A Comparison of Four Gear Types to Measure Entrainment of Larval Fish

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Abstract: A condenser cooling water (CCW) tap valve, a pump-net system, a fine mesh screen and a stationary net were used to measure larval fish entrainment at a power plant and were compared on the basis of relative efficiency, reliability, and cost. Mean densities of shad (*Dorosoma* sp.) collected were highest when using the CCW tap valve. Concurrent trawl samples indicated that mean densities in the pump-net and tap samples responded to changes in larval fish mean densities in the reservoir proximal to the plant intake. Overall, the CCW tap was determined to be the most efficient, reliable and cost effective method.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 39:288–297

In lakes and rivers which provide water for electric generating stations the fishery manager must be able to assess the impact of entrainment; the capture and inclusion of organisms in power plant cooling water (Schubel and Marcy 1978). While the methods devised to assess entrainment are diverse, comprehensive gear comparability studies are lacking, leaving the fishery manager little basis on which to select one particular method. Stationary nets (Snyder 1975, Ecological Analysts 1979*a*, Kelso and Leslie 1979), fine mesh screen (Tomljanovich et al. 1977), pump-net systems (Jude 1975, McGroddy and Wyman 1977, Elder et al. 1979, Ecological Analysts 1980) and condenser cooling water taps (McInerny 1980, Olmsted and Adair 1981) have all been used to capture larval fish at power plants. The purpose of this study was to compare a stationary net, a fine mesh screen, a pump-net system, and a condenser cooling water (CCW) tap for estimating density of larval fish entrained at a power plant and to evaluate their suitability based on collection efficiency, reliability and cost.

Methods

Sampling was performed at the McGuire Nuclear Station (MNS), a 2-unit plant utilizing once-through cooling on Lake Norman, North Carolina (13,156 ha).

The CCW system at MNS utilizes separate upper and lower intake structures. Only the upper intake was used during this study. Sampling occurred only at the upper intake and at the CCW tap inside MNS Unit 1. Four pumps for each unit draw water from 4.6 to 14.0 m below full pond through the upper intake structure. Each pump draws water through 2 31.2-m^2 openings into a pump bay in the intake structure. Vertical traveling screens are located behind each opening and a curtain wall above each opening prevents direct withdrawal of surface water (Fig. 1). Conduits carrying water from the Unit 1 CCW pumps join into a single pipe before entering the turbine building.

Three pumps of Unit 1 operated continuously through the entire study, drawing water through each intake opening at a velocity of 29.5 cm/second. All 6 of the operating pump openings were sampled sequentially each night with the stationary net and the pump-net system, beginning at a different opening each night. Only 3 openings were sampled each night with the fine mesh screen due to operational considerations. All techniques were operated concurrently. While the pump-net system and stationary net were used simultaneously at the same opening, the fine mesh screen was always used at an opening not being sampled with the pump-net or stationary net.

Sampling was conducted on 5 consecutive nights, 6–10 June 1982, beginning about 30 minutes after sunset. Sampling data were chosen to coincide with the peak

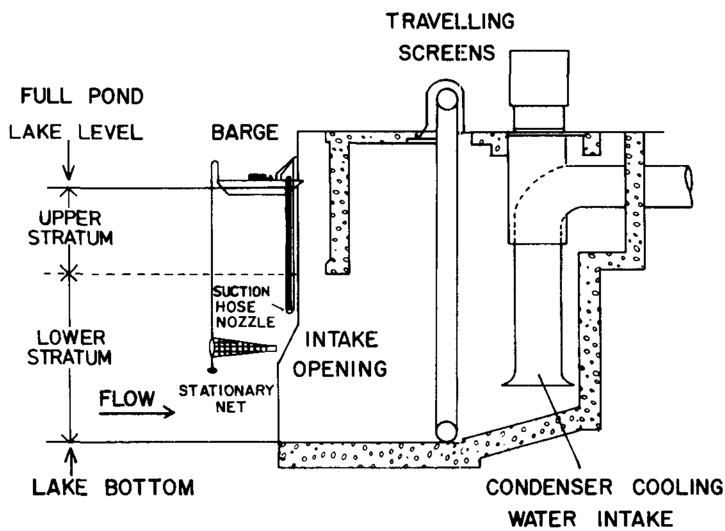

Figure 1. Cross section of McGuire Nuclear Station upper level intake structure, indicating the placement of the barge with the stationary net and pump suction hose. Trawl sampling strata are shown in relation to the intake opening.

abundance of threadfin shad (*Dorosoma petenense*) and gizzard shad (*D cepedianum*) in Lake Norman (Siler et al. 1982) in order to maximize sample size.

