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Procedure for Developing Biological Input for the Design, Location or Modification of Water Intake Structures

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PROCEDURE FOR DEVELOPING BIOLOGICAL
INPUT FOR THE DESIGN, LOCATION OR
MODIFICATION OF WATER INTAKE
STRUCTURES

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INTRODUCTION

Water is pumped in large quantities for use by industry, agriculture, and municipalities throughout the United States. In most cases, these pumping operations require intake structures to house the pumps. The structures are screened to protect the pumps from debris in the water. Operation of water intake structures can impact the aquatic communities that inhabit or use the same body of water. The most common impacts associated with water intake structure operation are entrainment and impingement. Entrainment is used in this report to refer to the pumped passage of fish and shellfish through the pump and in the case of power plants through the plant cooling system. Impingement refers to those fish and shellfish caught on the protective screens of intake structure during pump operation.

Water required for steam generated electrical power is much larger than for other industrial water users. Eighty percent of the water used for industrial cooling in the United States is used at steam electrical power plants (Barnes, 1976). The types of cooling systems used vary, although most have some common components, including the intake, power plant, and discharge (Figure 1). The construction, location, and operation of the intake and discharge facilities for these plants are regulated under the Federal Water Pollution Control Act (FWPCA). Therefore most of the discussion that follows refers to intake structures at power plants. However, the concepts developed are applicable to all water intake structures.

The FWPCA was amended in 1972, retaining water quality standards initiated in earlier laws and establishing new regulations dealing with the effects of cooling systems on aquatic organisms. Section 316(b) of the amended act provides protection for aquatic organisms that are affected by water intake structures. This portion of the Act requires that "the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Although the 1972 amendments do not define the best technology available, the U. S. Environmental Protection Agency (EPA) has determined closed-cycle cooling to be the best available technology.* The EPA determination is based on all aspects of cooling systems and the effect of these systems on aquatic life. One of the most visible effects to fish and shellfish from the operation of a cooling system is entrainment and impingement at the intake. Closed-cycle cooling is considered best available technology because the reduction in water used results in a reduction of the biota entering the condensers.

However, entrainment and impingement impacts are often associated with poor plant siting and poor intake location and design. The use of closed-cycle cooling to minimize entrainment and impingement impacts has several inherent problems, including construction and maintenance cost, loss of saleable energy, high water quality standards for the discharge, and increased use of terrestrial habitat (Reynolds, 1980). These things

*U. S. Code Fed. Reg. 40, pt 423 (as cited in Reynolds, 1980).

BIG BROWN POWER STATION FREESTONE COUNTY, TEXAS

TROJAN NUCLEAR PLANT, PRESCOTT, OREGON

JOHNSONVILLE STEAM PLANT, HUMPHREYS COUNTY, TENNESSEE

Figure 1. Three main types of cooling systems used at thermal generating plants in the United States (Becker et al., 1979; Freeman and Sharma, 1977; Stupka and Sharma, 1977).

considered, Reynolds (1980) suggests that wherever open-cycle cooling systems are feasible and risk to aquatic systems is minimal, open-cycle cooling systems or cooling reservoirs should be preferred over closed-cycle cooling. Additionally, the U. S. Fish and Wildlife Service points out that closed-cycle cooling may not be the best available technology in all cases (Boreman, 1977). Whenever possible, alterations in existing open-cycle systems that minimize impact to the aquatic environment should be recommended over closed-cycle cooling options (Reynolds, 1980).

To minimize adverse impact on the aquatic ecosystem from the operation of a water intake structure, design engineers must have information about behavior, physiology, and ecology of local fish and shellfish. This information will be necessary in the engineering and design of water intake structures (Hanson et al., 1977). To obtain this information, it will be necessary to develop a system of open cooperation and communication between biologists and engineers (McKenzie and Thomas, 1979; Fritz et al., 1980).

Figure 2 illustrates the interaction of biological information and environmental factors needed to design, locate, and modify water intake structures. Biological characteristics of fish and shellfish reflect the organism's environment and conditioning (Figure 3). Ambient environmental conditions near a water intake structure influence the biological characteristics of fish and shellfish. Water temperature will affect swimming performance, light may affect vertical distribution, and water currents are used by fish and shellfish for orientation.

Intake structure stimuli will affect the biological responses of fish and shellfish. Shadows cast by the intake alter ambient light. A forebay or intake channel will alter the contour of a shoreline.

Any stimuli encountered by fish and shellfish and the environmental factors near an intake can affect the response of a fish or shellfish receiving stimuli from water intake structures (Figure 3). A fish or shellfish receives stimuli and responds. The type and intensity of the response is governed by environmental factors and the conditioning of the organism. Identification of the stimulus/response relationship and the environmental factors that influence these mechanisms is the first step in incorporating biological information into water intake design. After identifying these relationships, mathematical functions which will facilitate the use of this biological information in the design, location, or modification of water intake structures (Figure 2) can be developed.

Ontological Considerations

Among the many variables that can affect the organism's response to a given environmental stimulus, one of the more important is the organism's age or stage of development. Young fish and shellfish are usually more vulnerable to changes in environmental conditions, and biological information for one life stage may not be applicable to others. Therefore, age-or life stage-specific information is required for designing water intake structures. If mathematical

Figure 2. System for biological input to engineering model for design, location, or modification of a water intake structure.

descriptions of biological information are developed, ontological changes should be included. For example, changes from a planktonic to nektonic life style can influence the potential for entrainment and impingement of many fish and shellfish species. In most instances, different life stages may be considered as different organisms.

The feeding habits of many fish change from larva to adult. Freshwater drum young eat zooplankton and chironomids mostly, while adults eat insects, fish and crayfish (Scott and Crossman, 1973). Morsell and Norden (1968) noted that landlocked adult alewives eat zooplankton until they are about 119 mm long, and larger fish eat increased numbers of benthic amphipods. The diet of striped bass changes from zooplankton to small fishes throughout life. Thus, the act of feeding in many young fish could influence their susceptibility to entrainment and impingement.

Figure 3. Stimulus/response mechanism and environmental factors affecting the mechanism.

Changing size can affect the way in which an organism responds to a stimulus. Beamish (1978) discusses many investigations of swimming performance related to fish length and weight. Atlantic herring swimming endurance increases as body length increases. The distance a sea lamprey can swim in laboratory tests increases with their weight. The burst swimming speed for brown trout, Atlantic herring, and goldfish was observed to decrease relative to length. This type of physiological information is important for the design, operation, or modification of a water intake structure at which current velocities are expected to affect fish swim performance. To choose a location, a screen size, or approach velocity, the design engineer must know how the relevant biological information changes with ontological differences in fish and shellfish populations.

SOURCES OF STIMULI AT WATER INTAKES

The presence and operation of a water intake structure present many stimuli that may elicit behavioral or physiological responses by fish and shellfish. The stimuli will vary with the intake design and the water body in which the intake is located. It is, however, important to hypothesize the types of stimuli and estimate the magnitude of these stimuli when designing an intake. Hypotheses and estimates can then be related to biological responses of the indigenous fish and shellfish (Figure 3). These relationships can aid engineers in designing an intake that reduces attracting stimuli and increases repulsing stimuli (Table 1) and are important to understanding why fish and shellfish are entrained and impinged.

Stimulus/Response Relationships Relative to Entrainment and Impingement

Some of the possible stimuli a fish or shellfish may encounter are changes in depth, bottom substrate, light, current velocity and direction, noise, and turbulence. These stimuli may result from excavation for intake installation, pump operation, movement of screening devices, or many other operational procedures necessary at the intake. Some fish and shellfish will respond to these

TABLE 1. Possible Stimulus/Response Relationships for Fish and Shellfish at Water Intake Structures and Potential Design Considerations to Reduce Entrainment and Impingement.

<u>Intake Component Structure</u>	<u>Stimuli</u>	<u>Response</u>	<u>Design Consideration</u>
	New habitat	Colonization	Surface modification unsuitable for colonization
		Predator avoidance	Eliminate areas from design area
	Change current	Attraction	Produce undetectable currents
Screens	Change current velocities and direction	Passage	Screen and mesh size that reduces passage
		Attraction and fatigue	Decrease through-screen velocity
	Impingement	Injury or death	Safe removal system
Pumps	Noise	Attraction or repulsion	Use noise level that repulses
Skimmer or curtain walls, bottom sills, porous dikes	Change currents	Attraction or repulsion	Increase repulsion
	Change access area	Blockage	Place in area that will prevent access
Discharge	Change temperature and current, chlorine	Change behavioral threshold	Place to avoid affecting population near intake

stimuli and will either avoid being entrained or impinged or be attracted by the intake. The variation in response of individual organisms will vary with many factors (Figure 3). The important consideration is which stimulus/response relationships increase or decrease entrainment and impingement.

Current/Attraction. There are current velocities and vectors that attract fish and shellfish. If the current is near an intake screen and the velocity is at the threshold of endurance for an attracted fish, the fish may become impinged. Below are other examples and how they might relate to increased entrainment and impingement of fish and shellfish at water intake structures.

Light/Attraction. Light can attract fish. If lights at a water intake structure are positioned so fish are attracted to areas where current velocities can impinge them, the stimulus (light)/response (attraction) increases impingement. The converse may result if lights attract fish away from impingement areas.

Topography/Habitat Preference. Fish or shellfish may prefer certain shoreline configurations or depths. If an intake forebay or channel is excavated to depths preferred by vulnerable fish and shellfish, entrainment and impingement may be increased. Again the converse, an intake may be placed to avoid preferred depths of indigenous fish and shellfish.

Turbulence/Response. Operation of intake pumps and screen washing devices creates turbulence. If turbulence attracts fish or shellfish, entrainment and impingement will increase. Turbulence may affect fish or shellfish orientation and could affect an organism's response to other intake stimuli.

