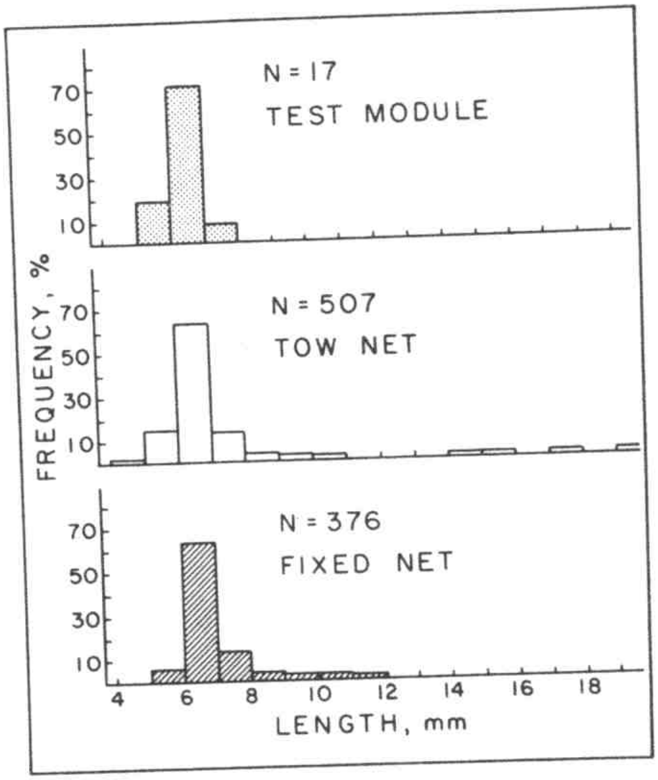

Figure 8. Length frequency distributions for carp larvae collected from pool 13, Mississippi River

