1978

Factors associated with accuracy in sampling fish eggs and larvae

R. R. Bowles
Virginia Institute of Marine Science

J. V. Merriner
Virginia Institute of Marine Science

G. C. Grant
Virginia Institute of Marine Science

Recommended Citation

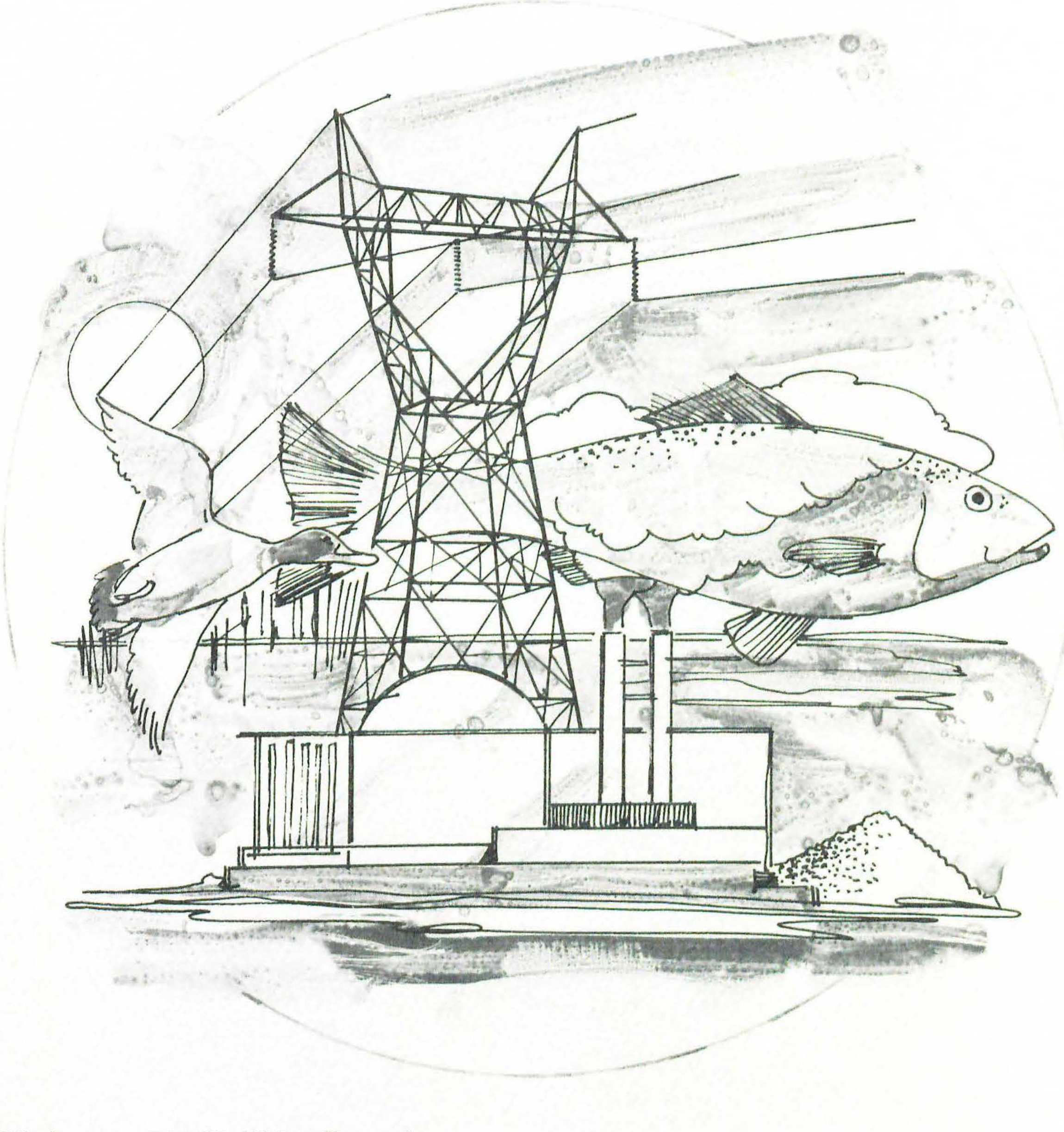
Bowles, R. R., Merriner, J. V., & Grant, G. C. (1978) Factors associated with accuracy in sampling fish eggs and larvae. Special scientific report; no. 89.. Virginia Institute of Marine Science, College of William and Mary. http://dx.doi.org/doi:10.21220/m2-5hjz-km96

55P89

Biological Services Program

FWS/OBS-78/83
October 1978

Factors Associated with Accuracy in Sampling Fish Eggs and Larvae



Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues which impact fish and wildlife resources and their supporting ecosystems. The mission of the Program is as follows:

1. To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.
2. To gather, analyze, and present information that will aid decision makers in the identification and resolution of problems associated with major land and water use changes.
3. To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decision making process to prevent or minimize the impact of development on fish and wildlife. Biological Services research activities and technical assistance services are based on an analysis of the issues, the decision makers involved and their information needs, and an evaluation of the state of the art to identify information gaps and determine priorities. This is a strategy to assure that the products produced and disseminated will be timely and useful.

Biological Services projects have been initiated in the following areas:

- Coal extraction and conversion
- Power plants
- Geothermal, mineral, and oil shale development
- Water resource analysis, including stream alterations and western water allocation
- Coastal ecosystems and Outer Continental Shelf development
- Systems and inventory, including National Wetlands Inventory, habitat classification and analysis, and information transfer

The Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams which provide the Program's central scientific and technical expertise and who arrange for contracting Biological Services studies with States, universities, consulting firms, and others; Regional staff who provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities who conduct in-house research studies.

FWS/OBS-78/83
October 1978

FACTORS ASSOCIATED WITH ACCURACY IN SAMPLING FISH EGGS AND LARVAE

by

R. R. Bowles
J. V. Merriner
G. C. Grant
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

U.S. Fish and Wildlife Service Contract No. 14-16-0008-2118

Project Officer

John Boreman
National Power Plant Team
2929 Plymouth Road, Room 206
Ann Arbor, Michigan 48105

Performed for

Power Plant Project
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior

DISCLAIMER

VIMS Special Scientific Report Number 89

EXECUTIVE SUMMARY

Ichthyoplankton sampling gear is reviewed and evaluated with emphasis on power plant impact assessment. Effects of biotic and abiotic factors on gear accuracy are discussed. Difficulties associated with obtaining representative samples from patchy population distributions are acknowledged. A listing of commonly used sampling gear has been compiled and indexed by ecosystem. Meter nets and variations of meter nets are the most widely used gear for sampling fish eggs and larvae. Comparative gear evaluation has been performed based on information compiled in the report. Although the diversity of habitats and the great number of relatively important species makes summarization difficult, the following comparisons are made. Meter nets sample greater length intervals and greater numbers of fish larvae per unit volume than half meter nets. Bridleless Bongo nets are more efficient in sampling larger larvae than meter nets. High volume pumps sample fewer or equal numbers of fish eggs than half meter and meter nets, but may provide better estimates of larger larvae. A check list highlighting important factors to consider when selecting gear is provided. Features to be optimized in gear design and deployment are summarized.

This report is submitted in fulfillment of contract number 14-16-0008-2118 by the Virginia Institute of Marine Science under the sponsorship of the Office of Biological Services, U. S. Fish and Wildlife Service. Work was completed as of April 1978.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviations

cm	centimeter
km	kilometer
knot	nautical mile per hour
μm	micrometer
m/s	meters per second
m^3/min	cubic meters per minute
min	minute

ACKNOWLEDGMENTS

Special thanks are expressed to the nearly three hundred specialists involved in ichthyoplankton sampling who patiently answered our questions and shared their results, experience, and opinions.

Personnel of several federal agencies provided valuable information. At the U. S. Nuclear Regulatory Commission, Drs. T. Cain and C. Billups of Operating Reactors and Environmental Specialists Branch respectively provided assistance with technical documents. Dr. Paul E. Smith and crew of the National Marine Fisheries Service Southwest Fisheries Center, La Jolla, CA shared the results of many years of sampling and gear evaluation. The scientific staff of each region of the Environmental Protection Agency brought us up to date on progress of section 316 (Public Law 92-500) demonstration documents.

The technical assistance of Mr. Jeff Govoni, Mr. Barry Kilch, and Ms. Jeanene Loy of the Ichthyology Department, Virginia Institute of Marine Science is gratefully acknowledged. Special thanks are expressed to Ms. Julia Millen and Ms. Barbara Gardner for typing the manuscript.

Finally, gratitude is expressed to Dr. John Boreman, U. S. Fish and Wildlife Service, who has patiently provided valuable suggestions.

INTRODUCTION

Potential adverse impacts on fish populations due to power plant entrainment mortality of fish eggs and larvae (ichthyoplankton) have been recognized by many authors (e.g., Carlson and McCann 1969; Marcy 1971; Goodyear 1977). Three types of sampling programs have been developed to assess impacts on ichthyoplankton: (1) taxonomic surveys to determine species composition; (2) differential intake/discharge mortality studies to measure effects of transport through the plant; and (3) near-field or far-field abundance surveys to measure population and/or community effects.

Each type of sampling program has specific gear requirements and sampling strategies. For example, to determine ichthoplankton species diversity, several types of gear are required to adequately sample various habitats at a single site. In an intake/discharge mortality sample, high gear induced mortality may confound estimates of power plant induced damage. On the other hand, the principal concern in abundance sampling is insuring an adequate, accurately measured sample volume. Each kind of sampling has specific objectives. The results of the various sampling programs are thus not directly comparable and only tangentially related even though carried out on the same body of water.

Ichthyoplankton sampling programs are subject to multiple sources of error that affect the reliability and applicability of the data which are ultimately used in impact assessments. These sources include errors in experimental design, sample collection, sample processing, and data processing (Table 1).

The scope of this report is limited to identifying four factors: (1) gear currently used to sample ichthyoplankton; (2) sources of error associated with collection of ichthyoplankton samples used to assess power plant entrainment mortality; (3) abiotic and biotic factors that may affect attainment of "representative" samples; and (4) factors that should be considered in the design or evaluation of ichthyoplankton sampling gear. During 1977, information on sampling gear was gathered from nearly three hundred interviews with utility biologists, private consultants, Federal regulatory agency personnel, research scientists, and more than three hundred pieces of literature including assessment documents such as annual reports, 316 demonstration documents, and environmental reports. We gratefully acknowledge the many people who provided information on sampling fish eggs and larvae throughout the United States.

Table 1. Possible Sources of Error in Ichthyoplankton Sampling Programs

---

EXPERIMENTAL DESIGN

- Poor timing with respect to spawning event
- Inappropriate sampling stations and depths
- Too few replicate tows, trends obscured by variance in distribution

SAMPLE COLLECTION

- Multiple tows that are not accurate replicate tows
- Poor deployment of gear
- Inappropriate sampling gear
- Failure to accurately measure volume of water sampled

SAMPLE PROCESSING

- Mislabeled or lost sample container
- Erroneous identification of organisms
- Unidentifiable and damaged organisms

DATA PROCESSING

- Miscoded data
- Lost or missing data
- Inappropriate statistical testing
- Questionable interpretation of results

ICHTHYOPLANKTON SAMPLING GEAR - PAST AND PRESENT

HISTORICAL REVIEW

Ichthyoplankton sampling devices have evolved from plankton nets first used in 1828 (Fraser 1968) and plankton pump samplers reported from 1887 (Aron 1958). Improvements in gear construction and design have paralleled the demand for increasingly accurate quantification of plankton productivity. For example, early plankton nets were metal rings with conical nets made from silk bolting cloth design for milling flour (Heron 1968). Net meshes are now made from nylon, perlon, or metal screening that does not rot or shrink. Meshes need to be of a constant size to assure retention of plankton in a nominal size range. Other innovations in net samplers include closing mechanisms, flow measurement, and sampler design modifications. Opening/closing nets were developed to provide samples from discrete depths. Early systems (e.g., Nansen 1915; Clarke and Bumpus 1939) used weighted messengers to close the net before recovery. A recently designed net system uses electronic signals to trigger opening and closing devices on a series of nets for sequential sampling, thus eliminating contamination (inadvertent collection of organisms) from other depth strata during deployment and recovery (Wiebe *et al.* 1976).

The exact volume of water filtered must be known to provide quantitative analysis of plankton samples. Initially, the volume of water sampled was assumed to be the amount of water presented to the mouth of the net. However, such theoretical calculations are not accurate because the net meshes clog reducing the water volume sampled as the tow progresses (Fraser 1966; Tranter and Heron 1967; Tranter and Smith 1968). First flow meter designs (e.g., Nansen 1915; Harvey 1934) were delicate and reported to be slightly more accurate than a guess. Accuracy of flow measurement was also determined by comparing net samples with roughly equivalent pump samples (e.g., Gibbons and Fraser 1937; Barnes 1949a). Several serious flow meter design problems remain including flow measurement under turbulent field conditions and development of an inexpensive, compact flow meter capable of measuring both moderate and low flows without stalling.

Sampler design is a dynamic process responding to specific gear needs and the desire to improve efficiency. Efficiency is the ability of the gear to representatively subsample the distribution and composition of an aquatic community. Plankton trawl nets (Isaacs and Kidd 1953), for example, increase efficiency by sampling large volumes of water. High speed samplers (e.g., Miller 1961; Gehringer 1962) increase efficiency by towing at a more rapid rate than conventional gear. Another sampler, the Bongo net (McGowan and Brown 1966), provides side by side simultaneous net samples. Efficiency of pump samplers improved as hand powered (e.g., Kofoid 1897; Fordyce 1898) and steam driven (e.g., Hensen 1887; Peck 1896) pumps were converted to gasoline and electric power. Innovations in pump design include development of centrifugal pump heads which cause less damage to specimens than bladed designs and portable high volume samplers. The point is that after 150 years of development the perfect ichthyoplankton sampling gear does not exist, that there has recently been a rapid increase in the variety of gear designs, and that various designs have been developed to enhance efficiency under specific conditions.

Early ichthyoplankton studies were abundance surveys used to predict year-class strength. For example, Hjort (1914) found year-class strength of Norwegian herring varied widely and was determined during early life history. More recently, Ahlstrom (1954) stated that the proportion of the larval population surviving to the post-planktonic stage has a direct relationship to the number of individuals of that year-class reaching commercial size. Quantitative sampling gear was first developed to provide reliable data on ichthyoplankton distribution and relative abundance as a tool in fisheries resource assessment (e.g., Ahlstrom 1968).

Plankton samplers were rarely used for resource assessment with respect to power plant entrainment mortality prior to the late 1960's (e.g., Kerr 1953; Markowski 1962). Entrainment occurs when small organisms such as fish eggs and larvae are pumped through the trash screens and into the power plant with the cooling water. Passage through the plant may result in direct mortality of the fish entrained due to mechanical, thermal, chemical, and pressure stress. The impact of entrainment mortality on a fish population in addition to natural mortality and sport/commercial fishing pressure has become a controversial issue (see Van Winkle 1977). Both the National Environmental Policy Act of 1969 (Public Law 91-190) and the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) require assessment of power plant impact on fisheries resources.

Sampling to estimate organism abundance near power plants (near field and far field sampling) requires high volume gear to predict the magnitude of entrainment mortality. For example, Yocum and Tait (1976) predicted that the number of organisms killed or damaged at Great Lakes power plants is proportional to the rate of lake water use. Edsall (1976) speculated that loss of young fish is directly proportional to their abundance in the highly productive littoral zone where most Great Lakes power plants withdraw cooling water.

Differential intake/discharge mortality sampling gear that performs well under high velocity and turbulent flow can provide valuable data. For example, net sampling in the intake and discharge structures at Contra Costa Power Station demonstrated that use of fine mesh screening to avoid entrainment resulted in fatal impingement of young striped bass, but screens of 0.95 cm (3/8 inch) mesh allowed bass 44 to 82 mm to pass through the plant with a 10% mortality rate (Kerr 1953). On the other hand, 0.5 m plankton net samples revealed 100% mortality for nine species of fish larvae (<15 mm) when discharge canal water temperatures rose above 30°C at the Connecticut Yankee Nuclear Generating Station (Marcy 1971).

TYPES OF ICHTHYOPLANKTON SAMPLING GEAR

Seven general catagories of gear are commonly used to sample fish eggs and larvae: low speed nets, high speed nets, plankton recorders, pump samplers, mid-water gear, diver operated gear, and within-plant sampling devices. Other less frequently used gears include grab samplers, plankton purse seines, and traps. Design modifications in each of the seven catagories have resulted in the great diversity of sampling gear available for entrainment studies. Descriptions of the gear and a few examples of ichthyoplankton sampling applications are given for each below. Additional information is available from sources listed in the references section or from an extensive bibliography by Jossi (1970). Advantages and disadvantages for the seven catagories are briefly described (Table 2).

Low Speed Nets.

Low speed nets (Figure 1A) are towed at boat speeds under five knots. Gear in this catagory is also commonly used to sample at fixed positions in power plant intakes and discharges (Figure 2). Fixed gear is usually secured to an additional rigid external frame so water will move through the mouth of the net and past the flow meter parallel to the direction of bulk flow. Without the external frame, turbulent intake and discharge flows cause the net mouth and flow meter to pitch and yaw resulting in inefficient filtration and inaccurate meter readings. Components of two conventional low speed nets, the meter net and the Bongo net, are shown in Figure 3.

Modifications of the basic conical meter net design are numerous. In addition to those modifications previously mentioned, Henson (1901) attached a non-porous collar to the mouth of the net to improve hydrodynamic efficiency. Gale (1975) developed a quick release sample bucket. Lewis, et al. (1970) added wings to a conventional half meter net to create a channel net. Square framed nets such as the neuston net used by Kjelson and Johnson (1973) and Matsuo, et al. (1976), the drop net described by Hoagman (1977), and the bow-mounted push net recommended by Herke (1969) are designs modified for shallow water and surface sampling. Many configurations of the meter

Table 2. Types of Sampling Gear

Design	Examples	Advantages	Disadvantages
Low speed nets (0 to 5 knots)	Bongo nets Meter nets Benthic sleds Tucker trawl Neuston nets Henson nets	• Sample large volume of water in short time. • Require only small vessel to deploy. • Can be fished fixed or towed • Inexpensive equipment	• Clogging of meshes is major problem. • Fishing characteristics highly variable in turbulence. • Avoidance by larger larvae. • Manpower needs are relatively high. • Limited by water body morphometry.
High speed nets (5 to 15 knots)	Jet nets Gulf nets Miller nets	• Reduced avoidance by larger larvae. • Sample large volume of water in short time. • Moderately expensive equipment.	• Requires larger vessels and usually winches to deploy. • May be some extrusion of smaller organisms through mesh. • Manpower needs relatively high.

Table 2. (continued)

Design	Examples	Advantages	Disadvantages
Plankton recorders	Hardy plankton recorders Bary plankton catchers	• Can be fished from high speed commercial vessels. • Can provide sample from a narrow band over a long distance. • Expensive equipment.	• Samples frequently mutilated. • Extrusion of sample through mesh. • Limited by bottom morphometry.
Pump	Centrifugal pumps Trash pumps Sewage pumps	• Can sample turbulent areas or areas inaccessible to nets. • Reduced manpower needs. • Can replicate samples easily. • Expensive equipment.	• Small sample volumes may be inaccurate. • Large size of pumps makes them difficult to handle in field.
Mid-water nets	Isaacs-Kidd mid-water trawl British Columbia trawl	• True pelagic samples. • Large sample volume.	• Manpower needs are relatively high. • Must maintain constant boat speed.

Table 2. (concluded)

Design	Examples	Advantages	Disadvantages
Diver operated	Slurp gun "Cookie cutter"	• Useful in highly specialized applications.	• Requires trained divers. • Samples only small area. • Difficult to quantify volume.
Within plant samplers	Pipe taps In-line filters	• Low manpower requirement.	• Mutilated samples. • Extremely turbulent flow.

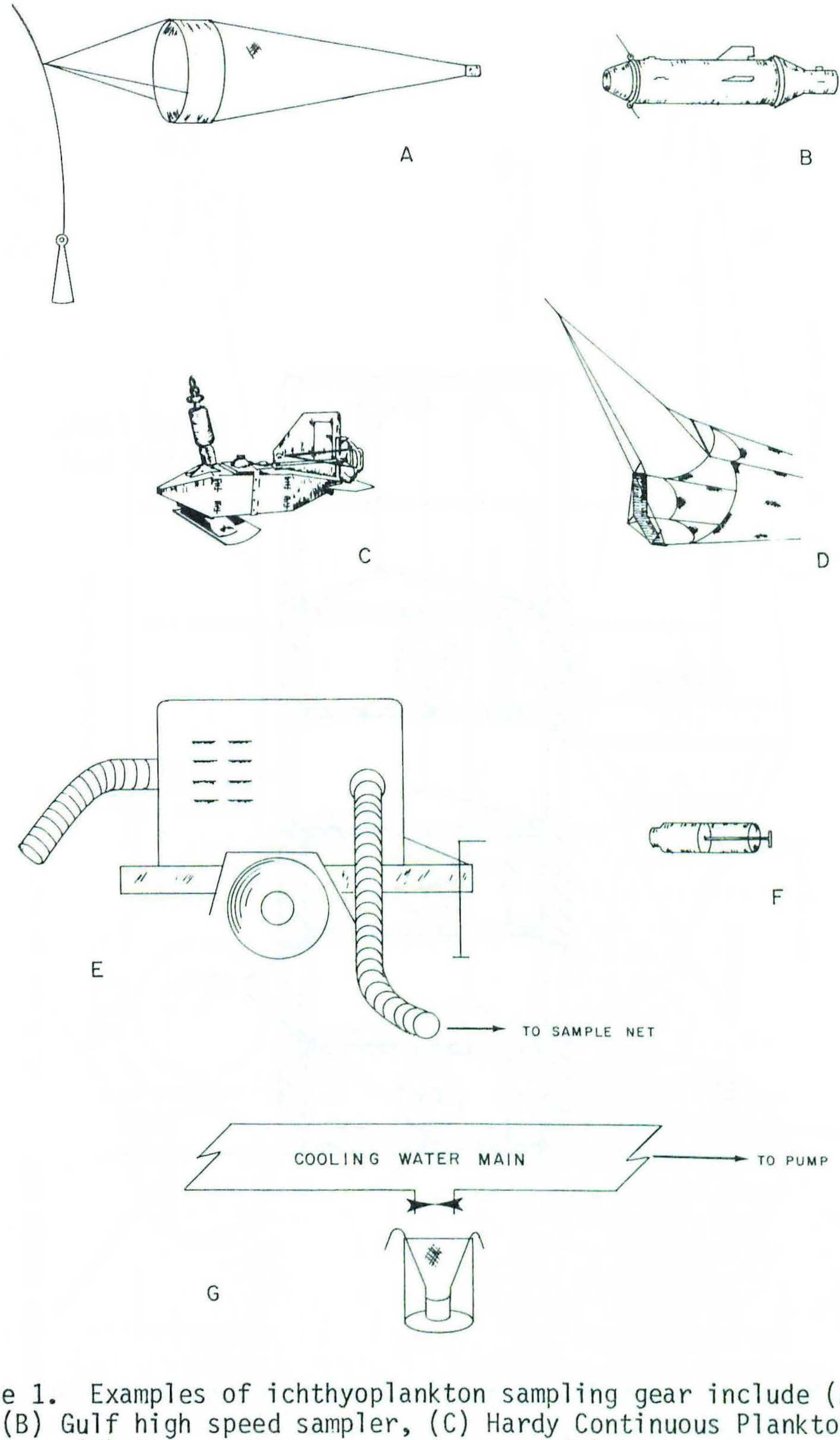


Figure 1. Examples of ichthyoplankton sampling gear include (A) meter net, (B) Gulf high speed sampler, (C) Hardy Continuous Plankton Recorder, (D) Isaacs-Kidd mid-water trawl, (E) high volume pump sampler, (F) slurp gun, and (G) pipe tap. (Figure 1 A, B, and C after Fraser 1968).