An important concept to consider when evaluating intake stimulus/organism response relationships is the threshold of an organism's response to a stimulus. If the intake is providing a stimulus at the threshold of an organism's ability to respond, response may occur after the fish is no longer able to avoid entrainment or impingement. Fish may avoid certain current velocities; however, if these velocities are too near the screens of an intake, the fish becomes impinged. The threshold of detection and the threshold of response capability have to be understood to predict the entrainment or impingement of a fish or shellfish.

A similar behavioral response might be acclimation to a stimulus. Often the strength of response is directly related to the degree of change in the stimulus. An intake design could include this type of information if the above relationship were known. For example, if a fish responds negatively (swims away) to turbulence this may be useful to direct fish away from areas where they become entrained or impinged. However, if the turbulence is not enough to elicit immediate response, the fish may acclimate to the turbulence and continue to swim toward areas of entrainment and impingement.

Hanson et al. (1977) used stimuli/response information to suggest three basic strategies for minimizing the entrainment and impingement of fish and shellfish at water intake structures. First, minimize the probability of fish and shellfish encountering the intake. Second, minimize the probability of entraining or impinging fish and shellfish near the intake; and third, maximize the survival of fish and shellfish that are impinged. The following two sections show some attempts that have been used to incorporate this information into intake design (HISTORICAL APPROACHES) and a proposal for future incorporation of biological information into intake designs (CONSIDERATIONS FOR INCORPORATING BIOLOGICAL INFORMATION).

HISTORICAL APPROACHES

Attempts have been made to incorporate behavioral and physiological responses of fish and shellfish into water intake structure design. Results of these attempts have been reviewed and evaluated (Sonnichsen et al., 1975; Hanson et al., 1977). Two basic approaches have been employed: barriers and guidance systems and selective operating schedules.

Barriers and Guidance Systems

Both behavioral and physical barriers have been used in attempts to prevent fish and shellfish from entering areas near water intake structures where they might become entrained or impinged. Behavioral barriers use the response of a fish or shellfish to changes in ambient environmental conditions to attack or repel the individual.

Air bubble screens have been utilized to create turbulence and noise to repel fish from the areas where they might become entrained or impinged. Success of bubble screens has varied with intake and the species observed. Sonnichsen et al. (1975) report a successful application of an air bubble screen at a thermal power plant on Lake Michigan. Prior to the installation of the air bubble screen, there were several shutdowns of the plant caused by screen at this site appears to be an effective repellent for alewives. Use of air bubble screens at Indian Point in New York showed little success (Stupka and Sharma, 1977). Experiments with salmonids indicate that bubble screens are not effective in either stopping or guiding fish (Bell, 1973).

Sonnichsen et al. (1975) reviewed the use of sound at power plants to repel fish and found sound to be an ineffective barrier. The use of sound at water intake structures to repel fish was tried at Indian Point Power Plant (Con. Ed., 1970) and at Surrey (Ristroph, no date). These studies proved to be ineffective in reducing the number of fish entrained or impinged at these plants. Fish, however, do respond to sound. Tavalga and Wodinsky (1976) measured threshold levels for nine species of marine fishes, demonstrating that the detection of low frequencies appears to be quite efficient for the species tested. The authors concluded that the lateral line functions as a shortrange obstacle and moving-object detector. Of particular interest is their observation that high-frequency sounds, such as those produced by air bubble and water currents, are "not likely to form any part of the perceptual world of fishes."

It appears that past attempts at using sound as a barrier to keep fish off intake screens (Sonnichsen et al., 1975; Con. Ed., 1970; Ristroph, no date) did not include prior research to define sounds that might be perceived by affected fish (Tavolga and Wodinsky, 1976). Effective sound barriers have to include frequencies that fish perceive and avoid. Sound produced at water intake structures cannot include frequencies to which fish are attracted, if entrainment and impingement are to be avoided.

Lights have been used at some intakes as a behavioral barrier for fish and shellfish (Hanson et al., 1977). For the examples reviewed, it was generally concluded that fish rapidly become acclimated to light and the barrier becomes useless. However, there are many examples of fish being attracted or repulsed by light. Protasov (1968) discusses feeding differences for fish and how this may determine the fish's reaction to light. Fish that react positively to light are chiefly plankton feeders. Fish that are nocturnal feeders react negatively to light. This type of biological information, when properly understood, could be used to reduce entrainment and impingement. Light could serve as a barrier at an intake to repulse nocturnal feeders or to guide plankton feeders away from areas where they could become entrained or impinged.

Another behavioral barrier that has been used with limited success at some water intakes is electric shock screens (Sonnichsen et al., 1975). These systems work by immersing electrodes and a ground wire into the water to establish an electrical field which then repels fish that swim into. Maxwell (1972) reviewed the effectiveness of these systems and concluded that although electric screens have been successful at some intakes, their overall utility is limited because of human safety hazards associated with their use.

Fish detect and respond to changes in current direction. Weight (1958) observed that fish are more likely to perceive and respond to horizontal, rather than vertical, changes in water velocity. Using these observations, the offshore intake structure at the San Onofre Nuclear Generating Station on the Pacific Coast was equipped with a velocity cap that induced horizontal flow. Reduced fish entrainment and impingement are reported under experimental (Weight, 1958) and operating conditions (Maxwell, 1972) using the velocity cap.

Physical barriers have also been used in some intake designs to guide fish and shellfish away from or to block entry into areas where they can be entrained or impinged. Most water intakes have screens to prevent debris from entering the pump intakes. These screens provide a barrier to juvenile and adult fish; however, diversion of eggs and larvae has not been successful at most water intake structures. Sharma and Palmer (1978) reviewed the status of various physical barriers which could exclude eggs and larvae of fish and shellfish from water intakes. These designs include filter beds (Richards, 1978) and collectors (Mikels and Bennett, 1978; Beskid, 1978) which filter water through large beds of gravel. Filter systems reduce or eliminate entrainment and impingement; however, they usually have limited pumping capacities. Other systems reviewed by Sharma and Palmer (1978) include fine-mesh

screening, perforated pipes and wedge wire screening. The biological effectiveness of these systems for larval exclusion and postimpingement survival depends on site- and species-specific considerations.

Other examples of barriers which have been installed at operating water intake structures to reduce impingement of fish or shellfish are: 1) fixed screens at Brayton Point Station in Massachusetts to prevent the impingement of horseshoe crabs; 2) the placement of a bottom sill at Canal Plant in Massachusetts to reduce the impingement of bottom-dwelling fishes; and 3) the installation of stoplogs at the Mystic Electrical Generating Station in Massachusetts to reduce the influx of winter flounder at the intake (Stupka and Sharma, 1977). An evaluation of the effectiveness of these systems could provide water intake designers with information that will influence future designs where reduction of entrainment and impingement is necessary.

Operation Schedules and Procedures

Changes in power plant operating schedules may be effectively used to reduce entrainment and impingement mortalities. These changes include but are not limited to reductions in cooling water requirements and/or scheduling of maintenance time during periods of peak abundance, reductions in biocide concentrations in the discharge, and modifications in duration and frequency of screen washing. These and other operational modifications are reviewed by Marcy et al. (1978). Although biologists often propose to take advantage of seasonal and diel migrations, such practices have not been widely implemented.

Proper approaches are exemplified by the operation of the Hanford Generating Project (HGP) in Benton County, Washington, and the Mt. Elbert pumped storage power plant in Leadville, Colorado. At HPG a continuous screen wash operating schedule is used during the outmigration of chinook salmon (Gray et al., 1978). This operating procedure, together with some modifications to the screens, has significantly reduced impingement mortalities (Gray et al., 1978). Because of the extra cost and maintenance required from a continuous rather than intermittent screen wash operation, the continuous operation is used only during the chinook salmon outmigration.

At Mt. Elbert three changes were made in the plant and its operation to decrease damage to the aquatic ecosystem. First, the outlet was raised to a shallower depth to help sustain stratification and to suppress entrainment of aquatic life and avoid stirring the bottom sediments. Second, the tailrace channel was diverted and dispersed toward the shore. Third, the operation schedule was modified to minimize significant impacts to the mysid populations. The third modification was made practicable after the diel activities of mysid populations were investigated.

CONSIDERATIONS FOR INCORPORATING BIOLOGICAL INFORMATION

Presently, the location and design of a water intake structure is based on a plant's location and the engineering criteria used to accommodate the plant with the selected site. Rarely has site-specific biological information been used in the design and location of water intake structures. The application of biological information in the design and location of an intake may diminish entrainment or impingement to a level which could eliminate the use of expensive off-stream cooling.

A list of biological information (behavioral and physiological responses of fish and shellfish) and how this information relates to intake design is illustrated in Figure 4. A decision process is also established to show how this information could be incorporated into the design process. As a design or location decision is considered, a list of possible information needs or questions arises. These are illustrated in the center column of Figure 5. Biological information that is relevant to these needs is shown in the right hand column and resulting decisions shown on the left. The decision train provides three basic options.

- 1) location to minimize entrainment and impingement,
- 2) design to avoid attraction or repulsion of fish and shellfish, and
- 3) inclusion of operation schedules or design features to minimize the magnitude of entrainment and impingement mortalities.

The biological information is organized in a manner to facilitate selection of an option. The seven main biological information types listed can be grouped to relate to the three central options of the center column.

- 1) Spatial distribution, environmental conditions, and habitat selection are related to location and design criteria that influence the possibility of entraining or impinging fish and shellfish.
- 2) Response to stimuli from a water intake structure, swimming performance and morphology, and hardiness relate to design criteria that influence the probability of entraining and impinging fish and shellfish or affect the survival of those fish and shellfish which become impinged.
- 3) Temporal distribution relates to the operating schedule and procedures for a water intake structure.