Stationary Net

A single, 0.5-m mouth diameter, conical nylon net (2.5-m long, 800-μm mesh) was suspended by a cable from a barge (2.4 × 6.1 m), secured to the front of the intake structure directly above an opening (Fig. 1). The net was deployed approximately 7 m in front of the intake structure openings by the use of a hand-operated winch. A 23-kg weight, attached to the bottom of the circular net frame, forced the cable and frame to hang vertically in the water column and prevented the net from being pulled into the intake trash racks. A General Oceanics Model 2030 flowmeter with a low-speed rotor was mounted in the mouth of the net. Sampling was performed by quickly lowering the net to the bottom of the intake opening and raising it in 1-m stages in front of the 9.4-m high effective intake opening. The net was rapidly retrieved upon reaching the level of the top of the opening. Rapidly lowering and raising the net caused it to collapse, effectively closing the net and preventing the flowmeter from recording during the descent and retrieval. During the first night, the net was raised at 2-minute intervals, but this provided smaller than desired sample volumes. The net was raised at 3-minute intervals on the remaining nights, resulting in an average sampling duration of approximately 27 minutes.

Fine Mesh Screen

The fine mesh screen consisted of a single 9-cm deep rectangular wooden frame with a 50.8 × 57.5-cm mouth opening covered on 1 side with 800-μm mesh Nitex® netting material. The fine mesh screen was attached to a panel of the traveling screens located within the intake bay being sampled. The traveling screens were controlled manually to position the fine mesh screen to face the flow of water through the openings and to raise the fine mesh screen in approximately 1-m stages every 4 minutes. Average sample duration was 38 minutes. After the fine mesh screen completed fishing at the level of the top of the intake opening, traveling screens were rotated without stopping to retrieve the sample.

A flowmeter could not be used on the fine mesh screen due to space restrictions. Sample volumes were calculated using the flow through the intake, the open area in the netting material, and the sample duration. Flow through the fine mesh screens was assumed to be the same as the theoretical flow when performing the calculations.

Pump-Net System

The pump-net system consisted of a 10.1-cm diameter centrifugal pump (2,270 liter/minute pumping capacity at a 0.6-m head), an intake hose, a discharge pipe, and a plankton net. Water was drawn through a 10.1-cm diameter flexible suction hose and discharged from a 10.1-cm PVC pipe through the net. A Controlotron

183P portable ultrasonic flowmeter was used to measure the flow through the discharge pipe.

The intake hose was lowered as close to the trash rack as possible. The intake nozzle was raised in 1-m stages at 3-minute intervals starting just above the bottom of the intake opening (Fig. 1). Average sample duration was 30 minutes.

The collecting net (0.91-m diameter, 2.4-m long, 794-μm mesh) was suspended in the lake from the side of the barge with the net mouth supported above the water surface. The discharge pipe extended just below the surface of the water to reduce mechanical damage to the larval fish.

Condenser Cooling Water Tap

Sample water was carried by a hose from a 7.6-cm gate valve on a condenser cooling water supply pipe to the filtering apparatus. Water was discharged into a plankton net (800-μm mesh) suspended in a 208-liter steel drum with the net opening supported above the water level in the drum. Discharged water flowed through the net and overflowed the rim of the drum into a floor drain. The filled drum cushioned the flow of water against the net and minimized mechanical damage to the fish. Two consecutive samples averaging 192 minutes each were taken each night. Duration of CCW tap samples was longer than that for the other techniques in an attempt to roughly approximate the volumes of water filtered by the other gear types. Flow rate was determined from the time required to fill the drum. Sample volumes were calculated as the product of flow rate and sample duration.

Trawl

Mid-water trawl samples taken in the intake embayment provided an estimate of the density and length frequencies of potentially entrainable fish. A 710-μm mesh Tucker trawl (Hopkins et al. 1973) with a 1-m^2 effective opening was fished from the bow of a modified 6.7-m boat. A Bendix flowmeter was used to obtain boat speeds.

Trawl sampling occurred on each night of the study. Samples were taken starting as close to the intake bays as possible and traveling in an approximately perpendicular direction away from the intake. The water column was separated into 2 strata for trawl purposes. One stratum extended from the surface to the depth of the top of the intake opening (approximately 4.6 m). The other stratum extended from the top depth of the intake opening to its bottom depth (approximately 14 m deep) (Fig. 1).