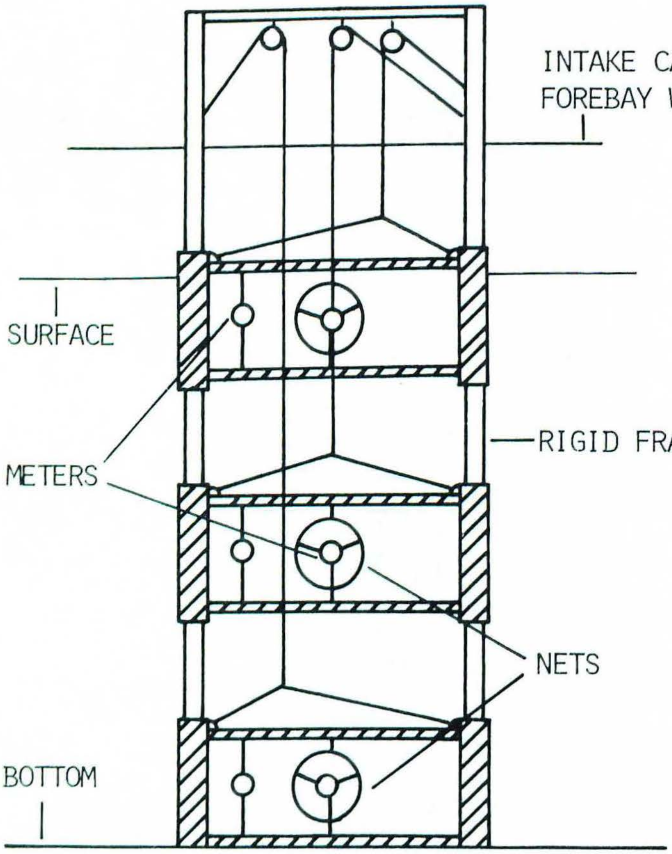


Figure 2. Meter nets are fished in fixed position in power plant cooling water intake structures.

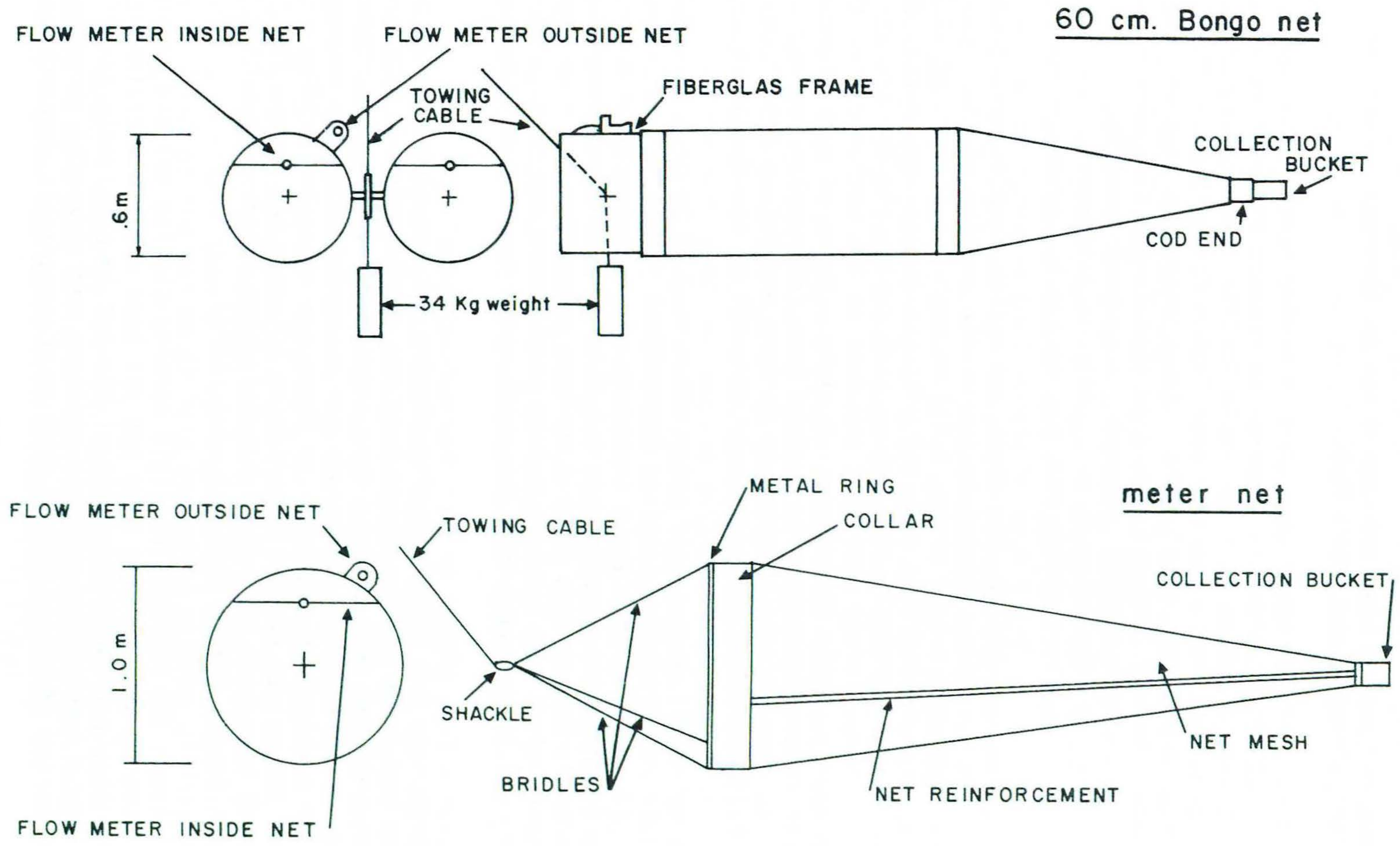


Figure 3. Diagram of a Bongo net and a meter net showing proper placement of current meters.

net frame and meshes have been subjected to theoretical and empirical evaluation (Tranter and Smith 1968).

Examples of low speed gear used in environmental assessment include use of a CalCOFI (Califronia Cooperative Oceanic Fishery Investigation) meter net with 0.505 mm mesh to sample Pacific Ocean ichthyoplankton in the turbulent, rocky shallows near Diablo Canyon Nuclear Power Plant, California (Icanberry, *et al.* 1978). They observed a lack of juvenile fish longer than 22.0 mm and suggested that larger fish were avoiding the net in daylight samples. However, a comparison of day/night samples for *Sebastes* spp. showed no such significant difference. Thus, the low tow speed (≤1.6 m/s) probably enhanced escape by larger juvenile fish.

Simultaneous surface, mid-depth and bottom samples were taken for two years at multiple stations in the middle portion of the Hudson River estuary with a half meter, 0.511 mm mesh net (Lauer, *et al.* 1974). They observed striped bass eggs and yolk-sac larvae were evenly distributed in the vertical water column both during the day and at night, but older larvae were most abundant at the bottom during the day and nearly evenly distributed at night. Dates of peak abundance were temperature dependent for striped bass ichthyoplankton and were similar to temperatures observed by Carlson and McCann (1969) who also used a half meter net to sample near Cornwall on the Hudson River.

Marcy (1971) used a half meter net with 0.39 mm mesh to sample in the intake and discharge canal at Connecticut Yankee Atomic Power Station 27 km (17 miles) above the mouth of the Connecticut River. Sampled ichthyoplankton ranged from 2.0 to 40.0 mm total length with post yolk-sac larvae less than 15 mm long accounting for more than 95% of those sampled. No larvae survived entrainment and passage through the long discharge canal when the canal water temperature rose above 30°C.

Bongo nets are paired opening-closing nets mounted side by side (McGowan and Brown 1966). Bongo nets are considered more efficient than conventional nets because they provide two samples simultaneously and they are bridleless. The nets are suspended between a towing cable and a weight or depressor so there are no towing bridles in the mouth of the net to encourage avoidance (Clutter and Anraku 1968). Bongo nets have been used for ichthyoplankton abundance sampling in estuaries (e.g., Marine Research, Inc. 1974).

Although the MOCNESS (multiple opening-closing net and environmental sensing system) nets have not yet been used in entrainment studies, they represent the state-of-the-art in electronic sampling technology. A shipboard computer monitors environmental parameters while a series of nets deployed from an oceanographic research vessel open and close sequentially in response to remotely controlled electronic commands. Such a net system has been used to study spatial patterns of marine zooplankton distribution (Wiebe, et al. 1976).

High Speed Nets.

High speed plankton samplers (Figure 1B) such as the Gulf series (e.g., Gehringer 1952), Miller High Speed Sampler (Miller 1961), and the Jet Net (Clarke 1964) were originally designed to rapidly sample large areas of open ocean. The use of funnel-shaped mouth cones to reduce drag and use of encased and/or metal meshes enabled high speed samplers to be towed at boat speeds between 5 and 10 knots. Such speeds would extrude smaller organisms through the meshes, mutilate the samples, or damage the meshes of conventional low speed gear. High speed samplers have not been widely used in power plant impact assessment even though they have been used successfully for abundance sampling in large rivers and lakes as well as the open ocean.

The Miller High Speed Sampler (Miller 1961) was designed to determine the vertical distribution of haddock eggs and larvae in the Gulf of Maine. The samplers are 60 cm long fiberglass tubes with an internal diameter of 13.75 cm and a mouth aperture of 10 cm. Behind the fiberglass body a 90 cm long net extends to a collection bucket. No significant difference in filtration rate was observed for nylon nets with 0.947, 0.526, or 0.263 mm mesh. Samplers were suspended in series from a single towing cable. A table giving the proper spacing on 0.6 and 1.25 cm diameter cable with a kite otter depressor to achieve desired sampling depths at 5, 7, and 10 knots was given. Larvae sampled ranged from 4 to 21 mm and less than 1% of the larvae collected during 30 min tows were unidentifiable.

A Miller High Speed Sampler was used to sample yellow perch and walleye fry in Lake Oneida, New York (Noble 1970). A variety of modifications to the basic sampler were tested and evaluated because observation had shown avoidance of gear (active or passive escape usually in the vicinity of the net mouth) begins when larvae are less than 8 mm total length. Enlarging the 10 cm mouth aperture by 1.5 times did not significantly increase the catch. Increasing towing speed to 10 knots reduced, but did not eliminate avoidance. Use of a clear sampler body rather than a darker one and use of an electric shocking grid in front of the net mouth both increased catches of larger larvae (12-16 mm).

By totally encasing the net, Gehringer (1952) developed what was intended to be a more efficient high speed sampler, the Gulf III. However, Tranter and Heron (1967) found that encasing the net reduced filtration efficiency. Catches of sprat and flatfish larvae were twice as high in the unenclosed Gulf V as compared to the encased Gulf III sampler.

The Jet Net (Clarke 1964), an encased net similar to the Gulf III, captures greater numbers and a wider size range of larvae than the Gulf III at tow speeds of 8.5 knots even though the Jet Net has a mouth aperture area equal to 25% of the aperture area in the Gulf III. The greater efficiency of the Jet Net is probably due to a series of expansions within the sampler body that reduce the filtration velocity across the net by a factor of 6.4. Clarke (1964) observed that the flow meter in the tail of the Gulf III stalled out at higher tow speeds. Flow meter readings from a modified Gulf III with a larger, 20 cm diameter mouth aperture used to sample herring larvae were so variable that the volume filtered had to be calculated (Schnack and Hempel 1971).

Plankton Recorders.

Plankton recorders (Figure 1C) have not been used in power plant related environmental assessment. However, recorders can provide far field abundance and taxonomic survey samples for near shore marine systems and with modification may sample very large rivers and lakes.

The Hardy Continuous Plankton Recorder (Hardy 1936) filters water through a continuous gauze ribbon that advances at a rate proportional to the speed of the tow. First used in 1925 to sample herring larvae and zooplankton, the Recorder was designed to rapidly sample the density and frequency of plankton patches horizontally along lengthy oceanic transects. Because the sampler body is streamlined, the Recorder can be towed by commercial vessels at 16 knots. As much as 480 km (300 miles) can be sampled without recovering the gear. Preliminary tows reported by Hardy (1936) contained a maximum of 7 fish eggs and 20 post larvae per 1.6 km (1 mile) in the southern North Sea.

Hardy (1939), Longhurst, *et al*. (1966), and Wiebe (1970) discussed multiple difficulties associated with plankton recorders. More than fourteen variations of recorders have been developed for discrete, sequential, or multiple sampling over shorter intervals than the original design. Biases become progressively more significant as sampling intervals become smaller. Haury, *et al*. (1976) identified the conflict inherent in plankton recorders between minimizing biases and maximizing resolution of plankton patch distribution. Tests of Longhurst-Hardy Plankton Recorders were made in the field by injecting known quantities of dead plankton and pellets into the net (Haury 1973). Biases in Longhurst-Hardy Plankton recorders which uses a 70 cm conical net instead of the heavy body of Hardy's design were identified as smearing due to retention in the net, stalling because of delay in the net, hang up in the net, and extrusion through recorder meshes. At longer tow intervals clogging became a serious problem.

Mid-water Gear.

Mid-water gear (Figure 1D) such as the Isaacs-Kidd Mid-water Trawl (IKMT)(Isaacs and Kidd 1953) are uniquely designed to fish at any depth. True pelagic trawls, unlike semi-pelagic otter trawls, balance the ascending force of the net with the descending force of a depressor or similar device. Depth of the tow can be adjusted by changing towing speed and/or towing cable length. Depth recorders, telemetry devices, or calculation of wire angle are required to measure towing depth.

As towing speed decreases, the sampling depth increases for the IKMT. In fact, Gehringer and Aron (1968) reported that slowing to 2.5 knots to facilitate net recovery after towing at 5 knots placed the IKMT below the depth sampled for about half of the net recovery period.

A comparative evaluation of 1.8 m (6 foot) and 3 m (10 foot) IKMT's was conducted in Puget Sound (Friedl 1971). The most abundant ichthyoplankton was herring. The 1.8 m net caught no herring while the 3 m net caught more and larger fish.

Pump Samplers.

Large pump samplers (Figure 1E) have recently gained popularity in power plant related sampling. Pump sampling in power plant intake and discharge structures is believed to be more quantitative than net sampling because turbulence does not interfere as much with pump performance (e.g., Icanberry and Richardson 1973; Davies and Jensen 1974). Even though high volume pumps are initially expensive and difficult to move in the field, they require fewer personnel to operate than most net samplers and they provide more samples per unit time because the gear is not recovered between samples.

Advantages and disadvantages of pump samplers have been reviewed by Lenz (1972) and Portner and Rohde (1977). Additional references are listed in Table 3. Generally, pumps are able to: (1) sample in areas difficult to access with nets; (2) reduce effects of clogging; (3) reduce avoidance by larger larvae; and (4) provide a more accurate measure of water volume filtered. Pumps are not able to: (1) be handled easily; (2) sample great depths; and (3) provide adequate abundance sample volume (unless high volume pumps are used) to overcome variance associated with patchy plankton distribution.

Table 3. Summary of plankton pump research
(Updated from Aron 1958)

Investigator and Year	Type of Pump	Capacity	Ecosystem Type
Hensen, 1887	Steam pump	Not given	Marine
Cleve, 1896	Ship's pump	Not given	
Giesbrecht, 1896 (describes Kramer's work)	Ship's pump	Not given	Marine: delivered bath water
Peck, 1896	Steam pump	2-inch hose	Marine: Buzzard's Bay
Kofoid, 1897	Double-acting force pump; hand operated	1 m^3/600 strokes; 2-inch suction hose	Lakes
Fordyce, 1898	Force pump; hand operated	347.5 in ^{3}/stroke	Lakes
Bachmann, 1900	Intermittent pump?	10 1 in 15 min. at 70 m depth	Lakes
Juday, 1916	Vane pump; gas powered	300 rpm; 30 1/min.	Lake Mendota
	a. Wing pump	0.1 1/stroke; 1.5-cm hose	Lakes
	b. Hand plankton pump	Size not indicated; probably worked by compressed air	Lakes
Kokubo and Tamura, 1931	Hand pump?	30 1 in 2½ min.	Aomori Bay, Japan
Kokubo, 1933	Wing pump	40 1/6 min.	Not given
Gibbons and Fraser, 1937	Centrifugal pump	2.5 m^3/10 min.	Marine
Tester and Stevenson, 1949	Portable gasoline-motor pump	Not given	Marine; British Columbia
Barnes, 1949	Ex-National Fire Service	350 1/min.	Marine
Tonolli, 1951	Suction pump	Not given	Lakes

Table 3. (concluded)

Investigator and Year	Type of Pump	Capacity	Ecosystem Type
Langford, 1953	Power pump, vane type	30 1/min. through 1-inch hose	Lakes
Collier. 1957	1/3 H.P. motor and pump	450 gallons/hour	Marine: Gulf of Mexico
Aron, 1958	Centrifugal pump	400 gallons/min.	Puget Sound - Marine
Manz, 1964	Gasoline powered centrifugal pump	28,000 gallons/ hour	Lakes
Leong, 1967	Submersible centrifugal pump	80 1/min.	Marine - Baha, CA
Beers, Stewart, Strickland, 1967	6 stage filtered, submersible centrifugal pump	40 gallons/min.	Marine - Pacific Ocean
Croce & Chiarobini	air-lift suction pump	1.25 m^3/min.	Marine
Leny, 1972	Vacuum pump	50 1/min.	Marine - Baltic Ocean
Baldwin, 1973	Vacuum and centrifugal pumps	130 gallons/min.	Marine - Kaneohe Bay Oahu
Icanberry & Richardson, 1973	Vacuum pump	48-141 1/min.	Marine
Ecological Analysts, Inc., 1976	Centrifugal pump	0.5 m^3/min.	Tidal river
Elder *et al.*, 1976	Centrifugal pump	4.3 m^3/min.	Marine
Portner & Rohde, 1977	Propeller driven suction pump	8.6 m^3/min.	Tidal river

Low Velocity Pump Samplers. Some pumps have incorporated low velocity design to reduce damage to organisms sampled. A suction chamber pump was developed to filter organisms before the water passed through the pump (Icanberry and Richardson 1973). A 90 to 95% zooplankton sampler survival rate was observed when a suction chamber pump was used to measure intake/discharge mortality (Icanberry and Adams 1974). Unfortunately, suction chamber size is limited and small sample volumes are unsuitable for quantitative ichthyoplankton sampling.

In another low velocity design, a low volume (0.5 m^3/min) centrifugal pump delivered power plant intake or discharge samples to a "larval fish table" (Ecological Analysts 1976). The table reduces water velocity by greatly expanding the area occupied by the water sample as it passes through the net. While the device may be adequate for relative mortality measures, the small sample volume makes it unsuitable for entrainment abundance quantification. Damage to organisms sampled due to net abrasion can also be reduced by placing the net underwater during filtration (Barnes 1949).

High Volume Pumps. Another type of pump, a high volume (4 m^3/min) centrifugal fry transfer pump, was used to sample in Pacific coast power plant intakes and was used aboard a boat for near field abundance sampling (P. Benson, Lockheed Marine Research, Inc., 1977, personal communication). The volume of water sampled by the fry pump was calibrated using a weir box that served as a net support system (with meshes underwater) during filtration. When such pumps were used aboard a boat, there was no significant difference in sample composition when the pump orifice was directed with or against the direction of boat travel (Aron 1958).

Portner and Rohde (1977) used a high volume (8.6 m^3/min) suction hose powered by an outboard propeller to sample striped bass eggs and larvae in the Chesapeake and Delaware Canal. A 10 cm-diameter suction pipe and air lift pump system successfully sampled depths as great as 100 m (Croce and Chiarobini 1971).

Diver Operated Gear.

Conventional sampling gear is neither adequate nor accurate for all species in all types of aquatic habitats. For example, slurp guns (Figure 1F), which are hand operated, syringe-like devices, are used by SCUBA (self-contained underwater breathing apparatus) divers to sample reef habitats.