The organization of the remaining sections of this report follows the organization of Figure 4. Each section discusses an environmental stimulus/biological response relationship that can affect the entrainment and impingement of fish and shellfish. Behavioral, physiological, and ecological research investigations are used to illustrate how this information might be used to design, locate, or modify water intake structures. Examples from the open literature and technical reports are used. Additional references concerned with the biology of fish and shellfish that might be relevant to their entrainment and impingement at water intake structures are listed in Appendix A.

Figure 4. Outline of biological information necessary to answer engineering needs for the design, location, or modification of water intake structures.

Figure 5. Four types of water intake structures, showing differences in their effects on shoreline and habitat changes.

The species discussed throughout the report are not necessarily species that have been reported as being entrained or impinged at water intakes. Rather, they represent examples of the type of behavioral, physiological, and ecological information necessary to make decisions. For readers interested or needing to know the species and the life stages that are entrained and impinged, Appendix B presents lists of species reported entrained and impinged at selected water intake structures throughout the United States. Appendix B also lists technical reports and journal articles that provide useful behavioral and physiological information on these species and life stages.

REVIEW OF BIOLOGICAL INFORMATION NEEDED FOR INTAKE DESIGN

This review addresses the questions outlined in Figure 4 and gives examples of biological information that might be used in intake design.

LOCATION OF INTAKE

Can the intake be located in an area not used by fish and shellfish? Can the intake be located to avoid areas where fish and shellfish are subjected to environmental stresses that might increase their chances of being entrained or impinged? If these questions can be answered positively, the design and operational impacts on the aquatic ecosystem will be minimal. However, to answer these questions the intake designer will need information about the spatial distribution of fish and shellfish and the environmental conditions in the proposed locations (Figure 4).

Spatial Distribution

Fish and shellfish are spatially distributed throughout the aquatic environment according to species requirements related to temperature, salinity, dissolved oxygen concentrations, and many other environmental conditions. Availability of food, refuge from predators, and presence of shelter can affect the distribution of fish and shellfish; migration routes and spawning and nursery areas are also important in determining where fish and shellfish are distributed.

Water intake structures and the area they affect are fixed spatially. If a water intake structure is located in an area used by fish for spawning or by larval fish and shellfish as a nursery area, chances for entraining or impinging these organisms are increased. To locate a water intake structure in the absence of fish and shellfish is unlikely; however, the spatial distribution characteristics of fish and shellfish should be considered when locating and designing a water intake structure.

Many studies have been conducted on the spatial distribution of fish and shellfish (Appendix A). A few relevant examples of distribution studies applicable to the location and design of a water intake structure include preferred habitat, migration routes, depth distribution, and food availability.

Preferred Habitat. Minns et al. (1978) studied the spatial distribution of nearshore fish in the vicinity of two thermal generating stations on the Great Lakes. They observed that fish density varied inversely with water depth. At both study sites fish were observed to prefer shallower depths (3 to 5m). No evidence of changes in fish distribution associated with water temperature changes was found. There was evidence of a relationship between fish community structure and shoreline characteristics. The densest clusters of fish occurred in the vicinity of turbulent portions of the discharge and nearby

streams. Minns et al. (1978) interpreted the lack of response to temperature and the density patterns observed as suggesting that the fish were responding to currents and perhaps topography.

These observed stimulus/response relationships could be used to locate a water intake structure. Depths less frequented by fish could be identified. Identification of areas where bottom topography is unattractive to fish and intake designs that avoid mimicking attractive shoreline topographies could contribute to reductions in entrainment and impingement problems. Spatial separation of intake and discharge areas could reduce the impingement and entrainment of fish attracted to the turbulent discharge area.

Migration and Spawning Routes. Many fish species migrate for long distances to spawn. Some fish spawn in fresh water and migrate to the ocean as juveniles. Some fish migrate from fresh water to salt water to spawn. In the Great Lakes, salmonids, particularly lake trout, use nearshore areas as migration routes during the fall spawning periods (Jude et al., 1981). In the Hudson River, three migration phases have been identified (ORNL, 1977). The fall phase is the period in which young-of-the-year anadromous species migrate downstream and out of the river. A winter phase and spring phase include spawning migrations of Atlantic tomcod and white perch. Along the Pacific Coast from California to Alaska, salmonids utilize coastal streams for their spawning migrations (Scott and Crossman, 1973). Juveniles may migrate seaward after less than 1 year in fresh water and the adults mature in the ocean generally in 3 to 6 years.

Water intake structures along these migration routes could entrain or impinge fish. If an area is used extensively for spawning or acts as a passageway for spawning, intakes should not be located there. Information on the location of migratory routes is important for locating a water intake structure.

Depth Distribution. The distribution of seven species and two invertebrates were studied in the Great Bear Lake, Northwest Territory (Johnson, 1975). Lake trout and four sculpin were found at all depths in the lake. Whitefish were seldom found in water over 20 m deep and their distribution was apparently restricted by the density of benthic organisms. Walleye distribution was restricted to a portion of the lake, McVicar Arm.

These data and observations could be useful in designing or locating a water intake structure. For example, entrainment or impingement of whitefish would be avoided by pumping water from areas of the lake not used by whitefish. Areas where there is a paucity of benthic organisms appear to be unused by whitefish. Interactions with the walleye population could be avoided by locating anywhere except in McVicar Arm.

Distribution/Food Availability, Predation Relationships. The distribution and abundance of 15 littoral zone fish species were studied in a small Michigan lake (Hall and Werner, 1977). These fish exhibited movements which coincided with changes in food levels and vegetation (habitat) development. Distribution of smaller fishes appeared restricted to areas that provided protection from

predation. The authors suggested that year-class strength was strongly influenced by the amount of vegetation available and its effect on predation mortality. Seasonal temperature appeared to set the bounds for movement and habitats utilized; however, other ecological interactions were probably responsible for microhabitat utilization.

Information about the relationship between temperature, fish movements and habitat selection could contribute to minimizing the interaction between fish populations and water intake structures. Additionally, intake designs which do not provide small fish with protection against predation by larger fish would likely attract fewer small fish and associated entrainment and impingement impacts would be smaller.

Environmental Conditions

The behavior, physiology, and ecology of fish or shellfish can be altered by environmental conditions which provide stimuli and regulate response (Figure 3). Response to environmental stimuli is interrelated with present stimuli and recent exposure to stimuli (e.g., thermal acclimation). These considerations are important in deciding the location of a water intake structure, because if fish or shellfish are stressed prior to encountering an intake they may have a reduced capacity to avoid or escape being entrained or impinged. For example, fish that are thermally stressed may not be able to swim as fast or may fatigue sooner than fish that are not stressed. This is true for many environmental conditions that adversely affect the water quality near a water intake structure. In addition to adverse changes in natural conditions, the presence of pollutants could affect the behavior, physiology, and ecology of fish and shellfish.

Research on fish and shellfish indicates varying behavioral and physiological responses when fish are exposed to or presented with gradients in environmental conditions. The following are examples of how this research could be applied to the design or location of a water intake structure.

Temperature. Dean (1973) reports the results of experiments that relate changes in environmental temperatures and the loss of equilibrium for chinook and coho salmon and rainbow trout. Fish acclimated to 15°C were exposed to water temperatures ranging from 27 to 30°C. Exposure continued until loss of equilibrium; then, fish were returned to 15°C water. The sequence of events observed for these fish was a dropping of the tail, followed by a period when the fish was unstable but could still recover with effort. In the final stages, the fish rolled over and could not regain the upright position. Dean notes that under such conditions, fish lacked control and became more subject to predation. Other investigators have used equilibrium loss or critical thermal maximum to evaluate the behavior and physiology of fish species relative to environmental changes (Becker and Genoway, 1979; Lee and Rinne, 1980). Otto et al. (1976) used critical thermal maximum to define the preferred temperatures of the alewife in Lake Michigan. Otto et al. (1976) conclude the predicted intake-discharge temperature difference at Zion Station Nuclear Power Plant may attract alewives to the increased temperature during spring.

These studies indicate the importance of understanding the physiological changes that can occur with fish encountering a change in water temperature. This is an important consideration for water intake design.

Water temperatures may vary from the ambient in intake channels, especially where intake designs include recirculated water for de-icing. This may expose fish and shellfish to sudden increases in temperature from ambient. If the fish that encounter this temperature change lose equilibrium, they will be more likely to be entrained or impinged.

Dissolved Gases. Fish exposed to water supersaturated with atmospheric gases can develop gas bubble disease. Rivers with hydroelectric dams usually become supersaturated during the spring runoff when river flows exceed the hydraulic capacity of the dam turbines. Water has to be spilled over the dam, resulting in the entrainment of large quantities of air. Investigations have shown that fish tolerances to other environmental stresses such as thermal stress and infectious diseases decrease after exposure to supersaturated water (Bouck et al., 1970). Therefore, locating a water intake structure in an area where the water is regularly supersaturated may increase the entrainment and impingement of fish and shellfish.

Industrial Wastes. Industrial wastes have been released into the aquatic environment for years. The most common pollutants in these wastes are heavy metals. Many of these metals are toxic in high concentrations; however, even at low concentrations they can affect the behavior and physiology of fish and shellfish. The larvae of the fiddler crab (Uca pugilator) shows altered behavioral and physiological responses when exposed to very low concentrations of mercury; swimming and metabolic rates of this crab decreased (Vernberg and Vernberg, 1972).

The effects of other industrial wastes, including organic toxins and radioactive wastes, have been studied. Cahn et al. (1973) reviewed some of the research on the effects of pesticides on fish. Temperature selection by young salmon can be altered by DDT (Ogilvie and Anderson, 1965). High dissolved solids can interfere with the migration of striped bass (Radtke and Turner, 1967). Rudd (1964) described the absence of adult spawning salmon in many DDT-sprayed freshwater habitats in Canada.