Two trawl tows, ranging from 2 to 5.5 minutes in duration, were taken in each stratum starting about 30 minutes after sunset and approximately every two hours afterwards, until sampling with the other types of gear was completed. Two sets of tows were made on the first, fourth, and fifth nights and 3 sets of tows on the second and third nights. Both strata were sampled with separate oblique tows beginning and ending at their upper and lower limits, respectively. A double-trip release mechanism held the net closed as it was lowered through the upper stratum before sampling the lower stratum. The net was also closed with the release mechanism before retrieval after all tows.

Sample Handling and Analysis

Samples were preserved in 10% formalin at the time of collection. All larval fish were picked from the sample, identified to the lowest taxon possible, measured to the nearest millimeter for total length, and counted by 1-mm length class.

Data Analyses

Gizzard and threadfin shad numbers were combined due to our inability to distinguish shad smaller than 21 mm. All analyses were performed on shad only, since this group comprised 94% of the fish collected. Densities of shad (number of fish per 1,000 m^3) were calculated for each sample and compared statistically. Shad larger than 27 mm collected with the trawl were excluded from data analyses because none of the 4 comparison techniques collected shad larger than 27 mm total length.

The effects of date and technique on densities of fish collected and interaction between technique and date were tested using a transformation ($\log_{10}$[density + 1]) with a 2-way ANOVA.

Results

Numbers of shad collected varied markedly among gear types (Table 1). Only 2 shad were collected with the stationary net during the entire study but total numbers collected with the other methods were much greater. Few shad were collected with the pump-net on 6 and 7 June due to a ripped seam in the net. The net was replaced on the third night and the numbers collected consequently increased.

Mean densities of the tap collections were greater each night than mean densities of the other compared gears, except on 10 June when the pump-net and tap mean densities were nearly equal (Table 1). Mean densities of the trawl collection from the upper stratum were much greater than mean densities of the comparison methods and of the lower stratum trawl collections. The lower stratum trawl mean densities were generally less than the CCW tap mean densities.

Larval densities collected with each technique did not vary significantly among dates ($P = 0.83$). However, the effect of technique on the estimates of density was significant ($P = 0.0001$). Mean densities of the pump-net and tap collections were not significantly different ($P = 0.60$). Stationary net and fine mesh screen collection densities were significantly different ($P = 0.0001$) from each other, as well as from the pump-net and tap methods.

Length frequencies of shad collected varied between techniques, most significantly between the pump-net and tap (Table 2). The percentages of shad ≤15 mm in length were 85% for the pump-net, 54% for the tap, and 22% for the trawl. The trawl collection contained an appreciable percentage (24%) of shad ≥25 mm in length.

Mechanical damage to the fish caused by the collection methods was minimal. Larval fish in the pump-net collections were damaged more often than fish in the

Table 1. Numbers (N) and mean densities (MD) (mean number of shad/1,000 m^3) of all shad collected with comparison gear and shad <28 mm total length collected with a Tucker trawl on Lake Norman, North Carolina, 6–10 June 1982, with average volume of water filtered per sample (m^3).

	Net		Screen		Pump		Tap		Upper Trawl		Lower Trawl	
Date	N	MD	N	MD	N	MD	N	MD	N	MD	N	MD
6	0	0.0	2	—[a]	1[b]	—[c]	5	56.4	164	195.3	27	27.9
7	0	0.0	8	34.0	6[b]	—[c]	12	182.0	590	410.5	190	70.7
8	1	4.7	15	53.0	38	91.1	10	103.0	659	536.4	75	43.1
9	1	7.5	11	43.0	80	196.9	25	346.1	511	666.1	86	76.4
10	0	0.0	10	32.1	36	82.4	4	82.0	279	406.5	134	85.7
Total N												
Individuals	2		46		161		56		2,203		512	
Average Sample Volume (m^3)		29		92		65		38		206		317

[a]Unable to calculate volume.
[b]Number not considered valid due to malfunctioning equipment.
[c]Density not calculated on invalid data.

Table 2. Length frequencies of shad collected with the pump-net, tap, and trawl.