Adhesive herring eggs are difficult to sample even with a Peterson benthic grab sampler. Tibbo, et al. (1963) used a diver operated "cookie cutter" sampler to quantitatively collect herring eggs and map their distribution in Chaleur Bay, New Brunswick. A 15 cm-diameter piece of stovepipe was used to isolate 183.9 sq. cm of sea bed. The area surrounding the sampler was cleared, the portion of seaweed within the cutter removed, bagged, taken to the surface and later counted in the laboratory. Divers also observed winter flounder predation on herring eggs.

Ennis (1972) described a diver operated half meter plankton net with 0.36 mm mesh that was propelled through the water by two diver towing vehicles traveling at 2.5 knots. Preliminary results indicated that sample composition was similar to samples collected in nets towed by boats at twice the speed. However, avoidance by post yolk-sac and older larvae would be an obvious problem. Suggested uses for such gear included shallow coastal areas over uneven bottom.

Within-Plant Samplers.

Within-plant sampling devices include in-line filters and pipe taps (Figure 1G) placed in cooling water mains or by-pass lines inside the power plant. A pipe tap or spigot is a piece of pipe, usually of small diameter relative to the diameter of the main, equipped with a shut off valve. A net is placed under the tap and the valve is opened to release the sample into the net for 1 to 24 hrs. Water velocity through pipes, even under turbulent conditions, decreases at the boundary layer near the pipe wall. The particle distribution of fish eggs and larvae within the pipe is affected by the water velocity profile. Samples representative of a cross section of the pipe are thus difficult to obtain. Addition of a high volume pump to pull samples through the tap may improve accuracy. Use of large diameter (with respect to cooling water main) taps may improve hydraulic representation of total pipe flow.

Within-plant sampling devices have low operating costs, but the ability of such gear to produce accurate samples has not been demonstrated. No results from successful pipe tap samplers or in-line filters are reported in the literature. Several utilities have discontinued within-plant sampling because of the large number of damaged and extruded organisms.

COMMONLY USED ENTRAINMENT SAMPLING GEAR

One objective of this report is to provide a timely summary of entrainment sampling gear and identify trends in gear use. Data were obtained from annual reports, environmental reports, section 316 demonstration documents (power plant related portion of Public Law 92-500) and conversations with several hundred utility biologists, scientists, and private consultants located throughout the United States.

There are several inherent problems in obtaining information on sampling gear. A major difficulty in obtaining a comprehensive list of gear is that the majority (approximately 70% of the utilities contacted during the study) of the utilities hire private consultants to perform entrainment surveys. Consultants consider all information proprietary and utilities are reluctant to allow release of gear information lest it be used against the utility in a legal proceeding.

Another difficulty is that a complete collection of 316 demonstration documents is not available at the time of this report. In fact, some regions of the Environmental Protection Agency (EPA - the federal agency responsible for regulation of Public Law 92-500) are only now drawing up technical specifications on the kind of information to be supplied by the utilities. Generally, there is a great need for standardization of the format for every type (316, environmental, etc.) of federally required report.

Nearly 100 utility annual and environmental reports were reviewed primarily at the offices of the Nuclear Regulatory Commission. Results are summarized by ecosystem (Table A-1) and discussed below. Reports included information from 1971 to 1976 with early reports generally lacking any information on ichthyoplankton or mentioning it briefly in conjunction with zooplankton sampling.

Available section 316 demonstration documents were reviewed at six of the ten EPA regional offices. Information reported varies with EPA region. Some 316 demonstration documents give incomplete or no information on ichthyoplankton sampling gear in spite of the fact that results of such sampling are reported. Other 316's refer to annual or environmental reports for descriptions of entrainment sampling gear and technique. Types of ichthyoplankton sampling gear used in section 316 studies are reported in Table A-2.

Information on ichthyoplankton sampling gear and gear performance was collected during specific interviews and site visits with more than 60 utility biologists, 150 scientists, and representatives from 20 consulting firms. Many other contacts were made at 2 regional and 4 national power plant related meetings. Additional information on sampling gear used in entrainment investigations was extracted from the literature. The diversity of information on gear gathered from such a wide variety of sources defies tabularization. However, reports of gear currently used are included in the following inventory of commonly used gear. Also, the comments and criticisms are incorporated elsewhere in the report, especially in the form of recommendations.

Half meter, circular-framed plankton nets are the most commonly used ichthyoplankton sampling gear in the United States based on our inventory. Meter nets, pump samplers, and bridleless Bongo nets are the second, third, and fourth most commonly used gears respectively. The diversity of mesh sizes utilized is impressive. Virtually every commercially available size mesh between 0.100 mm and 0.790 mm is used. The stratified tow taken at a nominal depth was a more common deployment than oblique (including stepped oblique), fixed or vertical tows (Figure 4).

Stratified tows are taken horizontally at a single depth. In power plant studies individual samples are frequently taken at the surface, mid-depth, and bottom. During an oblique tow, the gear is recovered continuously along a line at some angle between horizontal and vertical. Stepped oblique tows are discontinuous oblique tows with brief horizontal tows incorporated at certain depths (i.e., every 5 m). Fixed tows and/or drift samples are collected by holding the gear in a single place with respect to the flow. Vertical tows are taken from some depth to the surface in a straight line.

In lacustrine ecosystems half meter nets were the most widely used sampling gear. Mesh sizes ranged from 0.100 to 0.790 mm. Stratified tows taken at the surface were more common than fixed, vertical, or oblique tows. Duration of tows ranged from 1 min to 2 hrs, but 10 min was the most common interval.

For riverine systems, half meter nets were the most widely used gear. Mesh sizes ranged from 0.158 to 0.787 mm and stratified tows were more common than oblique tows. Sampling periods lasted from 2 min to 24 hrs with 5 min the usual duration.

Reservoir ecosystems were most frequently sampled with square framed meter nets and with meshes ranging from 0.333 to 0.790 mm. Typical tows were stratified and lasted 10 min.

Both half meter and meter nets were frequently used in estuarine sampling programs. Mesh sizes used to filter the sample ranged from 0.173 to 0.571 mm. Stratified tows of 5 min were typical.

In marine ecosystems meter nets were the gear used most often. Mesh sizes ranged from 0.200 to 0.505 mm. Oblique tows deployed for 10 min were most common.

Generally, mesh sizes used to sample estuarine and marine systems are smaller than mesh sizes fished in lakes, rivers, and reservoirs. Freshwater larvae are usually larger than marine larvae. Meter nets are usually fished with 0.500 mm mesh in freshwater and with 0.200 mm mesh in sea water. Bongo nets are the only sampling gear using relatively standardized mesh sizes (0.202 mm, 0.333 mm, and 0.505 mm). Pumped samples are typically filtered through 0.500 mm or larger mesh.

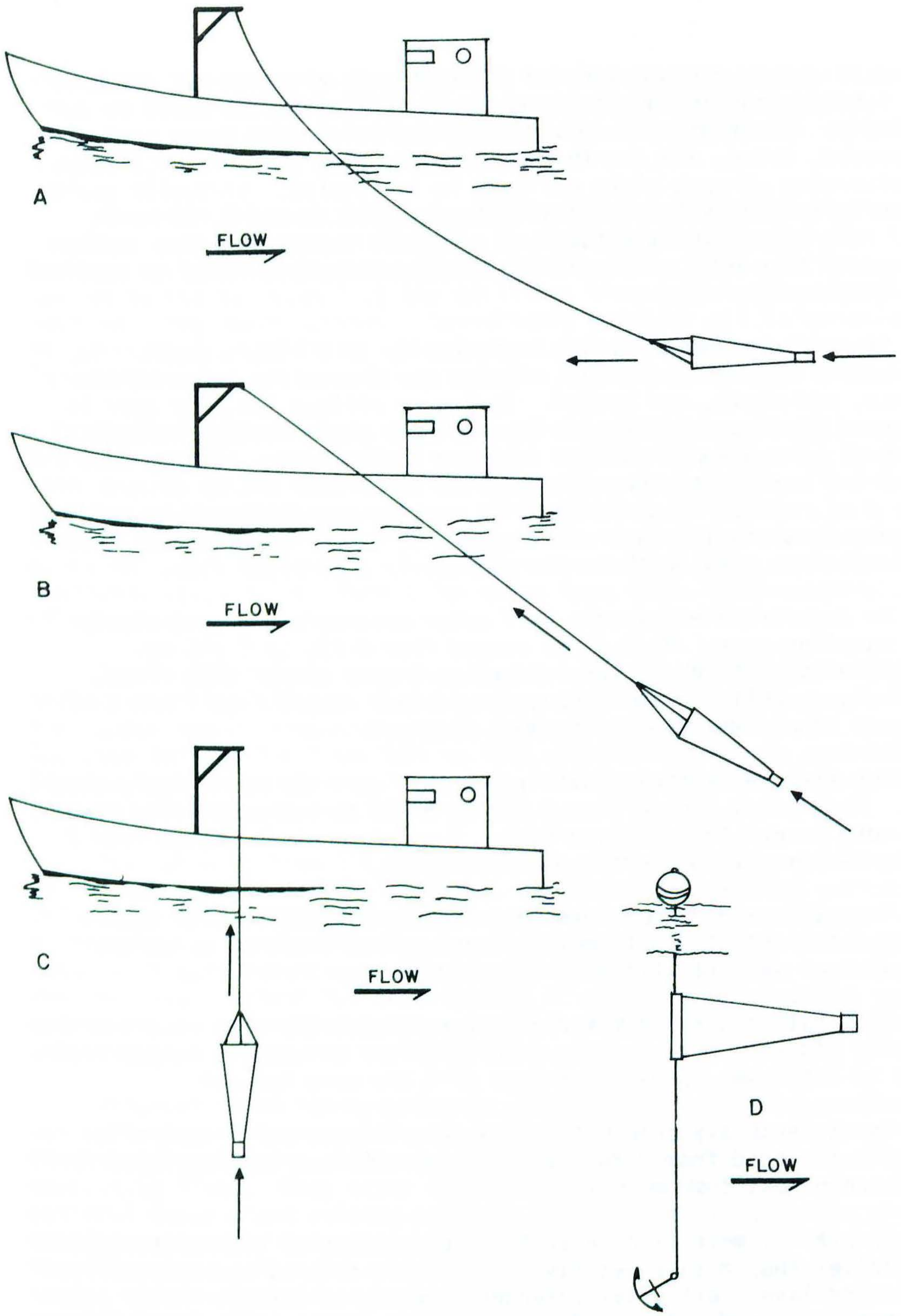


Figure 4. Gear deployment can be (A) stratified, (B) oblique, (C) vertical, or (D) fixed.

BIOTIC AND ABIOTIC FACTORS AFFECTING ACCURACY IN SAMPLING FISH EGGS AND LARVAE

Factors affecting the attainment of a representative sample of ichthyoplankton may be divided into abiotic and biotic. Abiotic factors include characteristics of the gear or sampling environment, while biotic factors include characteristics of the target organism. Table 4 lists abiotic and biotic factors found to influence accuracy of ichthyoplankton sampling gear. The most common factors are discussed below.

Precision may also affect sampling gear accuracy. Precision is a measure of the variability of data obtained in replicate samples. According to Fleminger and Clutter (1965), "contagious distributions of organisms decrease precision, while sampling gear performance and the reaction of the organisms affect the accuracy of estimates of population densities." Thus, variations in distribution (patchiness) are of primary importance in determining the number of replicate samples required to obtain a desired level of precision. As Lauer, et al. (1974) pointed out, each day of intensive sampling generates weeks of sample and data analyses. Unnecessary replication is expensive. The number of replicate samples required to obtain the desired precision may be predicted from equations based on the Poisson distribution (e.g., Burns, 1966; Lauer, et al., 1974). However, Cassie (1968), Langeland and Rognerud (1974), and others have recently suggested that ichthyoplankton sampling series deviate significantly from the Poisson model and show a high degree of over-dispersion. The negative binomial model has been used to predict the number of samples required to obtain a desired level of precision for over-dispersed populations (e.g., Elliot, 1971).

ABIOTIC FACTORS

Sampling Gear Efficiency.

Theoretically, the efficiency of a sampling device is a measure of the extent to which the device produces samples accurately representing the population studied. Empirically, however, ichthyoplankton sampling gear efficiency is the percent of organisms in the path of the sampler that are actually captured. Gear efficiency is one method of quantifying the impact of abiotic factors on gear accuracy.

Hydraulic Characteristics. Hydraulic characteristics of the gear and flow conditions in the vicinity of the gear are the most important factors influencing accuracy of ichthyoplankton sampling gear. Turbulence within and around a towed net, for example, may

Table 4. Abiotic and Biotic Factors Associated with Accuracy in Sampling Fish Eggs and Larvae

Abiotic Factors	Sampling Gear Efficiency	• accurate representation of system • clogging of net meshes • size range sampled due to mesh selection
	Gear Design	• hydrodynamics of sampling gear • ratio of mouth opening to open area of net mesh
	Gear Deployment	• tow speed, duration, depth • volume of sample
	Physical/Chemical Factors	• turbulence and currents • salinity, dissolved oxygen, temperature, weather, turbidity
	Site Specific Characteristics	• water body morphology • localized constraints on sampling
Biotic Factors	Avoidance	• active, fright response • passive, pressure wave effects
	Patchiness	• larval dispersion • three dimensional distribution
	Habitat Utilization	• spawning, nursery, or feeding grounds • community structure
	Species Specific Characteristics	• life history information • relatively important species

significantly reduce filtering efficiency of the gear. A steady, laminar-like flow of water through the sample gear is the ideal condition. In reality, pump orifices, towing bridles, shackles, warps, and net meshes generate turbulence as the gear is fished (Tranter and Smith 1968; Clutter and Anraku 1968). Vibrations or excessive turbulence caused by gear deployment or water movement around the gear may be sensed by ichthyoplankton and lead to active or passive gear avoidance.

Accurate measurements of the water volume filtered are essential for quantitative ichthyoplankton measurements. As a sample tow continues, gear efficiency decreases as organisms and debris become trapped between the meshes (clogging). The amount of water passing through the mesh is progressively reduced as the tow continues and the degree of clogging increases (Figure 5). Calculations of theoretical flows, the amount of water presented to the mouth of the net, are usually unreliable. Flow meters should be mounted inside and outside of the net. Center-mounted flow meters in bridled nets register a lower volume than actually filtered (Mahnken and Jossi 1967; Tranter and Smith 1968). Highest velocities are at the peripheries of bridled nets and the recommended position for the flow meter is at the point of the average velocity (usually 2/3 out from center) (Figure 3). In unbridled nets the flow is uniform across the mouth opening. The presence of a flow meter in the net mouth may reduce gear efficiency. Quirk, Lawler, and Matusky (1974) collected more larval fish in unbridled nets without flow meters than in comparable nets with meters in the mouth aperture.

Mesh Selection. Towed nets are selective. Retention of various size larvae and eggs is largely a function of the size and the distortion of the meshes (Vannucci 1968). A single mesh size cannot sample the entire larval size range of an important species with 100% efficiency. For example, the size of larval northern anchovy, Engraulis mordax, that may be present at the same time ranges from 2.5-3.0 mm at hatching to 20 mm prejuveniles (Ahlstrom and Moser 1976). Three size intervals can exist simultaneously: 1) larval fish and eggs small enough to be extruded through the meshes, 2) ichthyoplankton retained by the meshes, and 3) those larvae capable of avoiding the net (Quirk, Lawler, and Matusky 1974; Kjelson and Colby 1976). Net selectivity causes distortion that is frequently reflected in survival and growth curves (Ahlstrom 1954).

The early larval stages are frequently undersampled because of mesh selection due to extrusion through the net (Ahlstrom 1954; Saville 1959; Lenarz 1972). Escape of organisms larger than the meshes is aided by the compressibility of organisms and the flexibility of the net (Vannucci 1968). Kjelson and Colby (1976) recognized an active and passive extrusion where active extrusion involved orientation of the fish larvae to facilitate escape. Design of the collection bucket

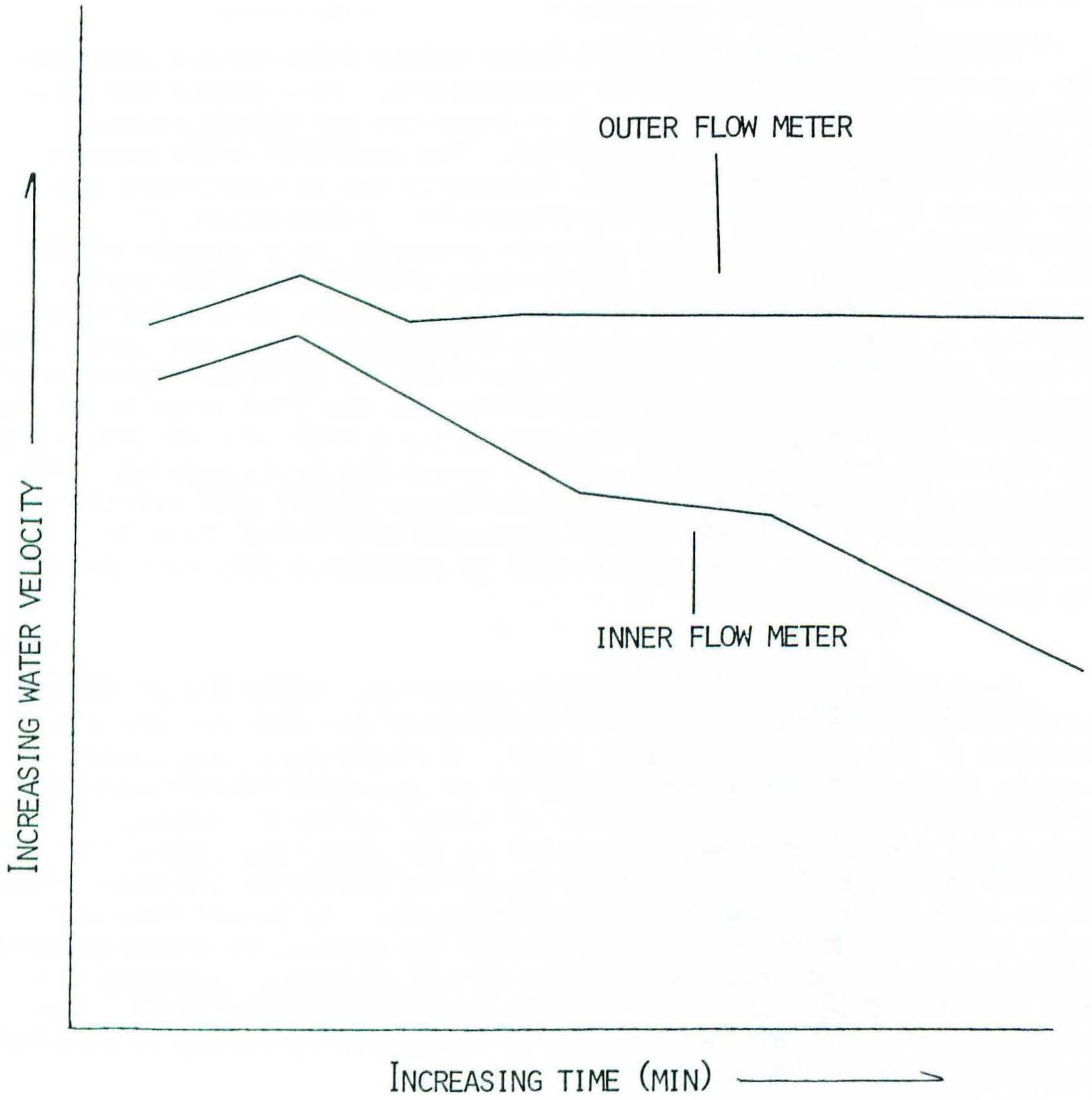


Figure 5. Clogging rate of a net showing decrease in efficiency as the tow continues.

at the cod end may be important. Faber (1968) observed that pressure head caused by the bucket holds larval fish in the adjacent netting and contributes to extrusion. Pump samples are also susceptible to extrusion. High pumping speeds cause extrusion and damage to organisms (e.g., Barnes 1949).

Extrusion can be reduced by decreasing the mesh size and adjusting net towing speeds. For example, Marine Research, Incorporated (1975) compared the performance of 0.333 mm mesh and 0.505 mm mesh Bongo nets. The 0.333 mesh was more efficient and yielded 19% more eggs and 36% more larvae in tows taken in the discharge structure of Pilgrim Nuclear Power Plant. Quirk, Lawler, and Matusky (1974) observed that smaller mesh nets are more efficient in collecting larvae at lower tow speeds than larger mesh nets.

Heron (1968) observed that the most effective net meshes are square with uniform aperture, stiff enough to resist bending, but flexible enough to be self-cleaning. Finer meshes are more susceptible to clogging. Heron also observed that filtration efficiency increased as the open area of the gauze increases until a plateau is reached when the open area of the gauze is more than three times the area of the net mouth. The diameter of the net mouth to the length of bag ratio of 1:6 increases gear efficiency by hydraulically inducing self-cleaning in plankton adhering to the meshes (Faber 1968).

Even though the same mesh size is used, results from different gear are probably not comparable because different gear designs sample the same organisms with different efficiencies. Fragile zooplankton present in net samples are frequently not found in comparable pump samples (e.g., Aron 1958; Beers, *et al*. 1967).

Gear Design. Sampling gear efficiency is not only a function of mesh selection, but also a function of appropriate gear design. Alteration of existing samplers and design of new gear continues, but inconsistent results from field evaluations of alterations in size, speed and conspicuousness of samplers make optimization difficult (Clutter and Anraku 1968).

For low speed nets, the size of the net mouth is an important aspect of design that affects sampling efficiency. Barkley (1972) provides a formula for calculation of the "lethal cone," a measure of the effective area of capture that precedes a towed net based on tow speed, escape speed of the organism, and diameter of the net mouth. Theoretically, the probability that larger diameter nets will capture more organisms per unit volume than smaller nets is great. Even though an organism actively attempts to avoid the net, it would usually have to travel farther to reach the peripheral escape zone (area outside the lethal cone) for a larger diameter net towed at an equal speed.