Location of a water intake structures in areas where industrial wastes have affected the behavior of an organism could result in increased entrainment and impingement. Biologists providing engineers with information to be used to design intakes have to be aware of behavioral and physiological changes in fish and shellfish populations that occur as the result of such non-intake related changes in water quality as industrial wastes.

DESIGN OF INTAKE STRUCTURES

Can the intake be designed to avoid attracting fish and shellfish? Can intake design incorporate features to repulse fish or shellfish away from

areas where they might become entrained or impinged? Can the intake be designed to minimize extreme change in ambient conditions? The intake design that can avoid attracting or can repel fish should reduce the probability of entraining or impinging those that reside near or pass by the intake.

Habitat Selection

Fish and shellfish inhabit given areas and vary their behavior within the aquatic environment for many reasons. They seek places to hide or escape from predators. They need places to protect themselves from extreme changes in environmental conditions, such as fast currents during tide changes. Sessile organisms such as oysters need suitable substrate for attachment. Shoreline configuration, substrate type, depth, and other topographical features of a body of water are important in defining the habitat and the resultant inhabitants.

Water intake structures present new or altered habitat in the aquatic environment. With the beginning of construction, the natural or present habitat is changed and the water intake structure provides an area for colonization and aggregation of aquatic species. The structure, after construction, may also act as a stimulus that attracts or repulses fish and shellfish. Intake structures may vary in the component parts or environmental intrusions (e.g., intake channel and shoreline interface). Four types of water intake structures are shown in Figure 5. The water body in which an intake is located will also in part determine the stimuli that are received by fish and shellfish. This is important in predicting the organism response (Figure 3). Four major types of water bodies in which intake structures are located are rivers, lakes and reservoirs, estuaries, and oceans (Sonnichsen et al., 1975). Table 2 shows some of the physical differences and how these differences might affect biological information needed for design considerations. Knowing how fish and shellfish will respond to the physical presence of an intake is important. If the design can include features that do not attract or features that repulse fish and shellfish, entrainment and impingement may be decreased.

Substrate. Bottom substrate in a body of water can affect the distribution of behavior of fish. Blennids (blennies), pomacentrids (damselfishes), and some juvenile salmonids (salmon) occupy areas subdivided into small individual territories. These fish are all small and demersal. The territory they occupy provides food, shelter, and resting sites. Blennies occupy a territory that primarily contains shelter from which to escape predators. Damselfish and salmon territories are mainly related to available food.

The size of individual salmon territories varies with visual isolation from neighboring salmon, current speed, and prey density. The size of Atlantic salmon territories increases with decreases in substrate size (Kallenburg, 1958). The visual blocks provided by the larger substrates allow neighboring fish to swim closer together before seeing one another. Hartman (1963) observed a similar relationship with current velocity. As current velocity increased, the salmon were more restricted to the bottom, thereby decreasing visual contact area. Slaney and Northcote (1974) observed similar relationships with food density.

TABLE 2. Physical Characteristics and Biological Considerations for Location of Water Intake Structures in Four Water Body Types, (in part from Sonnichsen, 1975.)

<u>Water Body</u>	<u>Physical Characteristics</u>	<u>Biological Considerations</u>
Rivers	uni-directional flow that usually prevents recirculation; therefore, shoreline location.	habitat usually used by juvenile life stages
	forebay necessary for lowest expect flow.	change in shoreline topography
	operation procedures for ice and debris removal	ice and debris accumulation may be attractive habitat.
		removal operation may result in environment stress (eg. thermal shock)
	structure can cause eddies	juvenile unable to control swimming in eddies.
		eddy provides concentration of food organisms.
Lakes and Reservoirs	temperature stratification	withdrawn water temperature may be preferred
	stratification	discharge can alter
	offshore structures used	new habitat
	recirculation(especially lakes)	biocides may be discharged near intake
Estuaries	flow reversal	same consideration as recirculation in lakes
	stratification	similar to lakes. Salinity, which is important to distribution of estuarine populations, may be affected.
	location	commonly used as spawning and nursery area for many marine species
Oceans	surf and waves often require offshore location	must know migratory patterns in proposed locations
	salinity	relation to marine communities
	flow changes with tides	effect on communities as discharge changes.

These territorial observations for blennies, damselfish, and salmon indicate a complex stimulus/response mechanism whereby an individual fish is able to find food and shelter. The data indicate that the stimulus used by individuals is visual, especially for Atlantic salmon. If this visual stimulus/response mechanism were studied relative to the visual stimulus perceived by fish near a water intake structure, it might provide information useful in designing the intake so it does not attract these fish.

Schooling. The schooling behavior of fish is altered by changes in the environment. As stated, a water intake can alter the habitat. Potts (1970) studied the schooling behavior of snapper in the Indian Ocean. The shape and position of the school in the water column changed with current speed. In slack water, the school was dense and became surface oriented. As the currents began to increase in speed, the schools polarized, with each fish heading into the current and settling in the bottom. With this example, we again observe an environmental stimulus (current velocity) that affects the response (depth performance) of the fish. This type of information needs to be studied and understood in order for biological information to be incorporated into water intake designs.

Reefing Response. Fish are attracted to structures in their habitat. There are many publications and reviews on the use of man-made artificial reefs to attract fish and shellfish to an area (Appendix A). Very few of these investigations offer explanations of the behavioral or physiological interactions between the organism and the structure. However, if the stimulus/response mechanisms were fully understood, then the attraction of man-made reefs could help intake designers. If the stimuli that attract fish or shellfish are understood, they can be avoided in intake design.

Visual Orientation. Kilma and Wickham (1971) investigated the attractions of coastal pelagic fish off Panama City, Florida to artificial structures. They used small (less than 2 m long) pup tent-shaped structures positioned in the water column. Complexity of the structures varied with the vertical slots placed on the sides of the structures. They report that attraction appears to be visual. They also studied variations in the structures, noting "simple" structures attracted more fish than "complex" structures. The vertical position of the structure also had some effect on the number of fish attracted.

Although the pup tent-like structure used in the investigations of Kilma and Wickham (1971) are not intake structures, this type of research may be useful for water intake design. Kilma and Wickham observed apparent differences in the attraction of these structures based on positioning in the water column and "complexity" of the structure. They suggest their data indicates that the attraction was dependent upon the visibility of the structures. This type of data may be useful for designing intakes that are not attractive to fish and shellfish or devices to attract fish and shellfish away from areas where they might become entrained or impinged.

Porous Dikes. The porous dike is an example of designing an intake to include fish habitat preferences. The dike is designed to present a habitat that does not attract fish. Marine Research, Inc. (1980) has investigated the behavioral response of 12 Atlantic Coast fish species to a porous rock dike relative to the currents resulting from intake operation. Attraction to the porous rock dike varied with species, age, and current velocities. Pollock (Pollachius virens), Atlantic silverside (Menidia menidia), fourspine stickleback (Apeltes quadracus), scup (Stenotomus chrysops), and northern searobin (Prionotus carolinus) displayed no attraction to the rocks at velocities of 3 cm/sec. Sheepshead minnow (Cyprinodon variegatus) were attracted to the porous rock dike. Threespine stickleback (Gasterosteus aculeatus) were attracted to the rocks, but at velocities up to 3 cm/sec they avoided passing through the screens. Tautog (Tautoga onitis) and cunner (Tautoglabrus adspersus) attempted to enter the rocks despite the relative size of the fish. Response of winter flounder (Pseudopleuronectes americanus) varied with age, with the larvae displaying apparent avoidance. However, winter flounder and windowpane (Scophthalmus aquosus) are poor swimmers and most passed through the screens when flow velocities were 1 cm/sec.

Substrate and Current Preference. Keck et al. (1973) studied tidal stream development and its effect on the distribution of the American oyster in the river mouths through Delaware Bay. Development of dense populations of oysters in these areas is dependent upon the morphological development of tidal channels with areas of bottom scouring. Dense populations are most often found associated with large meanders of such tidal channels. The differential current velocities associated with meanders result in scoured areas which are beneficial to development of oysters, and deposition areas which retard oyster development.

These observations indicate that the distribution of oyster bars in Delaware's tidal rivers depends on the interaction of biological and geological features. The larval oysters must be able to select a substrate with a high potential for survival, e.g. within the scour areas of meander formations. Plants locating or operating a water intake structure in this area should incorporate this biological and geological information into the planning and anticipate impacts on the oyster population.

Response to Stimuli at Water Intake Structures

As previously discussed, the behavior, physiology, and ecology of fish and shellfish can be altered by or are dependent on the ambient environmental conditions. At the water intake structure, a fish or shellfish encounters other stimuli. Some are stimuli resulting from the presence of the intake and others result from intake operation. An intake structure on a river shoreline, for example, usually has a forebay. A shore oriented fish that approaches a forebay encounters a change in depth, light, and possibly temperature and bottom substrate. This fish may be attracted to the light. If the light is in an area that is near the intake screen, the chances of the fish being impinged are increased. Also, a fish entering a forebay may respond by swimming toward the deepest area. In doing this, the fish may swim under a protective curtain

wall or toward an area where the current velocity is great enough to prevent it from escaping. When the intake pumps are operating, the fish or shellfish approaching the intake encounters changes in water velocity, current direction, and sound. Additionally, the intake design may include attractant and avoidance stimuli to reduce entrainment and impingement of aquatic organisms. Examples of the behavior and physiology of fish and shellfish as they relate to possible environmental stimuli at water intake structures are discussed below.