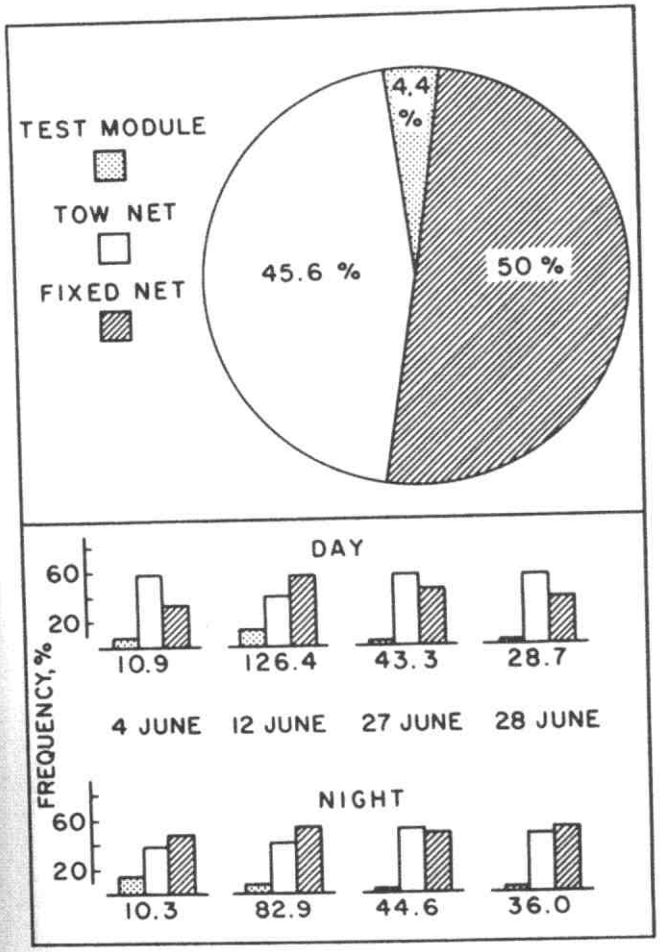

Figure 9. Relative catches of freshwater drum larvae

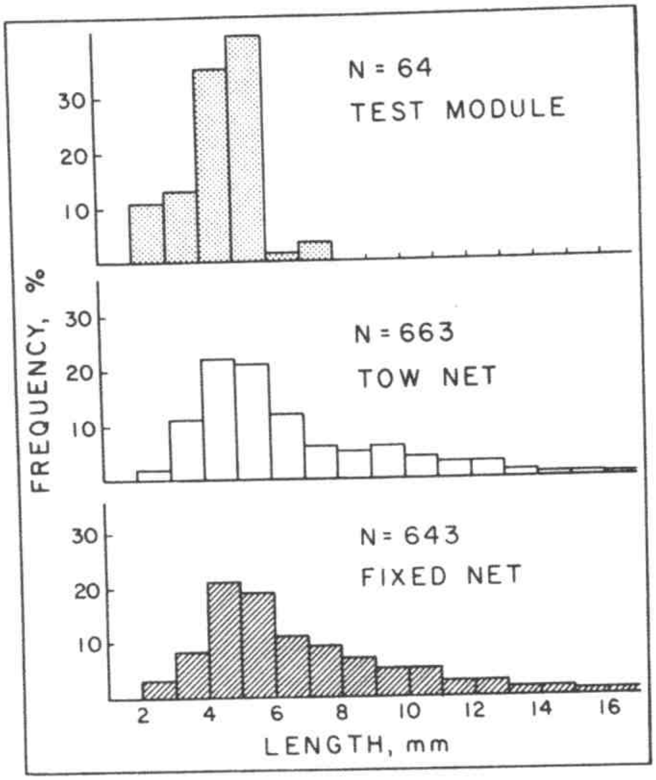

Figure 10. Length frequency distributions for freshwater drum larvae collected from pool 13, Mississippi River

larvae/100 m^3. The greatest catches occurred in May. Two species of crappies, white (*Pomoxis annularis*) and black (*Pomoxis nigromaculatus*), occur in Pool 13. However, there was no indication of distinct density peaks reflecting spawning activities of the two species. Day and night catches were comparable throughout the sampling period. Crappie larvae ranged from 3.0 to 15.9 mm in length with the majority being 4.0 to 5.0 mm long.

The module was not effective in reducing catches of crappie larvae below predicted (field) densities (Figure 11). Entrained organisms made up 25.4% of the total while the fixed and tow nets took 35.2 and 39.4% respectively. Time of day did not affect the result. Entrained larvae did not exceed 7.9 mm in length while small numbers of larvae in the net collections reached lengths as great as 15.9 mm (Figure 12).

DISCUSSION

Numbers entrained at the test module were well below background densities for the one taxon of eggs and four of the five taxa of larvae present at the test site in abundances great enough to permit evaluation. In the case of eggs, freshwater drum eggs are planktonic (semi-buoyant) and are highly susceptible to entrainment by a mid-channel intake. Egg diameter averages about 1.42 mm (Davis 1959), substantially larger than the 1 mm screen slot. We had hoped that these eggs might be totally excluded. Unfortunately,