When nets with mouths of 40, 80, and 160 cm-diameter were comparatively evaluated, fewer mysids and copepods were captured in the smaller diameter nets (Fleminger and Clutter 1965). Large mouth nets caught greater numbers of white perch larvae at lower tow speeds, but small mouth nets were more efficient at higher tow speeds (Quirk, Lawler, and Matusky 1974). Both 140 and 20 cm-diameter nets underestimated the total population, but the 140 cm-diameter net exhibited less sample variability and collected more larval fish per unit volume than the 20 cm-diameter net. Generally, larger diameter nets are more efficient, but nets greater than one meter in diameter are impractical for routine horizontal towing because of difficulties in handling and towing (Aron 1962). Larger nets cannot be towed fast because of drag, and smaller nets sample less water, clogged more readily, and have greater sample variability (Barkley 1964).

On the other hand, Winsor and Clarke (1940) observed no significant reduction in sample variance by increasing net diameter. When sampling zooplankton, longer tows increase precision by reducing variability better than increasing the diameter of the net mouth (Wiebe 1972).

The mouth opening diameter of plankton recorders was redesigned to increase sampler efficiency (Haury, et al. 1976). The ratio (R) of filtering area to throat aperture in Longhurst-Hardy plankton recorders was inefficient at R = 0.67. They found that R of nearly three was optimum.

Miller high speed nets with an aperture 1.5 times larger than the standard model were not more effective in sampling yellow perch larvae. Increasing the net size made the net more efficient up to a certain point, but avoidance also increased (Noble 1970). Other design modifications to high speed samplers include mouth reducing cones used to lessen drag. Mouth reducing cones were most efficient when the angle of expansion with respect to the sampler body was less than 3.5 degrees (Clutter and Anraku 1968). Design criteria for an efficient high speed sampler include: 1) simple design and construction, 2) ability to simultaneously sample multiple depths, 3) a towing speed in excess of 5 knots, 4) a high filtering ratio to prevent clogging, 5) ability to sample a large volume in a short time, and 6) absence of obstructions in the mouth of the device (Miller 1961).

Innovations in pump engineering have included bladeless impeller designs that cause less damage to organisms. Clear plastic cones placed over the pump oriface may reduce avoidance due to reduction of pressure waves in the vicinity of the sampler (P. Benson 1977, personal communication, Lockheed Environmental Research Center). High volume pumps reduce avoidance by reducing the peripheral escape zone and also reduce the duration of deployment required to obtain an adequate sample volume.

Deployment Parameters.

Deployment parameters include duration of the tow, towing depth, speed of towing or rate of pumping, and the type of tow. When replicate samples are taken, it is important that deployment parameters be reproduced as exactly as possible to prevent an additional source of variation.

Duration of Tow. Duration of a sampling tow should be long enough to provide an adequate sample volume to assure accuracy, but short enough to avoid sampling error due to clogging of the meshes (e.g., Winsor and Walford 1936; Silliman 1946; Barnes 1949; Yentsch and Duxbury 1956; Oray 1968). Adequate sample volume is the amount of water that must be filtered to accurately describe the distribution of the ichthyoplankton species of interest. If the species are randomly distributed, a rare occurrence with fish eggs and larvae, then sample volume is not critical. However, if the species occur in locally dense patches, then the size and distribution of the patches must be considered in determining sampling parameters (Barnes and Marshall 1951; Elliot 1971). A standard sample volume is, therefore, difficult to define not only because of variations in distributions of ichthyoplankton and clogging organisms, but also because sampling objectives and gear efficiency vary widely. Seasonal adjustments in the duration of tows may be necessary because of blooms of clogging organisms.

Sample Depth. Sample depth influences sample composition because ichthyoplankton are not randomly distributed over three dimensions within the water column. Many types of net closing devices have been designed to assure sampling of discrete depths (Faber 1968). However, most sampling devices are subject to various degrees of contamination (unintentional inclusion of species or density not present in the intended sampling zone). Samples can be contaminated by other depths as the net is deployed and/or retrieved, by differences in volume of water filtered, or by not sampling the appropriate depth. Large differences in the amount of contamination by organisms in the upper layers of the water column are frequently the result of poor technique during net retrieval (e.g., Netsch, et al. 1971). Contamination ranged from 14% for the deepest samplers to 2% for near surface samplers during recovery of a vertical series of high speed samplers (Miller 1961). Errors were not only the result of surface layer contamination of deeper samples, but also the difference in volume of water strained between surface and deeper samplers because deeper samplers were in the water longer. Small changes in boat speed can produce large changes in sampler depth when long lengths of towing cable are used. A Scripps depressor or similar device (Graham 1966) can be used to attain desired sample depths, however low speed fishing performance may be poor (Aron, *et al.* 1965).

Speed of Tow. Speed of the tow can be increased to reduce gear avoidance by larger fish larvae (e.g., Aron, *et al.* 1965; Noble 1970; Bernhard, *et al.* 1973; Quirk, Lawler and Matusky 1974). However, the faster the tow, the more distorted the mesh. Vannucci (1968) observed that mesh distortion affects retention and selectivity. Increased retention (catch) was observed with increased speed in high speed samplers towed at five to seven knots (Bernhard, *et al.* 1973). Small differences in tow speed affect the length-frequency distribution of some species in the catch (Aron and Collard 1969). Noble (1970) observed increased tow speed increased the number of larger yellow perch larvae captured and recommended a small increase in tow speed as more advantageous than a slight increase in sampler mouth diameter. Pumping rate in intake and discharge canals should equal the flow rate of the water passing the orifice to avoid flushing the sample away. Pumping rate for open water samples should be fast enough to provide an adequate sample volume in a reasonable period of time and prevent avoidance. However, excessive pumping speed may produce pressure waves that cause avoidance by older larvae and damage samples.

Type of Tow. Different measures of ichthyoplankton distribution are provided by oblique, vertical, fixed, and stratified tows. Vertical tows are useful for measuring diurnal variation within the water column. Stratified and oblique tows (including stepped oblique) are usually used in entrainment abundance surveys. Fixed deployment is used in intake/discharge mortality studies and in drift net studies of river or tidal estuarine plankton. The type of deployment should be based on distribution and life history of the relatively important species and morphometry of the sampling site.

Gear deployed over the stern of a vessel may yield biased samples due to active and passive avoidance response to turbulent prop wash. Push nets, beam trawls, or stern trawling by towing a circular path all produce samples not biased by prop wash effects.

Physical/Chemical Environmental Factors.

Many environmental factors affect distribution of fish eggs and larvae and the performance of sampling gear. Frequently, physical and chemical environmental parameters cannot be standardized across a sampling season or program. Measurements of such variables should be made for possible correlations with data sets.

Tidal cycles affect gear performance only indirectly by strongly influencing deployment parameters. Tidal cycles in estuaries and along the coast cause significant physical/chemical variations in the aquatic environment. Hopkins (1963) suggested that only variations exceeding 50% be considered significant if a station could not be sampled more than once during a single tidal cycle. Organisms that drift with the tidal flux are exposed to sampling or entrainment multiple times. Vertical salinity profiles can influence the buoyancy and thus, the distribution of ichthyoplankton. Sameoto (1975) observed that reasonably accurate estimates of nearshore marine zooplankton abundance could be obtained by making at least two vertical tows on a station at 6 hr intervals.

Turbulence, tidal motion, currents, and natural circulation may affect not only distribution of fish eggs and larvae (e.g., Bishai 1960; Jacobs 1968), but also the ability of the gear to representatively sample the population. Increased turbulence and run-off can increase turbidity and reduce visual stimulus to avoid sampling gear. Turbulence in intake and discharge canals can stall current meters and adversely affect the fishing performance of nets (Icanberry and Richardson 1973). Currents are the major factor affecting transport and dispersion of eggs and larvae. Information on circulation patterns in the vicinity of power plant intake structures can be modeled to predict entrainment mortality (e.g., Polgar, et al. 1975).

Weather conditions affect gear performance and plankton distribution. Sea state influences gear deployment, recovery, and fishing characteristics. Cloud cover affects the amount of light transmitted through the surface of the water body and influences gear visibility. While temperature rarely influences sampling gear directly (i.e., meshes freeze), temperature directly influences time of spawning, egg incubation period, growth and survival rate of ichthyoplankton. For example, Hudson River striped bass eggs were collected between 10-19°C, yolksac larvae between 10-20°C, and older larvae between 10-25°C. Thermal stratification also plays an important role in ichthyoplankton distribution.

Site Specific Characteristics.

Each sampling site has ecosystem and habitat specific features that make it unique. The diversity in sampling sites requires flexibility and variety in sampling gear. Selection of sampling gear can be difficult if unique features of the sampling site prevent use of conventional gear or substantially interfere with gear efficiency. Ichthyoplankton gear has been specially designed or modified to sample difficult sites including coves, weed-choked areas, tidal marshes, and turbulent intake/discharge structures (i.e., pumps, drop nets, square framed meter nets, etc.). All gear selection should be justified by demonstrating that an accurate representation of ichthyoplankton has been achieved under site specific conditions. The most commonly used method of demonstrating gear accuracy is performance of a gear comparison by simultaneously sampling with two or more alternative gears.

BIOTIC FACTORS

Avoidance.

Avoidance of sampling gear can be active or passive. Passive avoidance occurs when net meshes become clogged and a pressure wave is created at the mouth of the sampler. Organisms are swept beyond the net without exhibiting an escape response. Active avoidance may be stimulated by visual or hydrostatic pressure cues from sampling gear.

Fish are highly sensitive to pressure stimulus (see Knight-Jones and Qasim 1955). Plankton may detect and avoid the net because of the zone of pressure preceding the net (Bary, et al. 1958). Towing bridles set up vibrations which send out pressure waves from the mouth of the net (Fleminger and Clutter 1965; Clutter and Anraku 1968). Net design, mesh size, and speed of tow also influence the character of pressure waves (Quirk, Lawler, and Matusky 1974). Nets without bridles in the net aperture have significantly higher catches than standard plankton nets (Smith 1975).

Bridger (1956) stated that net avoidance is due to visual stimulus. When Fleminger and Clutter (1965) collected fewer mysids than copepods despite their equal relative abundance, they hypothesized that mysids have more acute vision and were able to respond to the visual stimulus of the net. Avoidance by larval yellow perch longer than 8 mm could have been due to development of eye function at that length (Noble 1970); a transparent Miller High Speed Sampler collected more yellow perch larvae than the standard (colored) sampler.

Greater numbers of larger marine larvae were collected at night when visual stimulation was lower than during comparable daylight tows (Ahlstrom 1954)(Figure 6). In addition to reduced gear visibility, larger catches of ichthyoplankton at night may be due to diurnal changes in distribution (i.e., migration to the surface). Catches of larval perch and walleye sampled with a Miller High Speed Sampler were greater at night (Noble 1970). Quirk, Lawler, and Matusky (1974) captured more riverine larvae at night, but failed to

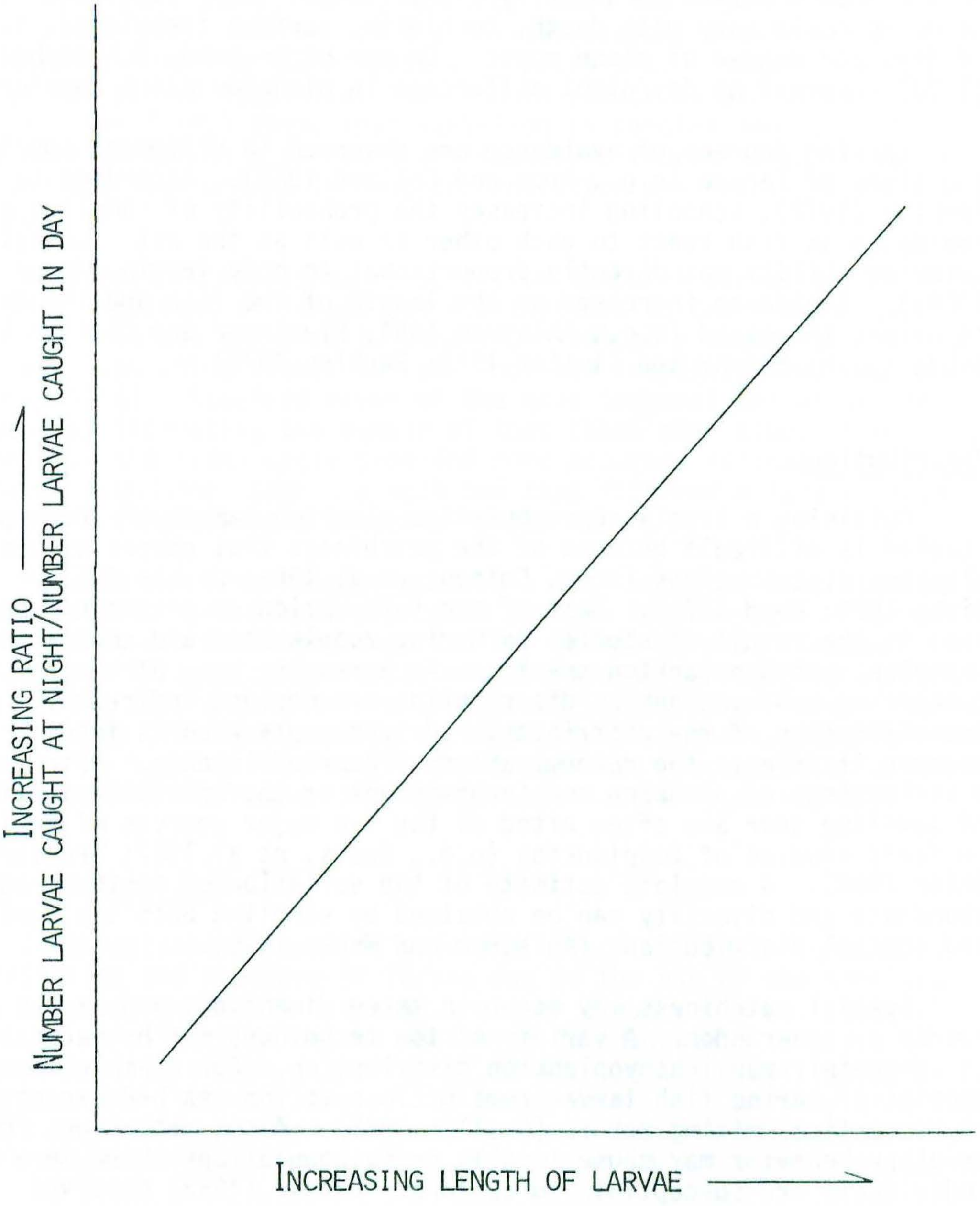


Figure 6. Gear avoidance demonstrated by larger catches of longer larvae at night. (After Ahlstrom 1954).

difficult sites including coves, weed-choked areas, tidal marshes, and turbulent intake/discharge structures (i.e., pumps, drop nets, square framed meter nets, etc.). All gear selection should be justified by demonstrating that an accurate representation of ichthyoplankton has been achieved under site specific conditions. The most commonly used method of demonstrating gear accuracy is performance of a gear comparison by simultaneously sampling with two or more alternative gears.

BIOTIC FACTORS

Avoidance.

Avoidance of sampling gear can be active or passive. Passive avoidance occurs when net meshes become clogged and a pressure wave is created at the mouth of the sampler. Organisms are swept beyond the net without exhibiting an escape response. Active avoidance may be stimulated by visual or hydrostatic pressure cues from sampling gear.

Fish are highly sensitive to pressure stimulus (see Knight-Jones and Qasim 1955). Plankton may detect and avoid the net because of the zone of pressure preceding the net (Bary, et al. 1958). Towing bridles set up vibrations which send out pressure waves from the mouth of the net (Fleminger and Clutter 1965; Clutter and Anraku 1968). Net design, mesh size, and speed of tow also influence the character of pressure waves (Quirk, Lawler, and Matusky 1974). Nets without bridles in the net aperture have significantly higher catches than standard plankton nets (Smith 1975).

Bridger (1956) stated that net avoidance is due to visual stimulus. When Fleminger and Clutter (1965) collected fewer mysids than copepods despite their equal relative abundance, they hypothesized that mysids have more acute vision and were able to respond to the visual stimulus of the net. Avoidance by larval yellow perch longer than 8 mm could have been due to development of eye function at that length (Noble 1970); a transparent Miller High Speed Sampler collected more yellow perch larvae than the standard (colored) sampler.

Greater numbers of larger marine larvae were collected at night when visual stimulation was lower than during comparable daylight tows (Ahlstrom 1954)(Figure 6). In addition to reduced gear visibility, larger catches of ichthyoplankton at night may be due to diurnal changes in distribution (i.e., migration to the surface). Catches of larval perch and walleye sampled with a Miller High Speed Sampler were greater at night (Noble 1970). Quirk, Lawler, and Matusky (1974) captured more riverine larvae at night, but failed to

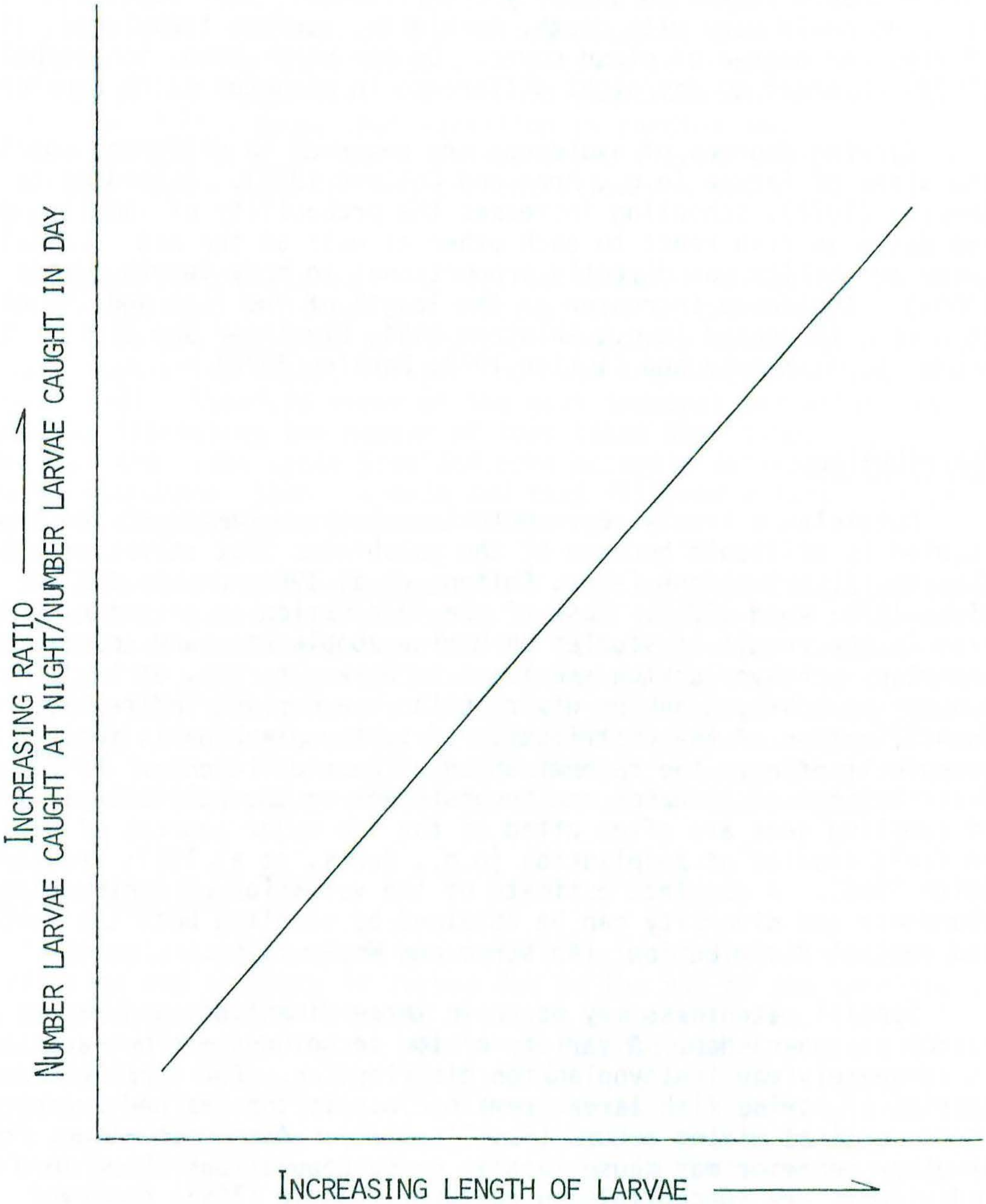


Figure 6. Gear avoidance demonstrated by larger catches of longer larvae at night. (After Ahlstrom 1954).

obtain enough larvae to quantify significance. They suggested visual stimulus could vary with depth, turbidity, surface turbulence, time of day, and degree of cloud cover. On the other hand, Schwoerbel (1970) observed no day/night difference in plankton catch abundance.

Varying degrees of avoidance are observed in different species and sizes of larvae (e.g., Aron and Collard 1969). According to Berkley (1972), schooling increases the probability of sampling gear avoidance as fish react to each other as well as the net. Larval swimming ability was directly proportional to body length (Houde 1969a). Avoidance increased as the length of the fish and the ability to orient increased (e.g., Ahlstrom 1954; Fleminger and Clutter 1965; Houde 1969b; Murphy and Clutter 1972; Barkley 1972).

Distribution.

Obtaining a truely representative plankton sample of the population studied is difficult because of the patchiness that characterizes plankton distributions (e.g., Colton, et al. 1961; Cassie 1963; Wiebe 1970; Wood 1971). Most of the information on plankton distribution is the result of studies on marine zooplankton and commercially important ichthyoplankton species. As a result, many of the conclusions concerning ichthyoplankton distribution are derived indirectly. Quantification of the distribution of ichthyoplankton is important because it effects the determination of gear efficiency. Patchy distributions of plankton and inconsistant or unpredictable inefficiency of sampling gear are often cited as the two major sources of variance in field studies of zooplankton (e.g., Beers, et al. 1967; Tranter and Smith 1968). A complete estimate of the variation of ichthyoplankton abundance and diversity can be obtained by sampling both the temporal and spatial distribution (Ahlstrom and Moser 1976).