Rheotactic Response. The response of an organism to a water current is a rheotaxis. Keenlyside and Hoar (1954) observed alterations in the rheotactic response of coho salmon fry and smolts when exposed to sudden changes in water temperatures. This stimulus/response relationship may be very important if fish or shellfish near an intake orient themselves into the currents created by intake pumps. This change in orientation may increase the chances of those individuals becoming impinged or entrained.

It is also important to note that rheotaxis is a response to a perceived force on the fish. If the fish cannot perceive that it is being drawn into a velocity field of an intake, then it cannot exhibit rheotaxis. A design consideration that may be useful would be to place visual cues near an intake so fish can perceive changes in or presence of currents. This design consideration may help fish orient properly and perhaps avoid being entrained or impinged.

Thermal Preference. The discharge of heated water at a thermal generating power plant can attract fish to the discharge plume. Romberg et al. (1974) observed a marked seasonal increase in the abundance and species composition of the fish attracted to the thermal discharge at Point Beach Nuclear Power Plant. Smelt and alewife were observed most often. Their abundance varied, with maximum numbers being observed from April to August. Large trout were present near the discharge plume in the winter, but the greatest concentrations near the plume occurred during spring and fall spawning periods.

The data of Romberg et al. (1974) would indicate that a water intake would have to be located to avoid the concentrations of fish that occur near the discharge plume. For example, intake designs that allow some recirculation of heated water to prevent icing need to consider this behavioral response to heated water.

Salinity. It is suggested that post larval shrimp orient to bays in the Gulf of Mexico by utilizing natural salinity gradients that extend seaward from the estuaries (Keiser and Aldrich, 1976). Diversion of the fresh water that flows into the estuaries could alter the natural gradients of salinity, thereby affecting the immigration of shrimp to the estuaries. Keiser and Aldrich (1976) studied the salinity preference of post larval brown and white shrimp (*Penaeus aztecus* and *P. setiferus*) in the laboratory to test the effect changes in salinity have on the suitability of the estuary as a nursery ground. Brown shrimp post larval distributions differed significantly according to the season of the year. Spring post larval shrimp preferred higher salinities than those

tested in the summer or fall. White shrimp postlarval distributions differed seasonally only at low salinity levels. Keiser and Aldrich (1976) suggested that any modification of the salinity gradients in the estuaries used by these species would directly affect the natural influx of post larval shrimp. The salinities preferred by these species, their distributions within these salinities, and seasonal changes of natural salinities in the estuaries would provide very important information for the location of a water intake structure. If operation of a water intake structure is expected to change the salinity pattern near the intake, this could affect the distribution of fish and shellfish in the area and would have to be considered to avoid attracting fish or shellfish to areas where they might become entrained or impinged.

Phototaxis. Protasov (1968) discusses the responses of fish to light and how these responses might change with developmental stages. Fish reaction to light is associated with adaptation to protection from enemies. A positive phototaxis was observed in young fish which seek protection from predators in the upper layers of water. A negative phototaxis was observed for fish that sought protection in the bottom layers of water. For some of the fish observed, as feeding and protection requirement changed with growth, their reaction to light changed. These observations, discussed by Protasov (1968), illustrate how lights or shadows at an intake structure could attract or repulse fish. The response observed at a specific site would depend on the species present and fish developmental stage.

MODIFICATION OF INTAKE DESIGN AND OPERATION

Can daily or seasonal schedules be used to minimize entrainment and impingement of fish and shellfish? Can fish and shellfish at the intake avoid being entrained or impinged? Can a screen size be used that minimizes entrainment? Can impinged fish and shellfish be returned to the environment unharmed? Location requirements and power plant design may require an intake structure that cannot avoid fish and shellfish populations. If designers have behavioral and physiological information about fish and shellfish in the area of the intake, however, impacts resulting from entrainment and impingement may be reduced.

Temporal Distribution

Some fish and shellfish move from one habitat to another (migrate) in response to environmental changes, food supplies, and reproduction requirements. These migrations may occur seasonally, daily, or once in a lifetime. If water intake structures are located along the migration route of a fish or shellfish, the chances of entraining or impinging these organisms is increased. Additionally, if operation schedules can be set to avoid periods of peak migration of fish and shellfish, entrainment and impingement may be reduced.

There are many environmental stimuli that elicit these movements or migrations. The hagfishes (Myxiniidae) are scavengers, detecting food by

chemical cues. After a hagfish detects a chemical stimulus, it responds with positive rheotaxis and swims upstream until it finds its food source (Strahan, 1963). Baggerman (1957, 1959) observed changes in salinity preference as an indication of migration disposition of three-spined sticklebacks. However, in later experiments, Baggerman again observed migrations while varying photoperiod, temperature, and salinity. Baggerman (1962) concluded that the salinity preference and migration activity resulted from stimulated thyroid activity caused by increased photoperiods.

These types of behavioral and physiological stimuli/response relationships related to temporal movements must be understood in designing and operating water intakes. Some of the important temporal movements listed in Figure 5 are described here and examples are given with discussion relative to water intake structures.

Diel Migrations. Pearcy (1972) studied the distribution and diel changes in the behavior of pink shrimp off the Oregon coast. Pink shrimp undertake diel vertical migrations, swimming off the bottom at night. Larger catches with midwater trawls occurred more often at night, while larger catches with bottom trawls occurred during the day. If placement of a water intake structure were necessary where aquatic organisms exhibited these types of diel movements, the intake should include the capability of drawing water from different parts of the water column. This could prevent or reduce entrainment of organisms by pumping away from the organisms.

Intertidal Movements. The intertidal movements of juvenile fish have been studied (Gibson, 1973). Juvenile plaice were observed migrating up and down the beach with each tide. Their vertical distribution was investigated and specific zones in relation to depth were observed. Gibson (1973) hypothesized that fish were able to select and maintain their position at a particular depth throughout a tidal cycle and thus be guided up and down the beach.

Onshore-Offshore Migrations. The landlocked alewife inhabits the open lake water most of the year. In the spring, these fish move into shallow areas to spawn. The timing of these inshore movements is temperature related (Scott and Crossman, 1973). Once in the shallows, the alewife moves inshore at night and offshore during the daylight (Graham, 1956). After spawning, most adults return to deeper waters. Understanding this type of ecological information and the environmental stimulus/behavioral and physiological response relationship is necessary if biological information is to be used in water intake designs.

Swimming Performance

The swimming ability or performance of a given species or individual can vary, depending on the individual and environmental conditions. A healthy individual can usually swim faster and further. The ability of a fish or shellfish to swim can be related in part to the probability of its being entrained or impinged at a water intake structure. Those fish and shellfish that cannot swim and are within the volume of water that is being pumped into a water intake structure will be entrained or impinged. Fish and shellfish

that are able to swim may be able to swim away from an intake. Therefore, it is important to consider the swimming performance of fish and shellfish near a water intake structure.

The water intake structure, especially during operation, presents several environmental changes that can affect the swimming performance of a fish or shellfish. The current velocity in an intake channel and across the screens may be greater than ambient current. Current velocities over the offshore intakes at San Onofre Nuclear Generating Station are designed to provide specific changes in flow direction and to elicit behavioral responses in fish that reduce their probability of being entrained (Stupka and Sharma, 1977).

How a fish or shellfish responds to the changes in velocity or current direction is important when designing and operating a water intake structure. The presentation and discussion of examples of research concerned with the behavior and physiology of fish and shellfish swimming performance is prefaced with a discussion of terminology used by investigators.

There are several ways to describe performance. We have used the terminology presented in Hoar and Randall (1978). They describe three major categories (Table 3), each reflecting time restraints and biochemical processes. Four other terms commonly used to describe swimming performance are given. These terms or descriptions are derived mainly from laboratory experiments and do not always reflect what occurs in nature; however, most swimming data are presented in these terms. The terminology of Hoar and Randall (1978) is used to discuss how the performance of fish and shellfish relates to the stimuli they might encounter at a water intake structure. Several examples follow which discuss the possible use of swim performance information relative to water intake design.

Swim Speed and Intake Approach Velocity. Dorn et al. (1979) studied the swimming performance of nine species of common California inshore fish. The objective of the study was to determine the swimming abilities of fish species entrapped by offshore water intakes. Sustained, burst, and prolonged swimming performance were measured or calculated. The data and analysis suggest that for the species tested, even the smallest fish are capable of escaping by burst swimming. Dorn et al. (1979) state intake velocities should not be a major consideration in evaluating causative factors of fish entrapment. They suggest that additional ambient environmental factors such as wave action, light and fish schooling, and feeding behavior may influence entrainment and impingement of the fish studied.

With this information it would be difficult to use any of the swimming performance data to help design a water intake structure. However, Dorn et al. (1979) have suggested a combination of environmental factors that might be considered in designing an intake to be placed in a habitat that includes these species of fish. It is probably true that swimming performance to some extent has to be considered. A water intake that is not pumping water will not entrain or impinge fish or shellfish. Some pumping capacity exists for which all fish and shellfish near the intake will be entrained or impinged. The fish

TABLE 3. Terminology by Hoar and Randall (1978) to Describe Swimming Performance

Term	Definition	Duration		
Type of Metabolism	Examples/Comments			
Sustained swimming	Swimming activity and speed maintained for an indefinite period	Usually exceeds 200 minutes under laboratory conditions	aerobic	foraging, station holding, schooling, swimming at preferred speeds, steady swimming (including migration)
Burst Speed	Fast swimming for short duration at high speed	Normally less than 15 seconds	anaerobic	fright response, avoidance, prey capture, predator avoidance
Prolonged swimming	Combination of sustained and burst swimming	Between 15 sec and 200 min	aerobic and anaerobic	-----
Fatigue	Point when a fish collapses and can no longer maintain a given swimming speed	-----	-----	-----
Critical swimming speed	Experimentally determined minimum sustained speed at which fatigue will occur	variable	-----	if a fish maintains a swimming speed of 10 cm/sec for 60 minutes and fatigues after 30 swimming minutes at a speed of 12 cm/sec, Hoar and Randall (1978) compute critical swim speed as: $10 + (12-10) \times 30/60 = 11 \text{ cm/sec.}$
Steady speed	observation of constant speed, easily quantified and often used in laboratory experiments	variable	-----	
Unsteady speed	swimming under conditions of continual alteration of direction and speed, most often observed under natural conditions	variable	-----	caution should be exercised when data from steady swimming experiments to situations where fish are swimming unsteadily

near the water intake structure studied by Dorn et al. (1979) were impinged at approach velocities not directly correlatable to laboratory-measured swimming performance. In this case, more information about the environmental conditions that affect swimming performance is required in order to incorporate this information into the intake design.