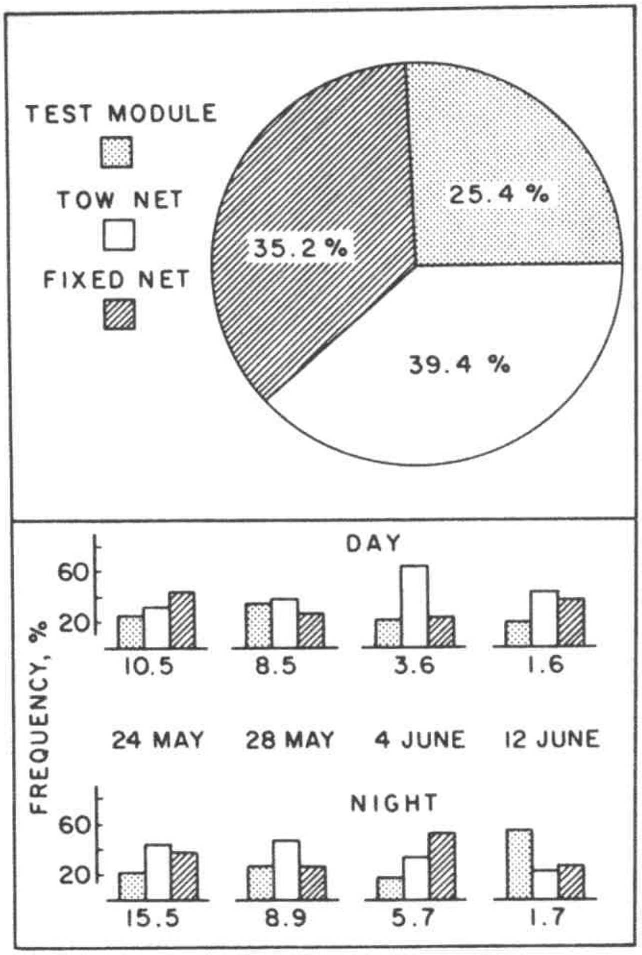

Figure 11. Relative catches of crappie larvae

we did not include measurements of entrained egg diameters or size-frequency comparisons of entrained and field collected eggs in our study program. Drum eggs have a large perivitelline space and may be deformable to a degree that would permit passage through the slots. Hanson (1979) observed comparable levels of entrainment under laboratory conditions for preserved striped bass eggs averaging 2.3 mm in diameter. However, it may also be that the entrained drum eggs were predominantly small (early or green) eggs or eggs that were not fertilized or water hardened. If this were the case, the effective entrainment (that which might potentially have an impact on adult stock size) would be further reduced. Future field evaluations should include measurements of egg size and viability.

The observed reductions in larval entrainment suggest to us that at least three exclusion mechanisms must exist. The most obvious is mechanical exclusion. Organisms that have no dimension smaller than 1 mm will have an obvious reduction in entrainment to the extent that they are non-deformable. However, the general reduction in entrainment and cut-off size observed for larvae suggests that mechanical exclusion is only of real importance for eggs.

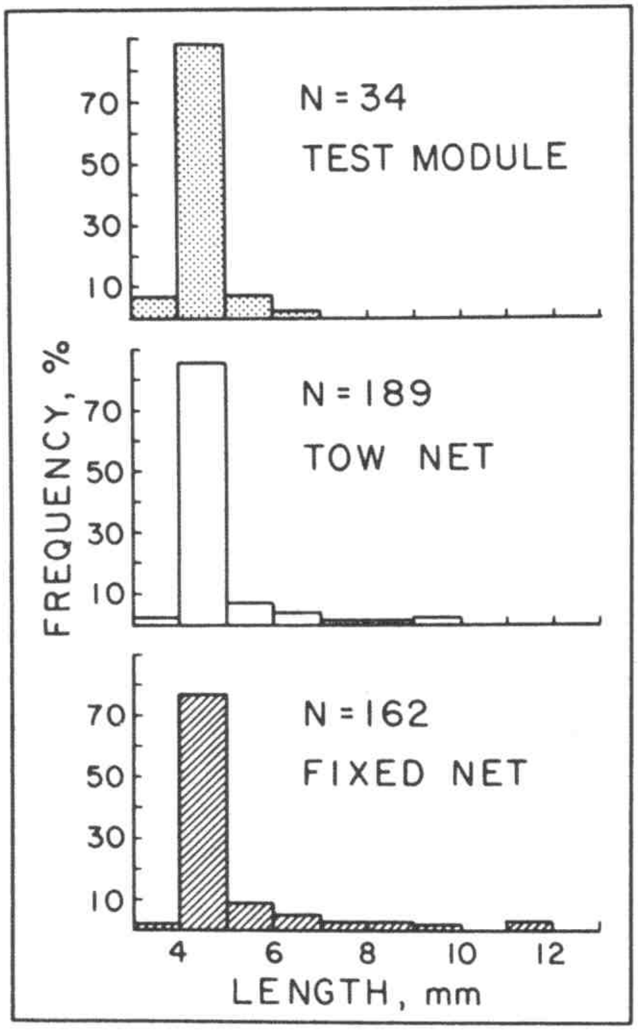

Figure 12. Length frequency distributions for crappie larvae collected from pool 13, Mississippi River