Spatial patchiness may occur in three dimentions and may be random or non-random. A variety of tow techniques may be necessary to adequately map ichthyoplankton distribution. For example, many species of marine fish larvae remain close to the sea bed except where vertical mixing occurs (Saville 1971). Also, schooling, feeding, or other behavior may cause locally dense populations where more individuals are susceptible to capture. Cassie (1963) observed non-random variations in zooplankton populations over distances as small as 5 cm. Because the spatial distribution of plankton is so variable, Schwoerbel (1970) stated that nets do not provide adequate quantitative samples.

The impact of variance attributable to the patchy distribution of ichthyoplankton can be accurately estimated by modifying gear deployment (altering the type of replication). Miller (1961) recommended circular towing around a bouy deployed with a drogue. Thus, by sampling the same water mass, variance among the replicates would be reduced. Pairing of tows (simultaneous) also reduces variance and provides some measure of patch size (Hopkins 1963). The use of paired sequential tows should reduce sample variation, but Silliman (1946) found that variation in sardine egg concentrations at a single station were not significantly different than variation between stations unless the egg concentration was nearly half or double.

Temporal patchiness can result from temporal variations in spawning, diel movement of larvae and fluctuations in the tidal cycle. Sampling programs designed to sample periodically cannot accurately estimate population peaks, but can indicate trends (Quirk, Lawler, Matusky 1974). Standard error of the mean temporal variation can be reduced by increasing the number of tows taken over time. Several tows taken over the tidal cycle provided more accurate estimates of estuarine plankton abundance than a single tow that filtered a larger amount of water in a single sample (Hopkins 1963).

Many larval fish species exhibit a diel vertical distribution and an appropriate diel sampling program must be implemented. Diurnal catch variations have been reported for larval herring (Dragesund 1971; Wood 1971; Stickney 1972), other clupeids (Bridger 1956; Colton et al 1961; Clutter and Anraku 1968), and yellow perch larvae (Noble 1970). Long (1968), observing vertical and diel distribution of larval salmon in a turbine intake, found the greatest concentration of larvae in the upper 9 m of water and the greatest activity at night.

Habitat Utilization.

Ichthyoplankton sampling gear efficiency may be influenced by distribution and abudance of larvae due to the use of the sampling site as a spawning ground, a hatching area, or a nursery area. Several types of sampling gear may be necessary to adequately sample all entainable life stages (Lauer et al. 1974). If as Edsall (1976) suggests, the littoral zone of the Great Lakes is a nursery area comparable to shallow estuarine areas, then similar gear may adequately sample both habitats even thaough they occur in different ecosystems.

Species Specific Characteristics.

Sampling programs for power plant impact assessment are usually designed around one or more relatively important species with commercial or sport fish value. Distributional patterns of ichthyoplankton are species specific. Although many species will be caught in a single sample, gear efficiency may be different for each species. Weighted data analysis may provide more accurate abundance estimates for species sampled with lower efficiency than target species.

obtain enough larvae to quantify significance. They suggested visual stimulus could vary with depth, turbidity, surface turbulence, time of day, and degree of cloud cover. On the other hand, Schwoerbel (1970) observed no day/night difference in plankton catch abundance.

Varying degrees of avoidance are observed in different species and sizes of larvae (e.g., Aron and Collard 1969). According to Berkley (1972), schooling increases the probability of sampling gear avoidance as fish react to each other as well as the net. Larval swimming ability was directly proportional to body length (Houde 1969a). Avoidance increased as the length of the fish and the ability to orient increased (e.g., Ahlstrom 1954; Fleminger and Clutter 1965; Houde 1969b; Murphy and Clutter 1972; Barkley 1972).

Distribution.

Obtaining a truely representative plankton sample of the population studied is difficult because of the patchiness that characterizes plankton distributions (e.g., Colton, *et al.* 1961; Cassie 1963; Wiebe 1970; Wood 1971). Most of the information on plankton distribution is the result of studies on marine zooplankton and commercially important ichthyoplankton species. As a result, many of the conclusions concerning ichthyoplankton distribution are derived indirectly. Quantification of the distribution of ichthyoplankton is important because it effects the determination of gear efficiency. Patchy distributions of plankton and inconsistant or unpredictable inefficiency of sampling gear are often cited as the two major sources of variance in field studies of zooplankton (e.g., Beers, *et al.* 1967; Tranter and Smith 1968). A complete estimate of the variation of ichthyoplankton abundance and diversity can be obtained by sampling both the temporal and spatial distribution (Ahlstrom and Moser 1976).

Spatial patchiness may occur in three dimentions and may be random or non-random. A variety of tow techniques may be necessary to adequately map ichthyoplankton distribution. For example, many species of marine fish larvae remain close to the sea bed except where vertical mixing occurs (Saville 1971). Also, schooling, feeding, or other behavior may cause locally dense populations where more individuals are susceptible to capture. Cassie (1963) observed non-random variations in zooplankton populations over distances as small as 5 cm. Because the spatial distribution of plankton is so variable, Schwoerbel (1970) stated that nets do not provide adequate quantitative samples.

The impact of variance attributable to the patchy distribution of ichthyoplankton can be accurately estimated by modifying gear deployment (altering the type of replication). Miller (1961) recommended circular towing around a bouy deployed with a drogue. Thus, by sampling the same water mass, variance among the replicates would be reduced. Pairing of tows (simultaneous) also reduces variance and provides some measure of patch size (Hopkins 1963). The use of paired sequential tows should reduce sample variation, but Silliman (1946) found that variation in sardine egg concentrations at a single station were not significantly different than variation between stations unless the egg concentration was nearly half or double.

Temporal patchiness can result from temporal variations in spawning, diel movement of larvae and fluctuations in the tidal cycle. Sampling programs designed to sample periodically cannot accurately estimate population peaks, but can indicate trends (Quirk, Lawler, Matusky 1974). Standard error of the mean temporal variation can be reduced by increasing the number of tows taken over time. Several tows taken over the tidal cycle provided more accurate estimates of estuarine plankton abundance than a single tow that filtered a larger amount of water in a single sample (Hopkins 1963).

Many larval fish species exhibit a diel vertical distribution and an appropriate diel sampling program must be implemented. Diurnal catch variations have been reported for larval herring (Dragesund 1971; Wood 1971; Stickney 1972), other clupeids (Bridger 1956; Colton et al 1961; Clutter and Anraku 1968), and yellow perch larvae (Noble 1970). Long (1968), observing vertical and diel distribution of larval salmon in a turbine intake, found the greatest concentration of larvae in the upper 9 m of water and the greatest activity at night.

Habitat Utilization.

Ichthyoplankton sampling gear efficiency may be influenced by distribution and abudance of larvae due to the use of the sampling site as a spawning ground, a hatching area, or a nursery area. Several types of sampling gear may be necessary to adequately sample all entainable life stages (Lauer et al. 1974). If as Edsall (1976) suggests, the littoral zone of the Great Lakes is a nursery area comparable to shallow estuarine areas, then similar gear may adequately sample both habitats even thaough they occur in different ecosystems.

Species Specific Characteristics.

Sampling programs for power plant impact assessment are usually designed around one or more relatively important species with commercial or sport fish value. Distributional patterns of ichthyoplankton are species specific. Although many species will be caught in a single sample, gear efficiency may be different for each species. Weighted data analysis may provide more accurate abundance estimates for species sampled with lower efficiency than target species.

COMPARATIVE GEAR EVALUATION

Few comprehensive gear evaluations have been performed. Most comparative studies based conclusions on a small number of samples without replication and results from studies on similar gear were often contradictory.

Two studies comparatively evaluated the affect of mesh size on gear efficiency. Quirk, Lawler, and Matusky (1974) evaluated thirty low speed net-mesh combinations. Optimum mesh size was a function of net design and dynamics, thus indicating a different preferred mesh size for each net design tested. Circular meter nets collected larger numbers and greater length ranges of larval Hudson River species than half meter or square framed nets. In a study on high speed net mesh, Bernhard, et al. (1973) observed actual mesh sizes varied from nominal sizes by as much as 10 µm about 10 to 20% of the time depending on mesh size. The number of organisms retained increased as the towing speed decreased and a plateau was reached at 5 to 7 knots. Also, live plankton frequently passed through a given mesh size that retained dead plankton of the same species and size.

Other Hudson River gear comparisons (e.g., Carlson and McCann 1969; Ecological Analysts, Inc. 1977; Texas Instruments, Inc. 1977) not only attempted to identify the most efficient sampling gear, but also attempted to empirically obtain correction factors to make diverse data sets from a variety of sampling gears compatable. For example, efficiency of meter nets and half meter nets was compared to Tucker trawls and epibenthic sleds. The meter net was judged most efficient because it caught more post-yolksac striped bass larvae than a Tucker trawl at night. The study concluded that gear used by a majority of the contractors sampling the Hudson River had such similar efficiencies for striped bass larvae that no correction factors were needed to make data sets compatable (Texas Instruments, Inc. 1977). Carlson and McCann (1969) found a 46 cm circular net more efficiently sampled Hudson River striped bass larvae than a 0.9 m square-framed net.

With the increasing use of pump samplers, comparisons of net and pump sampling gear performance have become more important. Aron (1958) compared samples from a 1.5 m^3/min centrifugal pump to samples from a half meter nylon plankton net. Data were collected during fifty simultaneous tows in Puget Sound. Volume of water sampled by the pump was 15 m^3/10 min and by the net was 200 m^3/min. Net and pump results showed close agreement for fish eggs and other non-copepod plankton. Beers, et al. (1967) compared the sampling efficiency of a high capacity submersible pump to that of a towed half meter net in side by side vertical hauls. The centrifugal pump delivered 0.15 m^3/min and had a 5 cm diameter suction hose oriented for horizontal intake. Greater numbers and diversity of zooplankton were obtained in pump samples than in net samples. On the other hand, Portner and Rohde (1977) observed a significantly greater catch of striped bass eggs and larvae 3 to 6 mm in a stationary net deployed from an anchored cable than a comparable pump sample. For larger striped bass (>76 mm), they found no significant difference between net and pump samples.

Langeland and Rognerud (1973) estimated the sampling error among Schindler traps, Clarke-Bumpus, and Friedinger samplers used to sample lakes. No significant differences were found in samples taken by Schindler traps and Clarke-Bumpus nets, but Friedinger samplers underestimated Daphnia spp. The variation was correlated to the sample volume of each device and there was a general trend toward lower precision when smaller samples were taken. Lawson and Grice (1977) compared vertical Bongo net hauls and a Schindler plankton trap using several species of zooplankton in the laboratory. Bongo nets gave better estimates of density.

Sampling performance of meter nets and Bongo nets was compared in four side-by-side paired oblique tows in Narragansett Bay. The meter net collected significantly less ichthyoplankton than the Bongo net (Marine Research, Inc. 1974). Lasker (1975) compared the collecting capabilities of the MARMAP open Bongo and the CalCOFI standard (meter) net and demonstrated significantly greater (over 50% per unit volume filtered) catches of larger larval anchovy with the bridleless Bongo net.

Ahlstrom and Moser (1976) evaluated neuston net hauls and oblique meter net hauls. Each technique effectively sampled different segments of the larval anchovy population. Larger anchovy larvae (14.5 mm +) were more efficiently sampled by neuston nets and smaller larvae were better sampled by oblique plankton hauls.

Results of comparative evaluations between low speed and high speed samplers were highly variable. Gulf III samplers caught more herring larvae than Hensen nets (Postuma and Zylstra 1974). Miller high speed samplers provided more accurate estimates of larval yellow perch abundance than meter nets (Noble 1970). However, Gulf III high speed samplers were only half as efficient per unit volume of water presented to the mouth of the net as the Helgoland larvae net for sampling plaice eggs (Oray 1968). Gulf III samplers captured only 53% of the number of herring larvae captured by the Helgoland larvae net, but the Helgoland net had greater variance per haul (Schnack and Hempel 1971). Catches of smaller zooplankton were higher in bongo nets than in Gulf samplers, but both sampled fish eggs (0.85 mm diameter) equally well (Sherman and Honey 1971).

In summary, meter nets were generally more efficient than half meter nets particularly when sampling older fish larvae. Meter nets sampled pelagic eggs better than any other type of gear. Bridleless Bongo nets were even more efficient than meter nets for capturing older larvae. High speed nets captured more older larvae than comparable meter net tows. Trap samplers were especially effective in sampling lake sites. Pump samplers were not as accurate as low speed gear in sampling fish eggs, but high volume pumps sampled older larvae as accurately as nets. Pumps could be used under certain sampling conditions where net sampling would have been impossible.

GEAR OPTIMIZATION

The following factors should be optimized to achieve accurate sampling gear performance.

1. Laminar-like flow through and in the vicinity of the net is necessary for optimum filtration. Hydraulic conditions around the orifice of pump samplers are as important as conditions at the mouth of a net.

2. Adequate sample volume is necessary to assure a representative sample. It may be necessary to pump for 30 min to obtain an adequate sample volume comparable to a 10 min net tow. Adequate sample volume is the amount of water that must be filtered to obtain samples representative of the distribution and abundance of fish eggs and larvae sampled.

3. Accurate measurement of the volume of water sampled is necessary for determining ichthyoplankton abundance. Under turbulent sampling conditions some propeller style current meters can stall and run in reverse. Current meters placed in the hydraulic shadow of towing bridles can also underestimate water volume filtered.

4. Clogging of net meshes reduces filtration capacity and creates pressure waves that stimulate avoidance at the mouth of the net. The length of time gear is deployed should be adjusted seasonally as abundance of clogging organisms increases.

5. The length of time gear is deployed in differential intake/discharge mortality sampling.

6. Gear selection should be based on life history information of the relatively important species. A variety of sampling gear or net mesh sizes may be necessary to adequately sample all entrainable life stages.

7. Gear selection should also be based on water body morphometry and site specific characteristics.

Optimal sampling gear performance is achieved when well designed gear is appropriately deployed. Appropriate deployment is based on minimizing factors that bias gear performance and acknowledging the contagious distribution of ichthyoplankton in the sampling design.

GEAR SELECTION CHECK LIST

The diversity of sampling gear available has created confusion and contention as to what is the optimal sampler for a given situation. The following items should be used to fully evaluate existing or proposed ichthyoplankton sampling programs.

- Evaluate the sampling environment.
  - -Identify site-specific characteristics. For example, if samples are to be taken in turbulent intake and discharge canals, a high volume pump may provide a more accurate sample than a net.
  - -Note areas that may be inaccessible to selected gear (i.e., coves, marshes) and plan to use more than one type of gear if necessary.

- Identify characteristics of the target species.
  - -Determine the most important or susceptible life stage.
  - -Check life history information to determine species-specific characteristics such as type of eggs, incubation period, and descriptions of eggs and larvae.

- Review several types of gear.
  - -Consider comparatively evaluating more than one sampler before beginning the sample program.
  - -If the sampling gear is deemed inappropriate or inefficient in the middle of a sampling program, consider the consequences of altering unknown bias before changing gear. Make a series of simultaneous comparative samples with the old and new gear so that all data can be made compatible.
  - -Consider biotic and abiotic factors that may affect sample accuracy. For example, a bridleless Bongo net may be more accurate than a meter net for sampling older larvae.
  - -Determine the appropriate mesh size.
  - -Determine adequate sample volume to be filtered. Avoid small volumes.

- Select a flow measuring device.
  - -Do not rely entirely on pre-calculated theoretical flows, since they are rarely reliable due to factors such as net clogging and turbulence.
  - -Calibrate the flow measuring device frequently.
  - -If a flow meter is used in a bridled net, place it 2/3 out from center rather than in the center of the net mouth.

- Plan gear deployment.
  - -Tow speed should be fast enough to reduce avoidance by larvae yet slow enough to prevent extrusion of organisms through the meshes.

- -Duration of the tow should be long enough to provide adequate sample volume, yet short enough to avoid clogging.
- -Select an oblique, stratified, vertical, or fixed tow pattern, depending on distributional characteristics of the target species or life stage.
- -Nocturnal sampling may provide better estimates of the abundance of older larvae than diel sampling.
- -Estimate the number of replicate samples required to obtain the desired level of precision.

RECOMMENDATIONS

The following recommendations are divided into two categories: identification of gear research and development needs and conclusions about ichthyoplankton sampling gear selection as an integral part of environmental assessment. Conclusions and suggestions are based primarily on discussions with individuals actively involved in ichthyoplankton/entrainment studies.

Three recommendations are made for meeting gear research and development needs:

1. Improvement in gear design continues to be a major need. Utilities and consulting firms (with a few notable exceptions) are reluctant to fund basic entrainment sampling gear design research. Much of the current design research is oriented toward marine ichthyoplankton sampling and is performed at federal laboratories or major oceanographic institutes. More participation in gear design activities by field biologists involved in entrainment sampling should be encouraged.

2. A "benchmark" comparative ichthyoplankton sampling gear evaluation is needed for each aquatic ecosystem across several larval seasons. Such research could be used to generate a handbook of recommended sampling gear with specific information on deployment parameters, mesh size, and suggested statistical techniques for data analysis. In addition to providing information on gear optimization, sampling gear evaluations could be designed to provide much needed information on ichthyoplankton distribution and larval population dynamics.

3. Increased awareness of and research on the importance of hydraulic characteristics associated with sampling gear performance is strongly recommended. Hydrodynamic efficiency (the ability of the sampling gear to obtain and filter a volume of water at a predictable level of performance) has recently been recognized as an important factor influencing sampling gear accuracy. Aerodynamic and hydraulic tests have demonstrated optimal flow meter placement, gear shape, and area of mouth aperture to mesh opening under controlled, laminar-like flow. Further hydrodynamic research is needed to describe filtration performance under simulated turbulent field conditions. Optimal shape, size and orientation of the pump sampler orifice must be determined. Improvement in flow meter performance in turbulent, low flow conditions is needed.

Selection of recommended ichthyoplankton sampling gear (Table 5) is based on information gathered for this report. Four recommendations on ichthyoplankton sampling gear selection are made:

Table 5. Recommended Ichthyoplankton Sampling Gear for Use in Entrainment Studies

Recommended Gear	Utilization	Discussion
A. Far field/Near field Sampling Gear		
Bridleless nets (low speed nets)	The 60 and 100-cm diameter Bongo or similar nets are most strongly recommended for quantitative ichthyoplankton sampling in all habitats.	Replicate samples are taken simultaneously. Unobstructed mouth decreases avoidance by larger larvae. Standardized mesh sizes of 202, 333, and 505 μ increase comparability of results.
Meter nets (low speed nets)	A widely used general purpose net. Excellent for quantitative egg sampling.	Recommended as second choice after bridleless nets. Not as efficient as bridleless nets for capturing larger larvae. Large volume of sample filtered in short time.
3m-Isaacs Kidd Mid-water trawl (mid-water nets)	Quantitative samples of pelagic ichthyoplankton, those most susceptible to entrainment, are taken by this type of gear.	Large net mouth provides large sample volume. Recommended especially for use in large sample volume.
Benthic sleds (low speed nets)	Quantitative sampling of epibenthic ichthyoplankton is strongly recommended when intake structures draw all or part of cooling waters from lower water column.	An underutilized gear that should be part of most near field sampling programs. Provides superior quantitative samples at depth.
High speed nets	Large larvae in large water bodies can sometimes be sampled more efficiently with high speed gear.	Recommended for use in large rivers, lakes, and estuaries. More expensive than other gear above.

Table 5. (concluded)

Recommended Gear	Utilization	Discussion
High volume, centrifugal pumps	Can frequently be used in areas inaccessible to nets or where clogging organisms present a problem.	Recommended for use in situations where gear listed above would not be suitable. Most expensive gear.
B. Intake/Discharge Sampling Gear		
Fixed meter nets	Usually fished at surface, mid-depth, and bottom simultaneously. Attached to a rigid frame.	Turbulence and water velocity in discharge canal makes it difficult to use fixed position nets.
High volume centrifugal pumps	Must have sufficient volume to equal rate of flow past the pump oriface. Use of an expansion cone at the oriface may reduce hydrostatic escape cues picked up by larger larvae.	Pumps may not be as susceptible as nets to influences of turbulence.

1. Ichthyoplankton sampling gear selection must be critically reviewed as an important element of the total sampling program design. Several types of gear should be considered and comparatively evaluated under site specific conditions. While this recommendation may seem obvious, the temptation to use inadequate gear already available rather than purchase an additional piece of expensive equipment is often too much to resist. Less than 25% of the ichthyoplankton sampling programs reviewed during this investigation reported any preliminary field evaluation/comparison of gear.

2. Sampling gear purchase or fabrication costs are only a small fraction of the total sampling budget, yet it is usually the first target in a move to economize. Ichthyoplankton sampling gear costs and accuracy are not directly proportional, but they are related. Maximum benefit is achieved when an accurate sample is obtained at the lowest possible cost. Selection of a low cost, but inaccurate or inappropriate sampler is false economy considering associated vessel, labor and analysis costs.

3. Some standardization of mesh size such as 202, 333 and 505 mm mesh used with Bongo nets is highly recommended. Use of square rather than rectangular meshes is recommended. Compatibility of data sets would be greatly increased if selected standard square mesh sizes were used for entrainment sampling.

4. Prediction and detection of entrainment related impact has been obscured by incompatibility of data from different sampling gear. The importance of a continuous historical record of population dynamics cannot be over emphasized. Changing sampling gear in programs lasting only a few spawning seasons is not recommended. Changing gear in long term studies should be avoided even though there are errors. If changes in gear are made, comparative sampling must be conducted to assure adequate measurement of biological and environmental extremes.

REFERENCES

Ahlstrom, E. H. 1954. Distribution and abundance of egg and larval populations of the Pacific sardine. Fish. Bull. 56:83-140.

Ahlstrom, E. H. 1959. Vertical distribution of pelagic fish eggs and larvae off southern California and Baja California. Fish. Bull. 60:106-146.

Ahlstrom, E. H. 1968. What might be gained from an oceanwide survey of fish eggs and larvae in various seasons. Calif. Coop. Oceanic Fish. Investigation, Report No. 12. pp. 64-67.