Preferred Swim Speed. Hanson and Li (1978) examined the behavior and physiology of juvenile chinook salmon (*Oncorhynchus tshawytscha*), bluegill (*Lepomis macrochirus*), and Mississippi silversides (*Menidia audens*) to develop a model based on "energetically optimal swimming speed." Oxygen consumption of sustained swimming fish was measured and expressed as oxygen consumption per unit distance swam. Selected swimming speeds, or swim speeds preferred by the fish, were determined by observation from behavior experiments. The relationship between oxygen consumption and preferred swimming speed was used to define the energetic optimum or speed at which the least oxygen was consumed.

Hanson and Li (1978) have designed an approach to derive water intake velocity design criteria based on the interaction of bioenergetics and fish behavior in velocity gradients. They assessed the behavior of these fish in the laboratory under conditions of possible encounter with a water intake structure. Their observations suggest that entrainment and impingement at water intake structures may be minimized if structures are designed to meet the physiological responses of fish to current velocities. Additionally, an intake velocity that is less stressful to a fish might increase survival of those fish impinged and subsequently removed by fish protection devices (Hanson and Li, 1978). This experimental approach would have to be tested for a site specific and species specific situation; however, these are the types of information that may lead to incorporating biological information into intake design.

Critical Swim Speed and Intake Channel Current Velocities. Jones et al. (1974) investigated the swimming speed of 17 species of fish from the MacKenzie River in Canada. Critical swimming speed was determined and related to fork length. From these relationships they predicted the size-class of a given species that can swim a given distance. This information was used to design culverts to provide passage for fish in areas where roads were constructed across streams.

An analogy between the current velocities in the culvert and some approach channels at intakes may provide useful design information for water intake structures. If there is an approach channel or area at or near the intake where current velocities are greatly increased by pumping, the critical swim speed of fish that could enter this area should be considered. If the currents are too fast, fish entering these might become fatigued and not be able to escape impingement.

Morphology and Hardiness

Some fish and shellfish that cannot avoid being impinged on intake screens may be returned to the environment without being killed or injured. However, fish and shellfish that become entrained and are pumped through the plant condenser probably never survive. Therefore, water intakes that cannot be designed or located to avoid entraining or impinging fish and shellfish may be modified to prevent pumping fish and shellfish through the condenser by impinging them on intake screens. Impinged fish and shellfish then have to be safely returned to the water away from the influence of the water intake structure.

Several investigators have looked at the concept of protecting larval fish at water intake structures by using fine-mesh screening (Salvatore et al., 1978; Murray and Jinette, 1978; and Mussalli et al., 1978). These designs usually include provisions to limit impingement time, a means for safely returning the fish to the water and a safe means of removing the fish from the screens. The size and shape of the fish or shellfish affected their ability to withstand the stress of being impinged, removed from the screen, and then returned to the water, as well as their susceptibility to disease and predation after encountering these stresses. In order to incorporate this concept into an intake design, information about the morphology and hardiness of the fish and shellfish that might be impinged is necessary. The design of an intake screen that limits entrainment of fish and shellfish is dependent on the size and shape of the organisms to be stopped at the screens. Additionally, as the fish and shellfish grow and/or metamorphose, their size and shape changes. Therefore, several screen sizes and shapes may need to be considered.

Fish and shellfish, like all organisms, can be stressed and fatigued. Being impinged on an intake screen is a stress situation, and if impinged for a long enough time, a fish or shellfish will become fatigued or may even die. The hardiness or condition of an impinged fish or shellfish will contribute to its chances of survival.

Investigations of chinook salmon entrainment and impingement at a water intake structure on the Columbia River in Washington were studied from 1973 through 1976 (Gray et al., 1978). Early in the study it was determined that entrainment or passage through the intake screen could be reduced by using a smaller mesh screen and plugging all possible fish entry points along the screen frames. These improvements, however, greatly increased the number of chinook salmon being impinged.

Changes in the screen wash system and intake operation were used to increase the survival of impinged fish. Biologists were able to provide design and operation engineers with information about the size and shape of the fish near a water intake structure. By correlating the size of the screen mesh on the intake with size and body shape, juvenile chinook salmon screen passage and entrainment were greatly reduced. Studies of the ability of the fish to withstand being washed off the screens into a fish return system enabled the engineers at the intake to design a spray wash system that safely removed fish from the intake screens.

Where fish and shellfish are successfully returned to the environment, the water intake could apparently operate without any impact to these populations. However, secondary effects need further investigation. Are fish and shellfish subjected to the sublethal stresses of a fish return system more susceptible to predation or disease. Although we have not reviewed any report investigating these possibilities, Dean (1973) reported that fish exposed to sublethal temperature stress may be more subject to predation.

CONCLUSIONS

This report reviews behavioral, physiological, and ecological literature of fish and shellfish. We have presented a compilation of information describing the relationship between environmental stimuli associated with water intake structures and behavioral and physiological responses of fish and shellfish. Further development of this information will be potentially useful for the design, location, or modification of water intakes.

The report set up a system to provide biological information for engineering models used to design, locate, or modify water intake structures (Figure 2). The type of information and how this information may be used with various design criteria is discussed (Figure 4). Examples of biological research that are potentially applicable to the design criteria presented in Figure 4 are reviewed.

The literature reviewed generally discussed one behavioral, physiological, or ecological response or characteristic of fish and shellfish and how it might relate to some environmental stimuli. Often the investigators in these reports concluded their observations by noting that they might be observing biological responses to a combination of environmental stimuli. This should be expected, even though it will complicate the further development of helpful information. Hanson et al. (1977) state that the flow of information between biologists and engineers is necessary to improve the results of future research related to the entrainment and impingement of fish and shellfish. Research investigations should examine the behavioral and physiological mechanisms associated with entrainment and impingement and the biological characteristics of the fish and shellfish influenced by water intake structures. This type of research would require a combination of laboratory studies investigating the interrelationship between intake hydraulics, and fish and shellfish orientation behavior, sensory physiology, and energetics. Hanson et al. (1977) conclude that coordination or predictive laboratory studies and field site verification studies is essential for developing biological input into intake design and location.

Two of the most important biological characteristics that need to be included in all research are ontological changes and the threshold limits of the species tested. As a fish or shellfish grows or develops, its response to stimuli will change. Biologists and engineers must understand this so biological information used relates to the life stages of fish or shellfish most likely to be entrained or impinged. The threshold response of an organism to a stimulus has to be considered. For example, a fish orienting into a current much slower than its sustained speed capability will demonstrate net movement in the direction of the current. This movement could possibly continue until the fish experiences a current from which it cannot escape.

The discussion of the literature reviewed usually shows how biological information might be applied to water intake design and location criteria. The next step in this study will be to develop and describe functions that relate the behavioral, physiological, and ecological information to the process of

intake engineering. With this review and the subsequent development of functions for some of this information, it will then be possible to describe the appropriateness of the available biological information and the needed precision for their use in design models. It will also be possible to then describe the data requirements to develop further functions for biological characteristics of fish and shellfish relevant to the design, location, and operation of water intake structures.

REFERENCES

- Baggerman, B. 1957. An experimental study on the timing of breeding and migration in the three-spine stickleback Gasterosteus aculeatus L. Archrv. Neerl. Zool. 12(2):105 (Cited in Winn and Olla, 1972).
- Baggerman, B. 1959. The role of external factors and hormones in migration of sticklebacks and juvenile salmon, pp 24-37. In: A. Gorbman (ed.), Comparative Endocrinology. John Wiley and Sons, Inc. New York, New York (Cited in Winn and Olla, 1972).
- Baggerman, B. 1962. Some endocrine aspects of fish migration. Gen. Comp. Endocrinol. Suppl. 1:188. (Cited in Winn and Olla, 1972).
- Barnes, O. 1976. Development Document for Best Technology Available for the Location, Design, Construction and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impacts. EPA 440/1-76/015a. 263 pp.
- Beamish, F. W. H. 1978. Swimming capacity, pp. 101-187. In: Hoar, W.S., and O. J. Randall (ed.), Fish Physiology Vol. VII. Locomotion. Academic Press, New York.
- Becker, C. D., C. E. Cushing, K. L. Gore, K. S. Baker, and D. H. McKenzie. 1979. Synthesis and Analysis of Ecological Information from Cooling Impoundments Volume 2: Appendix A - Study Site Histories and Data Synopsis. EPRI EA-1054. 283p.
- Becker, C. D., and R. G. Genoway. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. Env. Biol. Fish 4(3):245-256.
- Bell, M. C. 1973. Fisheries Handbook of Engineering Requirements and Biological Criteria. US Army Corps of Engineers, Portland, Oregon. (Cited in Sonnichsen et al., 1975.)
- Beskid, N. J. 1978. Hydrologic engineering considerations for Ranney collector well intake systems, pp. 27-36. In: Proceedings of Larval Exclusion Systems for Power Plant Cooling Water Intakes Workshop. San Diego, California.
- Boreman, J. 1977. Impacts of Power Plant Intake Velocities on Fish. FWS/OBS-76/20.1. U.S. Fish and Wildlife Service, Ann Arbor, Michigan. 10 pp.
- Bouck, G. R., G. A. Chapman, P. W. Schneider and D. G. Stevens. 1970. Observations on Gas Bubble Disease in Adult Columbia River Sockeye Salmon, (Oncorhynchus nerka). Pacific Northwest Laboratory, Federal Water Quality Administration, Corvallis, Oregon. (Cited in Environmental Protection Agency, 1971.)