Two behavioral mechanisms of entrainment avoidance are postulated. In the first case, we observed a measurably reduced rate of entrainment for all sizes of larvae. This seems unlikely to be the result of mechanical exclusion in that the smaller size groups of larvae and particularly the very slender clupeid larvae could easily pass through the 1 mm slots. Visual avoidance is also an unlikely mechanism in that the river is extremely turbid at the sampling location and that day and night collections were not markedly different. This general (non-size-dependent) response may reflect the ability of larvae to sense perturbations of the velocity streamlines caused by the structure. These larvae would then be taking evasive action well before they enter the higher velocity flow fields at the individual slots. Such a situation would require a reevaluation of the importance of through-slot velocities which currently seem to be set at a maximum of 15 cm/sec (0.5 ft/sec) by regulatory consensus (see comments of G. Milburn U.S. EPA in Johnson Division UOP Inc. 1979, concluding discussion).

A second category of behavioral response is suggested by the observation that, above a body length of 6 to 8 mm, virtually no larvae were entrained. Many of these larger larvae were still small enough to pass through the screen slots. This observation can be misleading in that the overall reduction in entrainment would make it less probable for the larger larvae (that occur at reduced field densities relative to the earlier life stages) to be taken. Nonetheless, when all of the abundant species are considered as a group, entrainment of some numbers of larger individuals would have been expected on the basis of total field densities. Perhaps 6 to 8 mm is the critical size beyond which those species occurring at our test site have acquired the swimming capability to escape approach velocities to the screen slots. Presumably this category would be responding directly to the physical presence of the screen structure (touch or vision).

These observations (or more correctly, speculations) are in general accord with the laboratory studies of Heuer and Tomljanovich (1978), Hanson *et al.* (1978), and Hanson (1979). A particularly encouraging aspect of all field and laboratory work to date is the dramatic increase in the effectiveness of the profile-wire screen as larval size increases. Entrainment losses are not only reduced but are restricted to the earliest life stages where population control mechanisms are most effective in minimizing or negating any impacts (McFadden 1977).

The observation that larval response to the test module varied with species is also in accord with earlier laboratory observations. Crappie larvae were the only abundant taxon present that did not clearly respond to the presence of the module. These larvae were similar in size and stage to the development of the minnow, clupeid and drum larvae that did experience reduced entrainment. The observations of Heuer and Tomljanovich (1978) suggest that such differences in response between species are behavioral rather than related to size or swimming capabilities. These authors also noted the occurrence of within-species (population level) differences in response for the striped bass, a species with a spawning and early life history strategy very similar to the freshwater drum.

Finally, it is certainly obvious that profile-wire screens as intake structures have generated a great deal of interest over the seven or so years that they have been in the public eye. To some extent, this probably reflects the fact that profile-wire screens are one of the few intake technologies currently under consideration for which a field evaluation can be made in a reasonable length of time and for a reasonable cost. In addition, this technology has been actively promoted by the manufacturer. However, these are not necessarily the best reasons for choosing (in the case of industry) or promoting (in the case of the regulatory agencies) a particular technology for a particular site. It is especially important that such factors not serve as a detriment to continued research or consideration or other potentially attractive technologies.

We want to emphasize that our study demonstrates only a reduction in entrainment relative to that which would be predicted from field densities, giving the entrained organisms no credit for avoidance capabilities in the face of other applications or technologies. In fact, there may be substantial avoidance (reduction in entrainment from that predicted by field densities) even at such simple structures as an unscreened (open) pipe as suggested by the observations of Zeitoun *et al.* (1981) on the effectiveness of profile-wire screens in Lake Michigan, and our data provide no basis for such comparisons. We also want to restate the obvious but often overlooked reality that, in the final analysis, the effectiveness of this or any other technology at a given site can only be measured in terms of the contribution of the "saved organisms" to the adult stock. Implementation of point solutions (*i.e.*, intake technologies) to entrainment problems must logically be dependent on an understanding of the dynamics of the populations or communities to be protected. Decisions on the relative priorities of mechanical and biological aspects of intake design and operation ought best be based on an understanding of both the range and operational characteristics of available technologies as well as the nature of the site and its biota as opposed to arbitrary assignments of generically-defined, best available technologies, be they profile-wire screens or other.

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