Ahlstrom, E. H., J. D. Isaacs, J. R. Thraikill, and L. W. Kidd. 1958. High-speed plankton sampler. Fish. Bull. 58:187-214.

Ahlstrom, E. H., and H. G. Moser. 1976. Eggs and larvae of fishes and their role in systematic investigations and in fisheries. Presented at the 2è Congres Europeen des Ichthyologistes. Paris. Sept., 1976. 37 pp.

Ali Khan, J., and G. Hemple. 1974. Relation of fish larvae and zooplankton biomass in the Gulf of Aden. Mar. Biol. 28:311-316.

Allen, G. H., A. C. Delacy, and D. W. Gotshall. 1959. Quantitative sampling of marine fishes-a problem in fish behavior and fishing gear, pp. 448-509. *In* E. A. Pearson (ed.), Proceedings of the First International Conference on Waste Disposal in the Marine Environment. Univ. of California, Berkeley. Pergamon Press, New York.

Amundrud, J. R., D. J. Faber, and A. Keast. 1974. Seasonal succession of free-swimming perciform larvae in Lake Opinicon, Ontario. J. Fish. Res. Bd. Canada 31:1661-1665.

Anonymous. 1976. Hudson River Ecosystem Studies. Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Addenda to: The 1973 Report. I. An analysis of the abundance of four life history stages of striped bass (*Morone saxatilis*) collected in the intakes and discharge canal of Indian Point Unit 1, and in the Hudson River at Indian Point. II. Larval striped bass (*Morone saxatilis*) length frequency analysis. Institute of Environmental Medicine, New York University Medical Center, New York. 57 pp.

Arnold, E. L., Jr. 1959. The Gulf V plankton sampler. Galveston Biological Laboratory Fishery Research for the Year Ending June 30, 1959. U.S. Fish and Wildl. Serv. Circ. No. 62. pp. 111-113.

Aron, W. 1958. The use of a large capacity portable pump for plankton patchiness. J. Mar. Res. 16(2):158-173.

Aron, W. 1962. Some aspects of sampling the macro-plankton. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 153:29-38.

Aron, W., E. H. Ahlstrom, B. M. Bary, A. W. H. Be, and W. D. Clarke. 1965. Towing characteristics of plankton sampling gear. Limnol. Oceanogr. 10(3):333-340.

Aron, W., and S. Collard. 1969. A study of the influence of net speed on catch. Limnol. Oceanogr. 14(2):242-249.

Aron, W., N. Raxter, R. Noel, and W. Andrews. 1964. A description of a discrete depth plankton sampler with some notes on towing behavior of a 6 foot Isaacs-Kidd midwater trawl and a 1 meter ring net. Limnol. Oceanogr. 9:324-333.

Asami, T. 1958. On the condition of dispersal and clustering of fish eggs and larvae in the sea. II. (In Japanese, English summary). Rep. Nakai Reg. Fish. Res. Lab. 9:92-102.

Bagenal, T. B. 1974. A buoyant net designed to catch freshwater fish larvae quantitatively. Freshwater Biol. 4(2):107-109.

Bagenal, T. B., and E. Braum. 1971. Eggs and early life history, pp. 167-198. In W. E. Ricker (ed.), Methods for Assessment of Fish Production in Fresh Waters. IBP Handbook No. 3, 2nd ed. Blackwell Science, Oxford.

Baker, P. H. 1966. Nets, pp. 95-110. In A. Calhoun (ed.), Inland Fisheries Management. Calif. Dept. Fish and Game, Sacramento.

Bakker, C., and N. DePauw. 1975. Comparison of plankton assemblages of identical salinity ranges in estuarine tidal, and stagnant environments. II. Zooplankton. Neth. J. Sea Res. 9(2):145-165.

Baldwin, W. J. 1973. Results of tests to investigate the suitability of fish pumps for moving live baitfishes. Prog. Fish-Cult. 35(1):39-43.

Barkley, R. A. 1964. The theoretical effectiveness of towed net samplers as related to sampler size and to swimming speed of organisms. J. Cons. perm. int. Explor. Mer 29(2):146-156.

Barkley, R. A. 1972. Selectivity of towed net-samplers. Fish. Bull. 70(3):799-820.

Barnes, H. 1949. On the volume measurement of water filtered by a plankton pump, with some observations on the distribution of planktonic animals. J. Mar. Biol. Assoc. U.K. 28:651-662.

Barnes, H. 1949. A statistical study of the variation in vertical plankton hauls with special reference to the loss of the catch with divided hauls. J. Mar. Biol. Assoc. U.K. 28:429-446.

Barnes, H., and S. M. Marshall. 1951. On the variability of replicate plankton samples and some application of contagious series to the statistical distribution of catches over restricted periods. J. Mar. Biol. Assoc. U.K. 30:233-263.

Bary, B. M., J. G. DeStefano, M. Forsyth, and J. Von den Kerkhof. 1958. A closing high speed plankton catcher for use in vertical and horizontal towing. Pacif. Sci. 12:46-59.

Be, A. W. H. 1962. Quantitative multiple opening-and-closing plankton samplers. Deep-Sea Res. 9:144-151.

Beers, J. R., G. L. Stewart, and J. D. H. Strickland. 1967. A pumping system for sampling small plankton. J. Fish. Res. Bd. Canada 24(8):1811-1819.

Bernhard, M., F. Möller, A. Nassogne, and A. Zattera. 1973. Influence of pore size of plankton nets and towing speed on the sampling performance of two high speed samplers (Delfino I and II) and its consequences for the assessment of plankton populations. Mar. Biol. 20(2):109-136.

Berval'd, E. A., and G. K. Barashkov. 1970. Power engineering and present day problems of fisheries management in impoundments. J. Ichthyol. 10(2):177-183.

Beverton, R. J. H., and D. S. Tungate. 1967. A multipurpose plankton sampler. J. Cons. perm. int. Explor. Mer 31:145-157.

Bishai, H. M. 1960. The effect of water currents on the survival and distribution of fish larvae. J. Cons. perm. int. Explor. Mer 25:134-136.

Bjørke, H., O. Dragesund, and Ø. Ulltang. 1974. Efficiency test on four high-speed plankton samplers, pp. 182-199. <u>In</u> J. H. S. Blaxter (ed.), The Early Life History of Fish. Springer-Verlag, New York.

Bongers, L. H., T. T. Polgar, A. J. Lippson, G. M. Krainak, L. R. Moran, A. F. Holland, and W. A. Richkus. 1975. The Impact of the Morgantown Power Plant on the Potomac Estuary: An Interpretive Summary of the 1972-1973 Investigations. PPSP-MP-15, Martin Marietta Corp., Baltimore.

Breder, C. M., Jr. 1960. Design for a fry trap. Zoologica 45:155-159.

Bridger, J. P. 1956. On day and night variation in catches of fish larvae. J. Cons. perm. int. Explor. Mer 22(1):42-67.

Bridger, J. P. 1958. On efficiency tests made with a modified Gulf III high-speed tow-net. J. Cons. perm. int. Explor. Mer 23(3):357-365.

Burd, A. C., and W. G. Parnell. 1973. The relationship between larval abundance and stock in the North Sea herring. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 164:30-36.

Burns, J. W. 1966. How big a sample, pp. 161-162. *In* A. Calhoun (ed.), Inland Fisheries Management. Calif. Dept. Fish and Game, Sacramento.

Cada, G. F. and G. L. Hergenrader. 1978. An assessment of sampling mortality of larval fishes. Tran. Am. Fish. Soc. 107(2):269-274.

Carlson, F. T., and J. A. McCann. 1969. Hudson River Fisheries Investigations (1965-1968) Rept. to Consolidated Edison Co. New York, by the Hudson River Policy Committee. 80 pp.

Cassie, R. M. 1963. Microdistribution of plankton. Oceanogr. Mar. Biol. Annual Rev. 1:223-252.

Cassie, R. M. 1968. Sample design, pp. 105-121. *In* D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Cassie, R. M. 1971. Sampling and statistics, pp. 174-209. *In* W. T. Edmonson, and G. G. Winberg (eds.), A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters. IBP Handbook No. 17. Blackwell Science Pub., Oxford.

Chadwick, H. K. 1974. Entrainment and thermal effects on a mysid shrimp and striped bass in the Sacramento-San Joaquin Delta, pp. 23-30. *In* L. D. Jensen (ed.), Entrainment and Intake Screening. Rept. No. 15. Electric Power Research Institute, Palo Alto, CA.

Clark, J., and W. Brownwell. 1973. Electric Power Plants in the Coastal Zone. Environmental Issues. Amer. Littoral Soc. Spec. Pub. No. 7, 80 pp.

Clarke, G. L., and D. F. Bumpus. 1939. Brief account of a plankton sampler. Int. Revue. Ges. Hydrobiol. Hydrogr. 39:190-192.

Clarke, G. L., and D. F. Bumpus. 1950. The Plankton Sampler - an Instrument for Quantitative Plankton Investigations. Amer. Soc. Limnol. Oceanogr. Spec. Pub. No. 5, 8 pp.

Clarke, W. D. 1964. The Jet Net, a new high speed plankton sampler. J. Mar. Res. 22:284-287.

Clutter, R. I., and M. Anraku. 1968. Avoidance of samplers, pp. 57-76. In D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Cole, R. A. 1977. Entrainment at a Once-through Cooling System on Western Lake Erie. U.S. Environmental Protection Agency, Ecological Series. (In Press.) 165 pp.

Colton, J. B. 1965. The distribution and behavior of pelagic and early demersal stages of haddock in relation to sampling techniques. Nat'l. Mar. Fish. Serv. Northwest Atlantic Fisheries Center Spec. Publ. No. 6. pp. 317-333.

Colton, J. B., K. A. Honey, and R. F. Temple. 1961. The effectiveness of sampling methods used to study the distribution of larval herring in the Gulf of Maine. J. Cons. perm. int. Explor. Mer 26:180-190.

Consolidated Edison Co. of New York, Inc. 1975. Final Environmental Statement Related to Operation of Indian Point Nuclear Generating Plant Unit No. 3. Vol. 1, Docket No. 50-286. NUREG-75-002. pp. V-185-V-274.

Conway, J. B., F. R. Schiebe, T. A. Olson, and T. O. Odlaug. 1971. A Practical Evaluation of the Clarke-Bumpus Plankton Sampler and Suggestions for its Use. Univ. of Minnesota, School of Public Health. Res. Rept. No. 1. 28 pp.

Copeland, B. J., and J. M. Miller, W. Watson, R. Hodson, W. S. Birkhead, and J. Schneider. 1977. Meroplankton: problems of sampling and analysis of entrainment, pp. 119-137. In L. D. Jensen (ed.), Third National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Melville, NY.

Counts, R. C. 1961. A device for measuring larval and juvenile fishes.Copeia (2):224-226.

Croce, N. D., and A. Chiarabini. 1971. A suction pipe for sampling mid-water and bottom organisms in the sea. Deep-Sea Res. 18:851-854.

Currie, R. I., and P. Foxton. 1957. A new quantitative plankton net. J. Mar. Biol. Assoc. U.K. 36(1):17-32.

Cushing, D. H. 1962. Patchiness. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 153:152-163.

David, P. M. 1965. The Neuston Net: A device for sampling the surface fauna of the ocean. J. Mar. Biol. Assoc. U.K. 45:313-320.

Davies, R. M., and L. D. Jensen. 1974. Entrainment of zooplankton at three mid-Atlantic power plants, pp. 131-155. *In* L. D. Jensen (ed.), Entrainment and Intake Screening. Rept. No. 15. Electric Power Research Institute, Palo Alto, CA.

DeLury, D. B. 1947. On the estimation of biological populations. Biometrics 3:145-167.

Dicenta, A., Y. Albert, and C. Piccenette. 1976. Nets for ichthyoplankton. Second series of comparative tests. Bol. Inst. Esp. Oceanogr. 212:1-27.

Dovel, W. L. 1964. An approach to sampling estuarine macroplankton. Chesapeake Sci. 5(1-2):77-90.

Dovel, W. L. 1971. Fish Eggs and Larvae of the Upper Chesapeake Bay. Natural Resources Inst., Univ. of Maryland, Spec. Rept. No. 4, Contr. No. 460. 71 pp.

Dragesund, O. 1971. Factors influencing year-class strength of Norwegian spring-spawning herring (*Clupea harengus* Linne). Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 160:74-75.

Ecological Analysts, Inc. July, 1976. Bowline Point Generating Station Entrainment Survival and Abundance Studies. 1975 Annual Interpretive Rept. Vol. 1. pp. 3-1-3-27. Melville, NY.

Ecological Analysts, Inc. June, 1977. A Review of Entrainment Study Methodologies: Abundance and Survival. Melville, NY. 58 pp.

Edsall, T. A. 1976. Electric power generation and its influence on Great Lakes fish, pp. 453-462. *In* Proceedings of the Second Federal Conference on the Great Lakes. Argonne Nat'l. Lab., Argonne, IL.

Edsall, T. A., and T. G. Yocom. 1972. Review of recent technical information concerning the adverse effects of once-through cooling on Lake Michigan. Presented at Lake Michigan Enforcement Conference. Sept. 19-21, 1972. Chicago. 86 pp.

Elder, J., J. Icanberry, D. Smith, D. Henriet, and C. Steitz. 1976. Assessment of a large capacity fish pump for sampling ichthyoplankton for power plant entrainment studies. Presented at the Calif. Coop. Oceanic Fish. Investigation Proceedings, July, 1976.

Elliot, J. M. 1971. Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates. Freshwater Biol. Assoc. Scient. Publ. No. 25. 144 pp.

English, T. S. 1963. A theoretical model for estimating the abundance of planktonic fish eggs. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 155:174-181.

Ennis, G. P. 1972. A diver operated plankton collector. J. Fish. Res. Bd. Canada 29:341-343.

Eschmayer, P. H. 1954. The reproduction of lake trout in southern Lake Superior.. Trans. Am. Fish. Soc. 84:47-74.

Faber, D. J. 1967. Limnetic larval fish in northern Wisconsin lakes. J. Fish. Res. Bd. Canada 24(5):927-937.

Faber, D. J. 1968. A net for catching limnetic fry. Trans. Amer. Fish. Soc. 97(1):61-68.

Ferrari, I., and O. Rossi. 1972. Lacustrine zooplankton catching efficiency of two nets with different mouth diameters. Arch. Oceanogr. Limnol. 17(3):275-286.

Fleminger, A., and R. I. Clutter. 1965. Avoidance of towed nets by zooplankton. Limnol. Oceanogr. 10:96-104.

Fordyce, C. 1898. A new plankton pump. Proc. Neb. hist. Soc. 2: 293-296.

Forney, J. L. 1975. Abundance of larval walleyes (Stizostedion vitreum) estimated from the catch in high speed nets, pp. 581-588. In R. L. Welcome (ed.), Symposium of the Methodology for the Survey, Monitoring, and Appraisal of Fishery Resources in Lakes and Large Rivers. Vol. II. FAO, Rome.

Fraser, J. H. 1966. Zooplankton sampling. Nature 211(5052):915-916.

Fraser, J. H. 1968. The history of plankton sampling, pp. 11-18. *In* D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Friedl, W. A. 1971. The relative sampling performance of 6- and 10-foot Isaacs-Kidd midwater trawls. Fish. Bull. 69:427-432.

Gale, W. F. 1975. A quick opening bucket for plankton and larval fish nets. Prog. Fish-Cult. 37(3):164.

Gale, W. F. and H. W. Mahr, Jr. 1978. Larval fish drift in a large river with a comparison of sampling methods. Trans. Am. Fish. Soc. 107(1):46-55.

Gehringer, J. W. 1952. An all metal plankton sampler (model Gulf III). U.S. Fish Wildl. Serv. Spec. Scient. Rept. Fisheries No. 88. pp. 7-12.

Gehringer, J. W., and W. Aron. 1968. Field techniques, pp. 87-104. *In* D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Gibbons, S. G., and J. H. Fraser. 1937. The centrifugal pump and suction hose as a method of collecting plankton samples. J. Cons. perm. int. Explor. Mer 12:155-170.

Gjøsaeter, J., and R. Saetre. 1974. The use of data on eggs and larvae for estimating spawning stock of fish populations with demersal eggs, pp. 139-149. *In* J. H. S. Blaxter (ed.), The Early Life History of Fish. Springer-Verlag, New York.

Glover, R. S. 1953. The Hardy plankton indicator and sampler: a description of the various models in use. Bull. Mar. Ecol. 4:7-20.

Goodyear, C. P. 1977. Assessing the impact of power plant mortality on the compensatory reserve of fish populations with demersal eggs, pp. 139-149. *In* J. H. Blaxter (ed.), Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Pergamon Press, New York.

Graham, J. J. 1966. A new depressor design. Limnol. Oceanogr. 11(1):130-135.

Graham, J. J., and P. M. W. Venno. 1968. Sampling larval herring from tidewaters with buoyed and anchored nets. J. Fish. Res. Bd. Canada 25(6):1169-1179.

Greze, V. N., E. P. Balandina, O. K. Bileva, and N. P. Makarova. 1957. Efficiency of plankton sampling equipment and estimation of the actual abundance of components of a pelagic biocenosis. Hydrobiol. J. 11(4):91-94.

Gulland, J. A. 1964. Manual of Methods of Fish Population Analysis. FAO Fisheries Tech. Paper No. 40. Rome. 62 pp.

Hardy, A. C. 1936. The continuous plankton recorder. Discovery Rept. No. 11. pp. 457-510.

Hardy, A. C. 1939. Ecological investigations with the continuous plankton recorder: object, plan, and methods. Hull. Bull. Mar. Ecol. 1(1):1-57.

Hardy, A. C., and R. Bainbridge. 1954. Experimental observations on the vertical migration of plankton animals. J. Mar. Biol. Assoc. U.K. 33:409-448.

Harvey, H. W. 1934. Measurement of phyto-plankton population. J. Mar. Biol. Assoc. U.K. 19:761-773.

Haury, L. R. 1973. Sampling bias of a Longhurst-Hardy plankton recorder. Limnol. Oceanogr. 18(3):500-506.

Haury, L. R., P. H. Wiebe, and S. H. Boyd. 1976. Longhurst-Hardy plankton recorders: their design and use to minimize bias. Deep-Sea Res. 23:1217-1229.

Heinle, D. R. 1976. Phytoplankton and zooplankton collection problems and relevance of entrainment to the ecosystem, pp. 101-117. In L. D. Jensen (ed.), Third National Workshop on Entrainment and Impingement. Ecological Analysts, Inc. Melville, NY.

Hemple, G. (ed.). 1973. Fish Egg and Larval Surveys. (contributions to a manual.) FAO Fisheries Tech. Paper No. 122. Rome. 82 pp.

Hemple, S., and G. Hempel. 1971. An estimate of mortality in eggs of North Sea herring (*Clupea harengus* L.). Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 160:24-26.

Henson, V. 1887. Uber die Bestimmung des Plankton. V. Ber. der Komm. zur Wiss. Untersuch. der Deut. Meere XII B. XVI.

Henson, V. 1901. Über die quantitative Bestimmung der Kleineren Plankton Organismen und über den Diagonalzug mittelst geeigneter Netzformen. Wiss. Meeresunters, Kiel, 5(2):69-81.

Hensen, V., and C. Apstein. 1897. Die Nordsee Expedition 1895 des Deutschen Seefischerei-Vereing uber die Eimenge der ins Winter laichended Fische. Wiss. Meeresunters., Kiel. 2(2):1-101.

Herke, W. 1969. A boat-mounted surface push-trawl for sampling juveniles in tidal marshes. Prog. Fish-Cult. 31:177-179.

Heron, A. C. 1968. Plankton gauze, pp. 19-25. In D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 20:1-228.

Hoagman, W. J. 1977. A freefalling drop net for quantitatively sampling a water column. Trans. Am. Fish. Soc. 106(2):140-145.

Hopkins, T. L. 1963. The variation in the catch of plankton nets in a system of estuaries. J. Mar. Res. 21:39-47.

Houde, E. D. 1969. Distribution of larval walleyes and yellow perch in a bay of Oneida Lake, and its relation to water currents and zooplankton. N.Y. Fish Game J. 16(2):184-205.

Houde, E. D., and J. L. Forney. 1970. Effects of water currents on distribution of walleye larvae in Oneida Lake, New York. J. Fish. Res. Bd. Canada 27:445-456.

Icanberry, J. W., and J. R. Adams. 1974. Zooplankton survival in cooling water systems of four thermal power plants on the California coast-interim report, March 1971-January 1972, pp. 13-22. In L. D. Jensen (ed.), Entrainment and Intake Screening, Rept. No. 15. Electric Power Research Institute, Palo Alto, CA.

Icanberry, J. W., and R. W. Richardson. 1973. Quantitative sampling of live zooplankton with a filter-pump system. Limnol. Oceanogr. 18:333-335.

Icanberry, J. W. and J. W. Warrick. 1978. Seasonal larval fish abundance in waters off Diablo Canyon, California. Trans. Am. Fish. Soc. 107(2):225-233.

Ida, H. 1972. Variability in the number of fish taken by larva nets. Bull. Jap. Soc. Scient. Fish. 38(9):965-980.

Isaacs, J. D. 1964. Night-caught and day-caught larvae of the California sardines. Science 144(3622):1132-1133.

Isaacs, J. D., and L. W. Kidd. 1953. Isaacs-Kidd Mid-water Trawl. Final Report. Scripps. Inst. Oceangr. Equip. Rept. No. 1. 53-3:1-18.

Jacobs, J. 1968. Animal behavior and water movement as co-determinants of plankton distribution in a tidal system. Sarsia 34:355-370.

Jensen, L. D. (ed.). 1974. Proceedings of the Second Workshop on Entrainment and Intake Screening. Rept. No. 15. Electric Power Research Institute, Palo Alto, CA. 347 pp.

John, H.-Chr. 1976. Beschreibung eines Zweistufen-Neuston sammlers nach dem Prinzip von Dsmeoto und Jaroszynski. Ber. dt. wiss. Komm. Meeresforsch. 24:342-344.