- Cahn, P. H., W. Siler and M. Fujiya. 1973. Sensory detection of environmental changes by fish. In: W. Chavin (ed.), Responses of Fish to Environmental Changes, C.C. Thomas, Springfield, Illinois.
- Chavin, W. 1973. Responses of Fish to Environmental Changes. Charles C. Thomas, Springfield, Illinois. 459 pp.
- Consolidated Edison Company. 1970. Fish Protection at Indian Point Unit No. 1. (Cited in Sonnichsen et al., 1975.)
- Dean, J. M. 1973. The response of fish to a modified thermal environment. In: W. Chavin (ed.), Responses of fish to environmental changes, C. C. Thomas, Springfield, Illinois. 459 pp. (Cited in Chavin, 1973).
- Dorn, P., L. Johnson and C. Darby. 1979. The swimming performance of common California inshore fishes. Trans. Am. Fish. Soc. 108:366-372.
- Freeman, R. F., and R. K. Sharma. 1977. Survey of Fish Impingement at Power Plants in the United States. Volume II. Inland Waters. ANL/ES-56/ 323p.
- Fritz, E. S., P. J. Rago, and I. Murarka. 1980. Strategy of Assessing Impacts of Power Plants on Fish and Shellfish Populations. Power Plant Project, Office of Biological Services, U.S. Fish and Wildlife Service, U.S. Department of Interior. FWS/OBS-80/34. 68 pp.
- Gibson, R. N. 1973. The intertidal movements and distribution of young fish on a sandy beach with special reference to the plaice (Pleuronectes platessa). J. Exp. Mar. Biol. Ecol. 12:79-102.
- Graham, J. J. 1956. Observations on the alewife, Pomolobus Pseudoharengus (Wilson), in fresh water. Univ. Toronto Stud. Biol. Ser. 62, Publ. Ont. Fish. Res. Lab. 74:43p (Cited in Scott and Crossman, 1973).
- Gray, R. H., D. A. Neitzel and T. L. Page. 1978. Water intake structures: engineering solutions to biological problems. The Northern Engineer 10(1):26-33.
- Hall, D. J., and E. E. Werner. 1977. Seasonal distribution and abundance of fishes in the littoral zone of a Michigan Lake. Trans. Am. Fish. Soc. 106(6):545-555.
- Hanson, C. H., and H. W. Li. 1978. A Research Program to Examine Fish Behavior in Response to Hydraulic Flow Fields Development of Biological Design Criteria for Proposed Water Diversions. Report for Office of Water Research and Technology Project C-7679, Grant 14-34-001-7254.
- Hanson, C. H., J. R. White and H. W. Li. 1977. Entrapment and impingement of fishes by power plant cooling water intakes: an overview. Mar. Fish. Rev. 39(10):7-17.

- Hartman, G. F. 1963. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. *J. Fish. Res. Board Can.* 20:F69-F87. (Cited in Keenleyside, 1979.)
- Hoar, W. S., and D. J. Randall. 1978. *Fish Physiology*, Vol. VII Locomotion. Academic Press, New York. 576 pp.
- Johnson, L. 1975. Distribution of fish species in Great Bear Lake, Northwest Territories, with reference to zooplankton, benthic invertebrates and environmental conditions. *J. Fish. Res. Board Can.* 32(11):1989-2004.
- Jones, D. R., J. W. Kiceniuk and O. S. Bamford. 1974. Evaluation of the swimming performance of several fish species from the McKenzie River. *J. Fish. Res. Board Can.* 31(10):1641-1647.
- Jude, D. J., S. A. Klinger, and M. D. Enk. 1981. Evidence of natural reproduction by planted lake trout in Lake Michigan. *J. Great Lakes Research*, Vol. 7.
- Kallenberg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout, Salmo solar L. and S. trutta L. *Rep. Inst. Freshwater Res. Drothningholm* 39:55-98. (Cited in Keenleyside, 1979.)
- Keck, R., D. Maurer and L. Watling. 1973. Tidal stream development and its effect on the distribution of the American oyster. *Hydrobiologia*, 42(4):369-379.
- Keenleyside, M. H. A. 1979. *Diversity and Adaptation in Fish Behavior*. Springer-Verlag, New York. p. 208.
- Keenleyside, M. H. A., and W. S. Hoar. 1954. Effects of temperature on the responses of young salmon to water currents. *Behavior* 7:77-87.
- Keiser, R. K., and D. V. Aldrich. 1976. Salinity Preference of Postlarval Brown and White Shrimp (Penaeus aztecus and P. setiferus) in Gradient Tanks. Texas A&M University Sea Grant Report No. TAMU-SG-75-208. 272 pp.
- Klima, E. F., and D. A. Wickham. 1971. Attraction of coastal pelagic fishes with artificial structures. *Trans. Am. Fish. Soc.* 100(1):86-99.
- Lee, R. M., and J. N. Rinne. 1980. Critical thermal maxima of five trout species in the Southwestern United States. *Trans. Am. Fish. Soc.* 109:632-635.
- Marcy, B. C., Jr., A. D. Beck, and R. E. Ulanowicz. 1978. Effects and impacts of physical stress on entrained organisms, pp. 135-188. In: J. R. Schubel and B. C. March, Jr. (eds.), *Power Plant Entrainment: A Biological Assessment*. Academic Press, New York.

- Marine Research, Inc. 1980. A Progress Report of a Study of the Porous Dike Concept in an Experimental Flume. Prepared for New England Power Company by Marine Research, Inc. Westborough, Massachusetts. p 25.
- Maxwell, W. A. 1972. Fish Diversion for Electrical Generating Station Cooling Systems, a State-of-the-Art Report. Florida Power and Light. (Cited in Sonnichsen et al., 1975.)
- McKenzie, D. H., and J. M. Thomas. 1979. A procedure for assessing biological effects of power plants on fish. *Fisheries* 4(6):23-27.
- Mikels, F. C., and T. W. Bennett. 1978. Cooling water intakes utilizing Ranney collectors or Ranney intakes, pp. 15-26. In: R. K. Sharma and J. B. Palmer (eds.), *Proceedings of Larval Exclusion Systems, for Power Plant Cooling Water Intakes Workshop*. San Diego, California.
- Minns, C. K., J. R. M. Kelso and W. Hyatt. 1978. Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. *J. Fish. Res. Board Can.* 35(6):885-892.
- Morsell, J. W., and C. R. Norden. 1968. Food habits of the alewife, Alosa pseudoharengus (Wilson), in Lake Michigan, pp. 96-102. *Proc. 11th Conf. Great Lakes Res.*
- Murray, L. S., and T. S. Jinnette. 1978. Survival of dominant estuarine organisms impinged on fine-mesh traveling screens at the Barney M. Davis Power Station. In: *Larval Exclusion Systems for Power Plant Cooling Water Intakes*. PB-291 024. Argonne National Laboratory, Argonne, Illinois.
- Mussalli, Y. G., E. P. Taft and P. Hofmann. 1978. Biological and engineering considerations in the fine-screening of small organisms from cooling water intakes. In: *Larval Exclusion Systems for Power Plant Cooling Water Intakes*. PB-291 024. Argonne National Laboratory, Argonne, Illinois.
- Oak Ridge National Laboratory. 1977. A Selective Analysis of Power Plant Operation on the Hudson River with Emphasis on the Bowline Point Generating Station, Vol. 2. ORNL/TM-5877/V2. Prepared for the U.S. Army Corps of Engineers by Oak Ridge National Laboratory under Contract No. 40-596-76. 252 pp.
- Ogilvie, D. M., and J. M. Anderson. 1965. Effect of DDT on temperature selection by young Atlantic salmon, Salmo salar. *J. Fish. Res. Board Can.* 22:503-512. (Cited in Chavin, 1973).
- Otto, R. G., M. A. Kitchel, and J. O. Rice. 1976. Lethal and preferred temperatures of the alewife (Alosa pseudoharengus) in Lake Michigan. *Trans. Am. Fish Soc.* 106(1):96-106.