1-mm Length Class	Numbers Collected		
	Pump-Net[a]	Tap	Total Trawl
5	5	0	0
6	8	1	1
7	11	3	11
8	11	2	45
9	10	2	78
10	16	5	116
11	13	1	105
12	12	3	71
13	11	6	77
14	22	3	65
15	11	4	76
16	3	1	84
17	3	1	82
18	2	0	94
19	3	1	97
20	2	2	174
21	1	1	183
22	5	7	272
23	2	7	266
24	1	3	282
25	0	0	247
26	0	1	183
27	1	2	106
>27	0	0	153

[a]Fish damaged too badly to be measured were excluded.

other collections; however, only 3% of the larval fish were unidentifiable due to pump-net damage. Damaged fish were not used in any analyses.

Discussion

The stationary net offered the advantages of simple operation and low equipment cost. Disadvantages of the method, however, more than offset the advantages. The stationary net collected very few fish, but that was not unexpected. The ineffectiveness of stationary nets in low flows similar to the intake at MNS has been reported (Graser 1977, Leithiser et al. 1979) as has the problems of net avoidance (Bowles and Boreman 1978, Leithiser et al. 1979), clogging of the net with debris (Ecol. Anal. 1976), mutilation of specimens (Ecol. Anal. 1980), and inaccurate flowmeter readings due to low flow velocities (Ecol. Anal. 1979*a*). The stationary net was prevented from being a practical method to assess entrainment because of the problem with low numbers of fish collected.

The fine mesh screen, although a passive system like the stationary net, collected more fish than the net. However, data interpretation was hindered by the inability to attach a flowmeter to the screen. The accuracy of using the theoretical flow rates to calculate sample volumes was affected by unknown screen and intake hydraulic characteristics, factors that greatly influence the accuracy of the sampling gear (Bowles and Boreman 1978). Although no backwash was assumed in calculating sample volumes, backwash probably occurred and affected actual sample volumes. Without accurate sample volumes, reliable data analysis is impossible.

Results of the pump-net system and the tap sampling were the most similar of the compared techniques. Although, mean densities of the tap collections were greater than mean densities of the pump-net collection on each sampling date, except 10 June (Table 1), densities of the 2 collections were not significantly different ($P \leq 0.05$). Mean densities from the pump-net and the tap collections varied similarly to the mean densities of larval fish in the lake proximal to the MNS intake, as the trawl data indicates.

Differences between the results of the pump-net and tap systems could have been caused by their respective sampling locations. The distribution of entrained larval fish in a power plant intake at any particular time is affected by the fluctuating nature of intake hydraulics and patchy spatial distribution of larval fish in water proximal to intake. These conditions can cause the densities of larval fish being entrained to vary temporally between intake openings and spatially across a single opening. Characteristics of intake flow can also tend to concentrate larvel fish in particular areas of the intake opening. The pump-net system sampled only a very small portion of an intake opening at any one time. If the suction hose was not in the proper location in the opening, the pump-net would have missed sampling the bulk of entrainment and the numbers of fish collected would have been significantly affected. The tap, however, sampled larval fish that had already been entrained into the plant through all operating openings and mixed throughout the water in the intake pipe. This mixing would have canceled any effects to the samples caused by uneven larval fish distribution in intake openings. The tap collections may be more representative of actual entrainment than those of the pump-net system if a homogeneous distribution of entrained fish is assumed to exist within the CCW pipe.

Advantages of a pump-net system include the ability to be mobile and automated (Ecol. Anal. 1979*b*) and to experience less avoidance than stationary nets (Leithiser et al. 1979). Disadvantages of this method include large expense (approximately $1,000–$6,000 for pump alone), potential mechanical malfunctions, need of mechanical abilities to maintain operation, possible sampling inefficiency, and manpower requirements (approximately 2.7 man-hours per sample). The CCW tap advantages include sampling an assumed homogeneous mixture of fish actually entrained, low expense (less than $50), simple operation, operation sheltered from the weather, and low manpower requirements (approximately 0.5 to 0.75 man-hours per sample depending on duration). Furthermore, sampling can be performed by plant personnel. Disadvantages of the tap method include possible difficulties with installation due to space and access restrictions.

Overall, the tap method was judged as the most preferable of the 4 methods under the conditions of this study. The tap method had a collection efficiency higher than the stationary net and the fine mesh screen, and at least as high as the pump-net system. The tap was also much easier to use, mechanically more reliable, and less expensive than the pump-net.

This study illustrated some distinct differences between existing entrainment measurement techniques. However, there have been few comparability studies performed to identify and measure these differences. In order to properly assess the magnitude of entrainment, a comparison of gear types should be included when designing a sampling program. The advantages that can be gained from choosing the most effective method and minimizing the long-term sampling cost could decidedly outweigh the labor and expense involved in a brief gear comparison.

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