Jones, F. R. H. 1958. Reactions of fish to stimuli. Proc. Indo-Pacific Fish. Council. (111):18-28.

Jossi, J. W. 1970. Annotated Bibliography of Zooplankton Sampling Devices. U.S. Fish Wildl. Serv. Spec. Scient. Rept., Fisheries No. 609. XFWS-A 609. 90 pp.

Jude, David J. 1977. Entrainment of fish larvae and eggs on the Great Lakes, with special reference to the D. C. Cook Nuclear Plant, Southeastern Lake Michigan, pp. 177-201. In L. D. Jensen (ed.), Third National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Melville, NY.

Kernehan, R. J. 1973. A Selected Bibliography on Fish Eggs, Fish Larvae, and Zooplankton Sampling Methods. Bull. No. I(2). Ichthyological Assoc., Inc. Ithica, NY. 9 pp.

Kernehan, R. J. 1974. A Selected Bibliography on Fish Eggs, Fish Larvae, and Ichthyoplankton Sampling Methods. Bull. No. II(3). Ichthyological Assoc., Inc. Ithica, NY. 12 pp.

Kernehan, R. J. 1976. A bibliography of Early Life History Stages of Fishes. Bull. No. 14. Ichthyological Assoc., Inc. Ithica, NY. 190 pp.

Kernehan, R. J., and S. I. Tyler. 1974. A Selected Bibliography on Fish Eggs, Fish Larvae, and Ichthyoplankton Sampling Methods. Bull. No. II(1). Ichthyological Assoc., Inc. Ithica, NY. 7 pp.

Kerr, J. R. 1953. Studies on fish preservation of Contra Costa Steam Plant of the Pacific Gas and Electric Company. Calif. Dept. Fish and Game, Fish. Bull. 92. 66 pp.

Ketchum, B. H. 1954. Relationship between circulation and planktonic populations in estuaries. Ecology 35:191-200.

King, D. P. F., and A. A. Robertson. 1973. Variability in bongo net catches of pilched eggs/zooplankton. Presented at the South Africa Dept. Ind. Sea Fish. Branch Symposium, Capetown. August 6-10, 1973. 35 pp.

Kjelson, M. A., and D. R. Colby. 1976. The evaluation of bias in the estimation of abundance of estuarine fish populations. Nat'l. Mar. Fish. Serv. Atlantic Estuarine Fisheries Center Annual Rept. to Energy Research Development Adm. pp. 342-355.

Kjelson, M. A., and G. N. Johnson. 1973. Description and evaluation of a portable drop-net for sampling nekton populations, pp. 653-662. In Proc. 27th Annual Conf. of Southeastern Assoc. of Game and Fish Comm.

Kjelson, M. A., G. N. Johnson, R. L. Garner, and J. P. Johnson. 1976. The horizontal-vertical distribution and sample variability of ichthyoplankton populations within the nearshore and offshore ecosystems of Onslow Bay. Nat'l. Mar. Fish. Serv. Atlantic Estuarine Fisheries Center Annual Rept. to Energy Research Development Adm. pp. 287-341.

Kjelson, M. A., W. R. Tarner, and G. N. Johnson. 1975. Description of a stationary drop-net for estimating nekton abundance in shallow waters. Trans. Amer. Fish. Soc. 104(1):46-49.

Knight-Jones, E. W., and S. Z. Qasim. 1955. Responses of some marine plankton animals to changes in hydrostatic pressure. Nature 175: 941-942.

Kofoid, C. A. 1897. On some important sources of error in the plankton method. Science/N.Y.) 6(153):829-832.

Kormilov, S. V., and V. P. Vgashkova. 1976. Statistical distribution of the results of treatment of river plankton samples. Zool. Zh. 55(4):600-601.

Kushlan, J. A. 1974. Quantitative sampling of fish populations in shallow freshwater environments. Trans. Am. Fish. Soc. 103(2): 348-352.

Kushnarenko, A. I. 1975. The behavior of juvenile fish around the webbing of a fingerling trawl and in the operational zone of the trawl. J. Ichthyol. 15(5):782-790.

Langeland, A., and S. Rognerud. 1974. Statistical analyses used in the comparison of three methods of freshwater zooplankton sampling. Arch. Hydrobiol. 73(3):403-410.

Lasker, R. (chairman). 1975. Comparison of the Collecting Properties of the MARMAP Open Bongo and the CalCOFI Standard Net with Similar Mesh Design on Three Stations: Winter, 1975, in the California Current. A Preliminary Report Prepared by *Ad Hoc* Committee, on Bongo-CalCOFI Net Comparisons. Nat'l. Mar. Fish. Serv. Southwest Fisheries Center Administration Rept. No. LJ-75-57. 8 pp.

Lauer, G. J., W. T. Waller, D. W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarick, P. Bibko, and P. C. Storm. 1974. Entrainment studies on Hudson River Organisms, pp. 37-82. *In* L. D. Jensen (ed.), Entrainment and Intake Screening. Rept. No. 15. Electric Power Research Institute, Palo Alto, CA.

Lawson, T. J., and G. D. Grice. 1977. Zooplankton sampling variability: controlled ecosystem pollution experiment. Bull. of Mar. Sci. 27(1):80-84.

Lenarz, W. H. 1972. Mesh retention of larvae of *Sardinops caerulea* and *Engraulis mordax* by plankton nets. Fish. Bull. 70(3):839-848.

Lenarz, W. H. 1973. Dependence of catch rates on size of fish larvae. Rapp. P.-v. Rêun. Cons. perm. int. Explor. Mer 164:270-275.

Lenz, J. 1972. A new type of plankton pump on the vacuum principle. Deep-Sea Res. 19:453-459.

Leong, R. 1967. Evaluation of a Pump and Reeled Hose System for Studying the Vertical Distribution of Small Plankton. U.S. Fish Wildl. Serv. Spec. Scient. Rept. Fisheries No. 545. 9 pp.

Lewis, R. M., W. F. Hettler, Jr., E. P. H. Wilkikens, and G. N. Johnson. 1970. A channel net for catching larval fishes. Chesapeake Sci. 11(3):196-197.

Linger, F. I. 1960. An Historical Survey of Macroplankton Sampling Gear. Dept. Oceanography, Univ. of Wash. (Unpublished manuscript).

Long, C. W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. Fish. Bull. 66(3): 599-609.

Longhurst, A. R., A. D. Reith, R. E. Bower, and D. L. R. Seibert. 1966. A new system for the collection of multiple serial plankton samples. Deep-Sea Res. 13:213-222.

Longhurst, A. R., and R. Williams. 1976. Improved filtration systems for multiple-serial plankton samplers and their deployment. Deep-Sea Res. 23:1067-1073.

Mahnken, C. V. W., and J. W. Jossi. 1967. Flume experiments on the hydrodynamics of plankton nets. J. Cons. perm. int. Explor. Mer 31(1):38-45.

Manz, J. V. 1964. A pumping device used to collect walleye eggs from offshore spawning areas in western Lake Erie. Trans. Am. Fish. Soc. 93(2):204-206.

Marcy, B. C., Jr. 1971. Survival of young fish in the discharge canal of a nuclear power plant. J. Fish. Res. Bd. Canada 28: 1057-1060.

Marcy, B. C., Jr. 1974. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant, pp 281-288. In L. D. Jensen (ed.), Entrainment and Intake Screening. Rept. No. 15. Electric Power Research Institute, Palo Alto, CA.

Marcy, B. C., Jr. 1975. Entrainment of organisms at power plants, with emphasis on fishes - an overview, pp. 89-106. In S. B. Saila (ed.), Fisheries and Energy Production. D. C. Heath, Lexington, MA.

Marcy, B. C., Jr. 1976. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant, pp. 141-168. In D. Merriman and L. M. Thorpe (eds.), The Connecticut River Ecological Study, The Impact of a Nuclear Power Plant. American Fishery Society, Washington, D.C.

Marcy, B. C., Jr. 1976. Planktonic fish eggs and larvae of the lower Connecticut River and the effects of the Connecticut Yankee Plant, including entrainment, pp. 115-139. In D. Merriman and L. M. Thorpe (eds.), The Connecticut River Ecological Study, The Impact of a Nuclear Power Plant. American Fishery Society, Washington, D.C.

Marine Research, Inc. December, 1974. Rome Point Investigations: Narragansett Bay Ichthyoplankton Survey: Final Report. pp. 47-49. (Unpublished manuscript).

Marine Research, Inc. October, 1975. Entrainment Investigations and Cape Cod Bay Ichthyoplankton Study: June-August, 1975. p. 45. (Unpublished manuscript).

Markowski, S. 1959. The cooling water of power stations: a new factor in the entrainment of marine and freshwater invertebrates. J. Anim. Ecol. 28:243-258.

Markowski, S. 1962. Faunistic and ecological investigations in Cavendish Dock, Barrow-in-Furness. J. Anim. Ecol. 31(1):43-45.

Maryland Power Plant Siting Program. 1975. Descriptions of Aquatic Monitoring Programs at the Calvert Cliffs Nuclear Power Plant. 16 pp. + append.

Matoda, S. 1976. Devices of simple plankton apparatus. J. Fac. Mar. Sci. Technicol. Tokai Univ. 9:93-102.

Matsuo, Y., T. Nemato, and R. Maruno. 1976. A convertible neuston net for zooplankton. Bull. Plankton Soc. of Japan 23(1):26-30.

McGowan, J. A., and D. M. Brown. 1966. A New Opening-closing, Paired Zoo-Plankton Net. Scripps Inst. of Oceanography Ref. No. 66-23. 53 pp.

McGowan, J. A., and V. J. Fraundorf. 1966. The relation between size of net used and estimates of zooplankton diversity. Limnol. Oceanogr. 11(4):456-469.

McGroddy, P. M., and R. L. Wyman. 1977. Efficiency of nets and a new device for sampling living fish larvae. J. Fish. Res. Bd. Canada 34(4):571-574.

Merriman, D., and L. M. Thorpe. 1976. The Connecticut River Ecological Study: The Impact of a Nuclear Power Plant. Am. Fish. Soc. Monograph No. 1. 252 pp.

Mihursky, J. A., et al. 1972. Ecological Effects of Nuclear Steam Electric Station Operations on Estuarine systems. Progress Report to U.S. A. E. C., Contract No. AT-(30-1)-4253. 100 pp.

Mihursky, J. A., et al. 1976. Final Report on Potomac Estuary Fisheries Study: Ichthyoplankton and Juvenile Investigations. Univ. of Maryland, Chesapeake Biological Lab. No. 76-12. 241 pp.

Miller, D. 1961. A modification of the small Hardy plankton sampler for simultaneous high-speed plankton hauls. Bull. Mar. Ecol. 5(45):165-172.

Morgan, R. P., II, R. E. Ulanowicz, V. J. Rasin, Jr., L. A. Noe, and G. B. Gray. 1973. Effects of Water Movement on Eggs and Larvae of Striped Bass and White Perch. Univ. of Maryland, Chesapeake Biological Lab. No. 73-111. 28 pp.

Murphy, G. I., and R. I. Clutter. 1972. Sampling anchovy larvae with a plankton purse seine. Fish. Bull. 70(3):789-798.

Nansen, F. 1915. Closing-nets for vertical hauls and for horizontal towing. J. Cons. perm. int. Explor. Mer 67:1-8.

National Marine Fisheries Service. September 9, 1971. Analysis of results of trials with bongo nets at different speeds. Nat'l. Mar. Fish. Serv. Tropical Atlantic Biological Lab. (Memo to: R. K. Sherman).

National Marine Fisheries Service. November, 1971. Recent Accomplishments in Coastal Ichthyoplankton Studies. Nat'l. Mar. Fish. Serv. Mid-Atlantic Coastal Fisheries Center. 3 pp. (Mimeo).

National Marine Fisheries Service. October, 1972. Preliminary Results: Bongo Sampler Tests on Avoidance and Extrusion. Nat'l. Mar. Fish. Serv. Northeast Fisheries Center, Narragansett Lab., Narragansett, RI.

National Marine Fisheries Service. July, 1972. Bongo Net Extrusion Tests. Tech. Rept. No. 1. 3 pp.

Nellen, W., and G. Hempel. 1969. Vesuche zur fangigkeit des "Hai" und des modifizierten Gulf V plankton samplers "Nackthai." Ber. dt. Wiss. Komm. Merresforsch. 20(2):141-154.

Nellen, W., and D. Schnack. 1975. Sampling problems and methods of fish eggs and larvae investigations with special reference to inland waters, pp. 538-551. _In_ R. L. Welcome (ed.), Methodology for the Survey, Monitoring, and Appraisal of Fishery Resources in Lakes and large rivers.

Nelson, W. R., R. E. Siefert, and D. V. Swedberg. 1968. Studies of the early life histories of reservoir fishes. Presented at the Reservoir Fishery Resources Symposium, April 5-7, 1967. Athens, GA.

Netsch, N. F., A. Houser, and L. E. Vogele. 1971. Sampling gear for larval reservoir fishes. Prog. Fish-Cult. 33(3):175-179.

New York University Medical Center Laboratory for Environmental Studies. 1976. Mortality of Striped Bass Eggs and Larvae in Nets. Spec. Rept. to Consolidated Edison Co. of New York, Inc. 21 pp.

Noble, R. L. 1970. Evaluation of the Miller high-speed sampler for yellow perch and walleye fry. J. Fish. Res. Bd. Canada 27(6): 1033-1045.

Noble, R. L. 1971. An evaluation of the meter net for sampling fry of the yellow perch, _Perca flavescens_, and walleye, _Stizostedion v. vitreum_. Chesapeake Sci. 12(1):47-48.

O'Connor, J. M., and S. A. Schaffer. 1976. The Effects of Sampling Gear on the Survival of Striped Bass Ichthyoplankton. A. J. Lanza Research Lab., New York University Medical Center. Tuxedo, NY. 17 pp.

Olson, T. A., T. O. Odlaug, and W. R. Swain. 1966. The Continuous Plankton Recorder: A Review of the Literature. Water Resources Research Center, Univ. of Minnesota. Bull. No. 3. 221 pp.

Oray, S. K. 1968. Unlersuchungen uber das Laichen der Scholle (Pleuronectes platessa L.) in der sudoslliche Nordsee. Ber. dt. Wiss. Komm. Meeresforsch 19:194-225.

Pacheco, A. L., ed. 1973. Proceedings of a Workshop on Egg, Larval, and Juvenile Stages of Fish in Atlantic Coast Estuaries. Nat'l. Mar. Fish. Serv. Mid-Atlantic Coastal Fisheries Center. Tech. Publ. No. 1.

Pearcey, W. G. (ed.). 1975. Problems of Assessing Populations of Nekton. Workshop Proceedings and Final Report. Santa Barbara, CA. 30 pp.

Peck, J. I. 1896. The sources of marine food. Bull. U.S. Fish Comm. 15:351-368.

Polgar, T. T. 1977. Striped bass ichthyoplankton abundance, mortality and production estimation for the Potomac River population. Pages 109-125, in W. Van Winkle, ed. Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Oak Ridge Nat'l. Lab., Oak Ridge, Tenn.

Polgar, T. T., R. E. Ulanowicz, D. A. Pyne, and G. M. Krainak. 1975. Investigations of the Role of Physical-transport Processes in Determining Ichthyoplankton Distributions in the Potomac River. Interim Report for 1974 Spawning Season Data. Md. Power Plant Siting Program Reports PPRP-11 and PPMP-14 (combined). 133 pp.

Portner, E. M., and C. A. Rohde. 1977. Tests of a High Volume Pump for Ichthyoplankton in the Chesapeake and Delaware Canal. PPSE-T-3. Johns Hopkins Univ. 50 pp.

Posgay, J. A. 1969. Recent investigations in the ICNAF area into some of the problems of collecting zooplankton. J. Cons. Perm Int. Explor. Mer. Plankton Committee. pp. 1-4.

Posgay, J. A. 1972. Grid vs. random sampling for ichthyoplankton. Nat'l. Mar. Fish. Serv. Northeast Fisheries Center, Preliminary Results: Bongo Sampler tests on Avoidance and Extrusion. (Mimeo).

Posgay, J. A., R. R. Marak, and R. C. Hennemuth. 1968. Development and Tests of New Zooplankton Samplers. International Commission Northwest Atlantic Fisheries Annual meeting, Doc. No. 85.

Quirk, Lawler, and Matusky Engineers. March, 1974. Cornwall Gear Evaluation Study. Q. L. & M. Laboratories Project No. 115-29, Tappan, NY. 96 pp.

Ray, S. S., R. L. Snipes, and D. A. Tomljanovich. October, 1976. A State-of-the-Art Report on Intake Technologies. U. S. Environmental Protection Agency. No. 600-7-76-020. 83 pp.

Richkus, W. A., and A. J. Lippson. 1975. An Evaluation of the Impact of the Morgantown SES on Macroplankton Populations. Morgantown Monitoring Program Report Series No. MT-75-3. Martin Marietta Corp., Baltimore. 45 pp.

Ricker, W. E. 1937. Statistical treatment of sampling processes useful in the enumeration of plankton organisms. Arch. F. Hydrobiol. 31:68-84.

Ricker, W. W. 1938. On adequate quantitative sampling of the pelagic net plankton of a lake. J. Fish. Res. Bd. Canada 4(1):19-32.

Russel, F. S. 1925. Depth recording with plankton nets. Nature 115:603-604.

Saila, S. B. (ed.). 1975. Fisheries and Energy Production. D. C. Heath, Lexington, MA. 300 pp.

Salli, A. J. 1973. A portable observation chamber for the study of fish behavior in the natural environment. Trans. Am. Fish. Soc. 102(2):456-459.

Sameoto, D. D. 1972. Distribution of herring (Clupea harengus) larvae along the southern coast of Nova Scotia with observations on their growth and condition factor. J. Fish. Res. Bd. Canada 29(3):507-515.

Sameoto, D. D. 1975. Tidal and diurnal effects on zooplankton sample variability in a nearshore marine environment. J. Fish. Res. Bd. Canada 32(3):347-366.

Saville, A. 1959. Mesh selection in plankton nets. J. Cons. perm. int. Explor. Mer 23:192-201.

Saville, A. 1971. The larval stage. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 160:52-55.

Schnack, D. 1974. On the reliability of methods for quantitative surveys of fish larvae, pp. 200-213. In J. H. S. Blaxter (ed.), The Early Life History of Fish. Springer-Verlag, New York.

Schnack, D., and G. Hempel. 1971. Notes on sampling herring larvae by Gulf III samplers. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 160:56-59.

Schwartz, F. J. 1973. An assessment of egg, larval, and juvenile fish research needs and problems with comments on research at the Univ. of N.C. Inst. of Marine Sciences. Nat'l. Mar. Fish. Serv., Mid-Atlantic Coastal Fisheries Center. Tech. Publ. No. 1. pp. 7-9.

Schwoerbel, J. 1970. Methods of Hydrobiology (Freshwater Biology). Pergamon Press, Oxford. 278 pp.

Scotton, L. N., R. E. Smith, N. S. Smith, K. S. Price, and D. P. de Sylva. 1973. Pictorial Guide to Fish Larvae of Delaware Bay. Delaware Bay Rep. Series, Vol. 7. College Marine Studies, Univ. of Delaware. 206 pp.

Senta, T. 1967. On the relation between the numbers of eggs, the larvae of fishes, and the volume of plankton collected simultaneously with the larval net. Jap. J. Ecol. 11(6):221-224.

Sherman, K., and K. A. Honey. 1968. Observations on the catching efficiencies of two zooplankton samplers. International Commission for the Northwest Atlantic Fisheries Redbook, Part III. pp. 75-80.

Sherman, K., and K. A. Honey. 1971. Size selectivity of the Gulf III and Bongo zooplankton samplers. International Commission Northwest Atlantic Fisheries Research Bull. No. 8. pp. 45-48.

Silliman, R. P. 1946. A study of variability in plankton tow-net catches of Pacific pilchard, Sardinops caerulea, eggs. J. Mar. Res. 6(1):74-83.

Singarajah, K. V. 1969. Escape reactions of zooplankton: the avoidance of a pursing siphon tube. J. Exp. Mar. Biol. Ecol. 3: 171-178.

Smith, P. E. 1972. Bongo Net Extrusion and Avoidance at Speeds of 1.5 and 4.5 Knots. Nat'l. Mar. Fish. Serv. Marine Monitoring Assessment Program. Tech. Rept. No. 3. 5 pp.

Smith, P. E. 1972. Bongo Net Extrusion and Avoidance at Speeds of 1.5 and 4.5 Knots with 0.505 mm Mesh. Nat'l. Mar. Fish. Serv. Marine Monitoring Assessment Program. Tech. Rept. No. 6. 2 pp.

Smith, P. E. 1972. Day-night Difference in Anchovy Larvae Catch Curve at 1.5 and 4.5 Knots. Nat'l. Mar. Fish. Serv. Marine Monitoring Assessment Program. Tech. Rept. No. 7. 3 pp.

Smith, P. E. 1972. Towing Errors Associated with Oblique tows. Nat'l. Mar. Fish. Serv. Marine Monitoring Assessment Program. Tech. Memo No. 8. 19 pp.

Smith, P. E. 1972. Apparent Retention Rate of Anchovy Larvae on 505 μm Mesh as Affected by Size and Towing Velocity. Nat'l. Mar. Fish. Serv. Marine Monitoring Assessment Program. Tech. Memo No. 9. 3 pp.

Smith, P. E. 1972. Comparison of Hake and Anchovy Larvae Retention as Affected by Larvae Size, Mesh Size, and Towing Speed. Nat'l. Mar. Fish. Serv. Marine Monitoring Assessment Program. Tech. Memo No. 11. 4 pp.

Smith, P. E. 1972. Field comparison of aluminum model of MARMAP Bongo w/505 mm nylon mesh and CALCOFI ring net w/505 mm nylon mesh in 200 meter oblique tows at less than 2 knots. Nat'l. Mar. Fish. Serv. Southwest Fisheries Center. (Memo to: R. K. Sherman).

Smith, P. E. (ed.). 1975. Proceedings from International Training Course in Fish Eggs and Larval Studies, Sept. 2-29, 1973. La Jolla, CA.

Smith, P. E., R. C. Counts, and R. I. Clutter. 1968. Changes in filtering efficiency of plankton nets due to clogging under tow. J. Cons. perm. int. Explor. Mer 32(2):232-248.

Snyder, D. E. 1975. Passage of fish eggs and young through a pumped storage generating station. J. Fish. Res. Bd. Canada 32(8):1259-1266.

Southward, A. J. 1970. Improved methods of sampling postlarval young fish and macroplankton. J. Mar. Biol. Assoc. U.K. 50(3): 689-712.

Stickney, A. P. 1972. The locomotor activity of juvenile herring (Clupea harengus L.) in response to changes in illumination. Ecol. 53(3):438-445.

Szlauer, L. 1964. Reaction of Daphnia pulex de Geer to the approach of different objects. Polsk. Arch. Hydrobiol. 12:5-16.

Tabery, M. A., T. J. Chambers, T. P. Goode, and B. A. Smith. 1976. A multi-purpose epibenthic sampler for fish eggs, larvae, juveniles and adults. Presented at the Thirty-second Northeast Fish and Wildlife Conference. Hershey, PA. 17 pp.

Taft, B. A. 1960. A statistical study of the estimation of abundance of sardine (Sardinops caerulea) eggs. Limnol. Oceanogr. 5:245-264.

Tanaka, S. 1955. Estimation of the abundance of the eggs of fish such as sardine: method of estimation by the vertical haul of plankton net. Bull. Jap. Soc. Sci. Fish. 21(6):382-389.

Tanaka, S. 1974. Significance of egg and larval surveys in the studies of population dynamics of fish, pp. 151-157. In J. H. S. Blaxter (ed.), The Early Life History of Fish. Springer-Verlag, New York.

Tetra Tech, Inc. 1977. Additional studies conducted at Pittsburgh Power Plant in support of the 316(A) demonstration. Tetra Tech. Rept. No. TC-638A. 47 pp.

Texas Instruments Inc., Ecological Services. 1974. Fisheries Survey of the Hudson River, March-December 1973. Vol. IV. 6 pp.

Texas Instruments Inc., Ecological Services. 1977. Gear Evaluation Studies, 1974 and 1975. Prepared for Consolidated Edison Company of New York, Inc.

Tibbo, S. N., D. J. Scarratt, and P. W. G. McMullon. 1963. An investigation of herring (Clupea harengus L.) spawning using free-diving techniques. J. Fish. Res. Bd. Canada 20(4):1067-1079.

Tomlinson, P. K. 1971. Some sampling problems in fishery work. Biometrics 27(3):631-641.

Tomljanovich, D. A., J. Heuer and C. Voightlander. February, 1977. Investigations on the Protection of Fish Larvae at Water Intakes Using Fine Mesh Screening. Tech. Note No. B-22. Tennessee Valley Authority, Norris, TN. 53 pp.

Tonolli, V. 1971. Methods of collection, pp. 1-25. In W. T. Edmonson and G. G. Winberg (eds.), A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters. IBP Handbook No. 17, Blackwell Science, Oxford.

Tranter, D. J. (ed.). 1968. Zooplankton Sampling. UNESCO Press, Paris. 174 pp.

Tranter, D. J., and A. C. Heron. 1967. Experiments on filtration in plankton nets. Aust. J. Mar. and Freshwater Res. 18:89-111.

Tranter, D. J., and P. E. Smith. 1968. Filtration performance, pp. 27-56. In D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Vannucci, M. 1968. Loss of organisms through the meshes, pp. 77-86. In D. J. Tranter (ed.), Zooplankton Sampling. UNESCO Press, Paris.

Van Winkle, W. (ed.). 1977. Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Oak Ridge Nat'l. Lab., Oak Ridge. 365 pp.

Vlymen, W. J., III. 1974. Swimming energetics of the larval anchovy, Engraulis mordax. Fish. Bull. 72(4):885-899.

Walker, R. B. 1974. Techniques for evaluating hydrostatic pressure effects on small and larval fishes. Assoc. Southeast Biol. Bull. 21(2):89.

Warsh, K. L. 1977. Final Summary of Estimates of the Entrainment Rate of Spawn of the Striped Bass (Morone saxatilis) into the Proposed Power Plant of Douglas Point. Johns Hopkins Univ. No. PPSE-T-2. 121 pp.

Wiborg, K. F. 1948. Experiments with the Clarke-Bumpus plankton sampler and with a plankton pump in the Lofoten area in northern Norway. Fisk. Skrift. 9(2):32.

Wiebe, P. H. 1970. Small-scale spatial distribution in oceanic zooplankton. Limnol. Oceanogr. 15(2):205-217.

Wiebe, P. H. 1971. A computer model study of zooplankton patchiness and its effects on sampling error. Limnol. Oceanogr. 16(1):29-38.

Wiebe, P. H. 1972. A field investigation of relationships between length of tow, size of net, and sampling error. J. Cons. perm. int. Explor. Mer 34(2):268-275.

Wiebe, P. H., K. H. Burt, S. H. Boyd, and A. W. Morton. 1976. A multiple opening-closing net and environmental sensing system for sampling zooplankton. J. Mar. Res. 34(3):313-326.

Wiebe, P. H., and W. R. Holland. 1968. Plankton patchiness: effects on repeated net tows. Limnol. Oceanogr. 13:315-321.

Winsor, C. P., and G. L. Clarke. 1940. A statistical study of variation in the catch of plankton nets. J. Mar. Res. 3(1):1-34.

Winsor, C. P., and L. A. Walford. 1936. Sampling variations in the use of plankton nets. J. Cons. perm. int. Explor. Mer 2:190-204.

Wood, R. J. 1971. Some observations on the vertical distribution of herring larvae. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 160:60-64.

Yentsch, C. S., and A. C. Duxbury. 1956. Some of the factors affecting the calibration number of the Clarke Bumpus quantitative plankton sampler. Limnol. Oceanogr. 1(4):268-273.

Yocom, T. G., and H. D. Tait. 1976. Energy-related research of the U.S. Fish and Wildlife Service on the Great Lakes, pp. 513-518. Presented at the Second Federal Conference on the Great Lakes. Argonne Nat'l. Lab., Argonne, IL.

Zweifel, J. R. 1973. A non-parametric approach to the estimation of relative change in fish population size from egg and larval surveys. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer 164:276-281.

APPENDICES

Table A-1. Power plant ichthyoplankton sampling gear by habitat type
A summary of information from available environmental reports

A. Lacustrine

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Nine Mile Point Nuclear Station	0.5/1.0 m		0.571 mm	TSK	Semimonthly/ Bimonthly	D & N	30 min		Stratified	
Monroe Power Plant		Kenco	0.760 mm				1-5 min		Stratified & oblique	
Palisades Power Plant	Wisconsin net	plankton			Weekly			Assumed 9 ft/Sec		4 larvae captured not identified
Point Beach Nuclear Plant		Diaphram pump	0.363 mm				15-60 min		Vertical	Occasional 1.0 m^2 net tows in upper waters
Zion Generating Station	0.5 m	Homelite suction pump	0.526/ 0.351 mm	GO	Weekly Semimonthly	N	3 min		Stratified	0.351 mm nets towed at surface only
Oconee Nuclear Station					Semimonthly					Sampled spigot at condenser - no larvae caught in 3 years
Browns Ferry Nuclear Plant	0.5 m				Weekly	D & N	2 hr		Stratified	Near field nets stationary-Far field towed
Yellow Creek Nuclear Plant	0.5/1.37 m^2		0.790 mm	TSK313	Weekly		10 min		Surface & Vertical	Vertical net was 1.37 m^2
Kewaunee Power Plant		Homelite suction pump	0.153 mm		Bimonthly	D	3 min			
Peach Bottom Atomic Power Station	0.5/1.0 m		0.500 mm	GO2030	Weekly	D & N	10-15 min		Stratified	
Benton Harbor Power Plant	0.5 m		0.280 mm		Monthly		10 min	2-4 knots	Stratified	
Ginna Nuclear Power Station	0.5 m	unspecified	0.571 mm	GO2030					Stratified	Near field sampled 24 hr, Bottom samples pumped
Fitzpatrick Nuclear Power Plant	0.5 m		0.571 mm	TSK	Monthly	D & N	30 min	Variable	Stratified	Fixed nest at Intake

Table A-1. (continued)

B. Riverine

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Duane Arnold Nuclear Power Plant	Drift Net									
Cooper Nuclear Station	0.5 m		0.571 mm		Bimonthly		2-5 min		Stratified	
Oyster Creek Power Station	36 cm Bongo & 12.5 cm Clarke-Bumpus				Semiweekly	N			Oblique	
Hennepin Power Station	0.5 m		0.760 mm	G02030						
B. E. Morrow Power Station		Kenco #134	0.333 mm		Weekly	D & N	24 hr	30-143GPM		*Promoxis* sp.221 Of 236 larvae
Tanners Creek Plant/Beckjord Plant/Kyger Creek Plant	0.5 m		0.571 mm	G02030					Stratified	
Susquehanna Steam Electric Station		Pump(?)	0.261 mm		Semimonthly & Weekly	D & N	5 min	25001/ min	Stratified	
Beaver Valley Power Station	0.5 m		0.505 mm		Monthly				Stratified	
Prairie Island Nuclear Generating Plant	1.0 m		0.787 mm & 0.560 mm	GO	Weekly	D			Surface	May-June, 1 m^2 0.787 mm. July-Sept., 1 m dia., 0.660 mm
Quad Cities Station	0.42 m Drift Net		0.571 mm	G02030	Weekly		15 min			
Limerick Generating Station	10 cm		0.471 mm	Gurley 625F	Semimonthly	D & N	1 hr			2-6 nets per 12 1 hr collections
Jacksonville Electric	20 cm Bongo		0.333 mm	G02030		D				
Arthur M. Williams Station	0.5 m		0.505 mm	G02030	Monthly	D & N			Stratified & Oblique	Far field Tows oblique
H. B. Robinson Steam Electric Station	30 cm		0.570 mm			D & N	5 min		Stratified	
Chay Boswell Steam Electric Station	0.5 m		0.333 mm	Wildco #39	Semimonthly		2 hr		Stratified	

Table A-1. (continued)

C. Estuarine

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Maine Yankee Atomic Power Plant	30 cm/50 cm 0.5 m		0.363 mm		Semimonthly	N			Stratified	
Calvert Cliffs Nuclear Station	0.5 m		0.244 mm/ 0.173 mm	G02030	Monthly/Weekly	N	5 min		Stratified	Near field sampled monthly with 0.178 mm mesh net
Brunswick Nuclear Station	0.5 m/1.0 m		0.571 mm/ 0.760 mm		Monthly/Bi-monthly	D & N	5 min		Stratified	
Cutler Plant	Drift Net		1/8 in		Monthly	D & N	24 hr			
Big Bend Steam Electric Station	1.0 m		0.363 mm	unspecified	Weekly/ Quarterly	D & N	10 min		Stratified	

Table A-1. (concluded)

D. Marine

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Diablo Canyon Nuclear Generating Station	1.0 m		0.505 mm	GO2030	Semimonthly		3 min		Stepped oblique	
San Onofre Nuclear Generating Station	1.0 m		0.202 mm	GO		D	10-15 min		Stepped oblique	
Hunting Beach Generating Station	0.5 m		0.249 mm				10 min			
New Jersey Offshore Floating Nuclear Power Plant	1.0 m		0.500 mm		Weekly					
Pilgrim Nuclear Generating Station	Bongo (NMFS Standard)		0.505 mm	GO2030	Monthly	D	5 min	2 knots	Stratified	Typical marine boreal species captured
E. F. Barrett Generating Station		Neilson Fish Pump #51515	0.363 mm				5 min		Stratified (surface only)	
Northport Power Station	0.75 m		0.363 mm	TSK	Semimonthly/ Monthly/		5 min		Stratified	
Shoreham Nuclear Power Station			0.363 mm	GO	Weekly/Semimonthly/ Monthly	D & N	5 min		Stratified	Some 24 hr sempling

Table A-2. Ichthyoplankton sampling gear used in power plant entrainment studies (Section 316b Demonstration Documents)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Moline Generating Station	"Fry" Net		0.500 mm	unspecified	Weekly		10-20 min		Surface	
Joppa Generating Station			0.363 mm	unspecified	Weekly	D & N			Stratified	Sampled 3 times/ 24 hr
Robert A. Gallagher Generating Station		unspecified	1.00 mm		Once/4 days	D & N	6 hr	190-380 l/min	Vertical	4, 6 hr samples/ sampling date
Manitowoc Generating Plant		Homelite Submersible	0.363 mm	unspecified		D & N	24 hr		Stratified	
Rocl River Generating Station		Homelite Submersible	0.571 mm	Badger MLFT Propeller-Type	Weekly/Semi-monthly	D & N	24 hr		Stratified	
Blackhawk Generating Station		Homelite Submersible	0.571 mm	Badger MLFT Propeller-Type	Weekly/Semi-monthly	D & N	24 hr	9000 GPH	Stratified	
Nelson Dewey Station		Homelite Submersible	0.571 mm	Badger MLFT Propeller-Type	Weekly/Semi-monthly	D & N	24 hr	90-100 GPM	Stratified	
Valley Power Plant		Kenco #139	0.333 mm					80-90 GPM	Stratified	
Commerce Street Power Plant	1.0 m	2 Kenco #139	0.333 mm					90-130 GPM	Stratified	
Conesville Generating Station	0.5 m	Hydromatic SM20A	0.158 mm		Monthly	D & N	5-6 min	20 GPM		Every 2 hr for 3 days/month
Seabrooke Generating Station	0.5 m		0.571 mm		Once/4 days/ 8 days	D & N	24 hr			
Dixon Generating Station	0.5 m		0.571 mm		Once/4 days/ 8 days	D & N	24 hr			
Cahokia Power Plant	12 in		0.571 mm	unspecified	21/year		15 min			10 Replicates
Dresden Nuclear Power Station	0.5 m		0.571 mm	unspecified	Weekly	D & N				Also used drift nets when practical
Havana Power Station	0.5 m		0.760 mm	G02030						
Weston Power Plant	1.0 m		0.576 mm	G02030						

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Russel Power Station	0.5 m		0.571 mm	GO2030	Semimonthly	D & N	4 hr	Variable		Fixed nets at Intake
Cayuga Station Generating Station	0.5 m	unspecified	0.505 mm	GO2030	Semimonthly/ Monthly			360/1.5k GPM	Stratified	Bottom samples pumped from Epibenthic sled
For Lake Generating Station	0.5 m/12.5 cm, Clarke-Bumpus		0.153 mm		Semimonthly/ Weekly/Monthly	D & N	5-50 min	2-3 FPS		Far field - Clarke-Bumpus net only - Nearfield at discharge
D. H. Mitchell Station	0.5 m		0.351 mm	GO	Once/4 days/ 8 days				Stratified	Sampled Intake & Discharge
Avon Lake Stream Station	0.5 m		0.505 mm	GO	Semimonthly		5 min		Stratified	
Eastlake Stream Station	0.5 m		0.505 mm	GO	Semimonthly		5 min		Stratified	
Presque Isle Power Station	0.18 m^2/0.47 m^2		0.536 mm/ 0.351 mm	TSK313	Weekly/Semi-monthly		10-15 min		Oblique	
Bay Front Generating Station		Kenco #139	0.333 mm		Weekly		24 hr			
Edgewater Generating Station	1.0 m	Kenco #139	0.333 mm		Weekly			50-70 GPM		
Pulliam Generating Station	1.0 m		0.526 mm	GO2030	Weekly	D & N				
Port Washington Generating Station	1.0 m	2 Kenco #32N1	0.333 mm			D & N	24 hr	140-170 GPM	Stratified	Pumps at 20% & 80% Depth, Intake
Lakeside Generating Station	1.0 m	2 Kenco #139	0.333 mm			D & N	24 hr		Stratified	Intake
Oak Creek Power Plant	1.0/1.5 m	Kenco #139	0.333 mm		Once/4 days	D & N	5 min/24 hr	50-60 GPM	Stratified	1.5 m net towed Far field
Hoot Lake Generating Station	12.5 cm Clarke-Bumpus		0.153 mm		Weekly	D & N	2 hr		Stratified	
Stateline Generating Station	0.5 m	Homelite suction pump	0.526 mm	unspecified		N	3 min	385 GPM/ 2-3k		Far field - towed 0.5 m net

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Paradise Steam Plant										
Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (Upstream & Downstream) 150 m^2/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates 75-150 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excessive water velocities: 75-150 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface - mid-bottom 100-200 m^3/min filtered
Allen Steam Plant										
Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	5 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates 16-58 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	52.0 m^3/min filtered

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Cumberland Steam Plant Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 50-150 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excessive water velocities: 50-200 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surfaced-mid-bottom 93-6-382 m^3/min filtered
Kingston Steam Plant Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-11 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired sampling: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 15-100 m^3 filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excessive water velocities: 50-200 m^3/min filtered

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day (D)/ Night (N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Kingston Steam Plant (cont'd) Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface mid-bottom: 100-350 m^3/min filtered
Colbert Steam Plant Far field		Homelite trash pump 120Tp3-1	0.790 mm.	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	5 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 25-100 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excess water velocities 10-200 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface mid-bottom 100 m^3/ filtered
Watts Bar Steam Point Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 75-100 m^3/min filtered

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Watts Bar Steam Plant (cont'd)										
Far field	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excess water velocities: 50-200 m^3/min filtered
Near field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	D & N	1 hr	0.3 m/sec	Stratified	Pump used because of intake structure & turbulence 40-60 m^3/ min filtered
John Sevier Steam Plant										
Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 15-95 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excessive water velocities: 75-150 m^3/ min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface mid-bottom 70-200 m^3/ min filtered
Widows Creek Steam Plant										
Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Widows Creek Steam Plant (cont'd)	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 28-45 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical because of excessive water velocities: 63-211 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface mid-bottom 189.1-226 m^3 filtered
		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	D & N				30-40 m^3/min filtered
Browns Ferry-Nuclear Far field	1.0 m		0.790 mm	unspecified		D & N			Stratified	2 replicates
Near field	.5 m		0.790 mm	unspecified		D & N	2 hrs		Stratified	Surface mid-bottom
Johnsonville Steam Plant Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered
Bull Run Steam Plant Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-10 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered

Table A-2. (continued)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Bull Run Steam Plant (cont'd)										
Far field	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 15-95 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	128.6-136 m^3 filtered
Shawnee Steam Plant										
Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	2-6 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	Paired samples: (upstream & downstream) 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 19-56 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.1 m/sec	Oblique	Could not use vertical lifts because of excessive water velocities: 80 m^3/min filtered
	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface mid-bottom 100-200 m^3/min filtered
Gallatin Steam Plant										
Far field		Homelite trash pump 120Tp3-1	0.790 mm	unspecified	Bimonthly	N	10 min	0.3 m/sec	Stratified	4-11 m^3/min filtered
	0.78 m square frame		0.790 mm	TSK	Bimonthly	N	2.5 min	1.3 m/sec	Stratified	3-5 replicates: 150 m^3/min filtered
	1.88 m square frame		0.790 mm	unspecified	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 15-100 m^3/min filtered

Table A-2. (concluded)

Facility	Net	Pump	Mesh(s)	Flowmeter	Sampling Frequency	Day(D)/ Night(N)	Duration of Tow/Pump	Speed of Tow/Pump	Sampling Design	Remarks
Gallatin Steam Plant (cont'd)	0.78 m square frame		0.790 mm	TSK	Bimonthly	N		0.5-1.0 m/sec	Vertical	3-5 replicates: 15-100 m^3/min filtered
Near field	0.196 m square frame		0.790 mm	unspecified	Bimonthly	D & N	1 hr		Stratified	Surface mid-bottom 160-250 m^3/min filtered
Edgemoore Power Station	0.5 m		0.500 mm	G02030	Semimonthly		3 min		Stratified	
Beebee Power Station	0.5 m		0.571 mm	G02030	Semimonthly	D & N	4 hr			Stationary nets at Intake
Gilbert Generating Station	0.5 m		0.500 mm	G02030	Weekly	D	3 min		Stratified	
Salem Nuclear Generating Station	0.5 m		0.500 mm	GO	1-3/month	D & N	5-10 min		Stratified	Some collections made with 9 ft semi-balloon trawl
Hickling Station	0.5 m		0.571 mm	G02030	Semimonthly		3 min		Stratified	Collected only 8 larvae
Goudey Station	0.5 m		0.571 mm	G02030	Semimonthly		3 min		Stratified	
Jennison Station	0.5 m		0.571 mm	G02030	Semimonthly		3 min		Stratified	Collected only 4 larvae
Werner Generating Station	20 cm Bongo		0.505 mm	G02030	Semimonthly	D	4-6 min		Oblique	
Indian Point Nuclear Power Plant	0.5 m/1.0 m		0.571 mm	G01031	Weekly/Semi-monthly/Monthly	D & N	10 min	2-3k	Stratified	
Roseton Generating Station	0.5 m/1.0 m		0.571 mm	TSK	Semimonthly	D & N	5 min		Stratified	
Danskammer Point Generating Station	0.5 m/1.0 m		0.571 mm	TSK	Semimonthly	D & N	5 min		Stratified	
Bowline Point Generating Station	1.0 m	Midland Whirl Pump	0.505 mm/ 0.571 mm	TSK/GO	Weekly/Semi-monthly/Monthly	D & N	5-15 min	85-95 CPS	Stratified/ oblique	Benthic collections with sled
Lovett Generating Station	1.0 m		0.571 mm	TSK	Semimonthly/ Monthly	D & N	5 min	85-95 CPS	Stratified/ oblique	Benthic collections with sled

☆ U. S. Government Printing Office: 1978 - 650-630

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural value of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

March 3, 1849

UNITED STATES
DEPARTMENT OF THE INTERIOR
Fish and Wildlife Service
Biological Services Program
Washington, D.C. 20240