- Pearcy, W. G. 1972. Distribution and diel changes in the behavior of pink shrimp (Pandalus jordani) off Oregon. Proceedings of the National Shellfisheries Association 62:15-20.
- Potts, G. W. 1970. The schooling ethology of Lutianus Monostigma (Pisces) in the shallow reef environment of Aldabra. J. Zoo. Land. 161:223-235. (Cited in Keenleyside, 1979.)
- Protasov, V. R. 1968. Vision and Near Orientation of Fish. Israel Program for Scientific Translation Jerusalem. (translated from Russian) 175 pp.
- Radtke, L. D., and J. L. Turner. 1967. High concentrations of total dissolved solids as a block to spawning migration of striped bass, Roccus saxatilis, in the San Joaquin River, California. Trans. Amer. Fish Soc. 96:405-407.
- Reynolds, J. Z. 1980. Power plant cooling systems: policy alternatives. Science 207(4429):367-372.
- Ristroph. No date. A free ride for fish. Electrical World. (Cited in Sonnichsen et al., 1975.)
- Richards, R. T. 1978. Engineering considerations in the use of artificial filter beds, pp. 5-12. In: Proceedings of larval exclusion systems for power plant cooling water intakes workshop. San Diego, California.
- Romberg, G. P., S. A. Spigarelli, W. Prepejchal and M. M. Thommes. 1974. Fish behavior at a thermal discharge into Lake Michigan. In: J. W. Gibbons and R. R. Sharitz (eds.), Thermal Ecology. Proceedings of a symposium held at Augusta, Georgia, May 3-5, 1973. 670 pp.
- Rudd, R. 1964. Insecticides and the Living Landscape. University of Wisconsin Press, Madison. (Cited in Chavin, 1973.)
- Salvatore, H. M., D. A. Tomljanovich, J. H. Heuer, S. Vigander, and M. N. Smith. 1978. Investigations on the protection of fish larvae at water intakes using fine-mesh screening impingement-release concept: laboratory study of a single-entrance, double-exit, vertical traveling concept. In: Larval exclusion systems for power plant cooling water intakes. PB-291 024. Argonne National Laboratory, Argonne, Illinois.
- Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull. 184. 966 pp.
- Sharma, R. K., and J. B. Palmer. 1978. Larval exclusion systems for power plant cooling water intakes. Proceedings of workshop held in San Diego, California. p. 235.

- Slaney, P. A., and T. G. Northcote. 1974. Effects of prey abundance on density and territorial behavior of young rainbow trout Salmo gairdneri in laboratory stream channels. J. Fish. Res. Board Can. 31:1201-1209.
(Cited in Keenleyside, 1979.)
- Sonnichsen, J. C., with W. E. Farr and H. S. Riesbol. 1975. Fish Protective Devices: A Compilation of Recent Designs, Concepts and Operating Experience of Water Intakes used in the United States. HEDL-TME 75-38. Hanford Engineering Development Laboratory, Richland, Washington. 82 pp.
- Straham, R. 1963. The behavior of myrinoik. Acta. Zool. 44:73-102.
(Cited in Keenleyside, 1979.)
- Stupka, R.C., and R.K. Sharma. 1977. Survey of Fish Impingement at Power Plants in the United States, Vol. III: Estuaries and coastal waters. ANL/ES56. Argonne National Laboratory, Argonne, Illinois. 310 pp.
- Tavolga, W. N., and J. Wodinsky. 1976. Auditory capacities in fishes: pure tone threshold in nine species of marine teleosts. Bull. Amer. Nat. Hist. 126(177):179-239. In: W. N. Tavolga (ed.), Sound Reception in Fishes. Halsted Press, Stroudsburg, Pennsylvania.
- Vernberg, W.B., and F.J. Vernberg. 1972. Environmental Physiology of Marine Animals. Springer-Verlag, New York. 346 pp.
- Weight, R.H. 1958. Ocean cooling water system for 800 MW power station. Jour. Power Division. Proc. Am. Soc. Civil Engineers. pp. 188-1-1888-22.

APPENDIX A

Throughout the report examples of behavioral, physiological and ecological investigations of fish and shellfish are used to illustrate the type of information a design engineer might use to design, locate or modify a water intake structure. Additional references concerned with the biology of fish and shellfish that might be relevant to their entrainment and impingement are listed here. The outline of the appendix follows the list of biological information listed in Figure 4.

SPATIAL DISTRIBUTION

- Anderson, S. S. 1972. The ecology of Morecambe Bay. Part II. Intertidal invertebrates and factors affecting their distribution. *J. Appl. Ecol.* 9(1):161-178.
- Batzli, G. O. 1969. Distribution of biomass in rocky intertidal communities of the Pacific Coast of the United States. *J. Anim. Ecol.* 38:531-546.
- Chew, K. K., J. W. Wells, D. H. McKenzie and C. K. Harris. 1974. Depth distribution and size of spot shrimp (Pandalus platyceros), trawled in Dabob Bay of Hood Canal, Washington from 1966 to 1971. *Proc. Natl. Shellfisheries Assoc.* 64:28-32.
- Cross, J. N., K. L. Fresh, B. S. Miller, C. A. Simenstad, S. N. Steinford and J. C. Fegley. 1978. Nearshore Fish and Macroinvertebrate Assemblages Along the Strait of Juan de Fuca Including Food Habits of the Common Nearshore Fish. NOAA Tech. Memorandum ERL MESA-32. 118 pp.
- Evans, J. W., and R. L. Noble. 1979. Longitudinal distribution of fishes in an East Texas stream. *Am. Midl. Nat.* 102(2):333-343.
- Foster, B. A. 1971. On the determinants of the upper limit of intertidal distribution on barnacles (Crustacea: Cirripedia). *J. Anim. Ecol.* 40(1):33-48.
- Gascon, D., and W. C. Leffett. 1977. Distribution, abundance and resource utilization of littoral zone fishes in response to nutrient/production gradient in Lake Memphremagog. *J. Fish. Res. Bd. Can.* 34:1105-1117.
- Hambrick, P. S., R. E. Jenkins and J. H. Wilson. 1975. Distribution, habitat and food of Cyprinid fish (Phenacobius teretulus), a New River endemic. *Copeia* 1:172-176.
- Hergenrader, G. L., and A. D. Hasler. 1965. Diel Periodicity of Activity and Vertical Distribution of Perch (Perca flavescens) Under the Ice. The Office of Naval Research Nonr-1202(14), NR 301-903. 18 pp.

- Kendall, A. W., and L. A. Walford. 1979. Sources and distribution of bluefish, (Pomatomus saltatrix), larvae and juveniles off the east coast of the United States. Fish. Bull. 77(1):213-228.
- Louda, S. M. 1979. Distribution, movement and diet of the snail (Searlesia dira) in the intertidal community of San Juan Island, Puget Sound, Washington. Mar. Biol. 51:119-131.
- McFarland, D. J. 1977. Decision making in animals. Nature 269:15-21.
- Peden, A. E., and D. E. Wilson. 1976. Distribution of intertidal and subtidal fishes of Northern British Columbia, Canada and Southeastern Alaska, USA. Syesis 9:221-248.
- Ross, J. R. P., and D. Goodman. 1974. Vertical intertidal distribution of Mytilus edulis. Veliger 16(4):388-395.
- Stevenson, M. M., G. D. Schnell and R. Black. 1974. Factor analysis of fish distribution patterns in western and central Oklahoma. Syst. Zool. 23(2):202-218.
- Strock, T. W., D. W. Dufford and K. T. Clement. 1978. The distribution of limnetic fish larvae in a flood control reservoir in central Illinois. Trans. Am. Fish. Soc. 107(3):419-424.
- Swaidner, J. E., and T. M. Berra. 1979. Ecological analysis of the fish distribution in Green Creek, a spring fed stream in Northern Ohio. Ohio J. Sci. 79(2):92-94.
- Wankowski, J. W. J., and J. E. Thorpe. 1979. Spatial distribution and feeding in Atlantic salmon (Salmo salar) juveniles. J. Fish Biol. 14(3):239-248.
- Youngbluth, M. J. 1976. Vertical distribution and diel migration of Euphausiids in the central region of the California current. Fish. Bull. 74(4):925-936.

ENVIRONMENTAL CONDITIONS

- Beamish, F. W. H. 1970. Influence of temperature and salinity acclimation on temperature preferenda of the euryhaline fish (Tilapia nilotica). J. Fish. Res. Bd. Can. 27:1209-1214.
- Brett, J. R., M. Hollands and D. F. Alderdice. 1958. The effect of temperature on the cruising speed of young sockeye and coho salmon. J. Fish. Res. Bd. Can. 15(4):587-605.
- Carlson, A. R., and L. J. Herman. 1978. Effect of long-term reduction and diel fluctuation in dissolved oxygen on spawning on black crappie. (Pomoxis nigromaculatus). Trans. Am. Fish. Soc. 107(5):742-746.

- Davenport, J. 1971. Salinity tolerance and preference in the porcelain crabs, Porcellana platycheles and Porcellana longicornis. Mar. Behav. Physiol. 1:123-238.
- Deacutis, C. F. 1978. Effect of thermal shock on predator avoidance by larvae of two fish species. Trans. Am. Fish. Soc. 107(4):632-635.
- Dizon, A. E. 1977. Effect of dissolved oxygen concentration and salinity on swimming speed of two species of tunas. Fish. Bull. 75(3):649-653.
- Eldrige, M. B. 1977. Factors influencing distribution of fish eggs and larvae over eight 24-hr samplings in Richardson Bay, California. Calif. Fish and Game 63(2):101-116.
- Kelso, J. R. M. 1977. Density, distribution and movement of Nipigon Bay fishes in relation to a pulp and paper mill effluent. J. Fish. Res. Bd. Can. 34:879-885.
- Leslie, J. K., and J. R. M. Kelso. 1977. Influence of a pulp and paper mill effluent on aspects of distribution, survival and feeding of Nipigon Bay, Lake Superior, larval fish. Bull. of Environ. Contam. Toxicol. 18(5):602-610.
- Maciorowski, H. D., R. McV. Clarke and E. Scherer. 1977. The Use of Avoidance Preference Bioassays with Aquatic Invertebrates. Proc. 3rd Aquatic Toxicity Workshop, Halifax, N.S., Nov. 2-3, 1976. Environmental Protection Service Technical Report No. EPS-5AR-77-1, Halifax, Canada. pp. 49-58.
- Meldrim, J. W., J. J. Gift, and B. R. Petrosky. 1974. The Effect of Temperature and Chemical Pollutants on the Behavior of Several Organisms. PB-239 347. Environmental Protection Agency, Washington, D.C. 129 pp.
- Neill, W. H. 1979. Mechanisms of fish distribution in heterothermal environments. Amer. Zool. 19:305-317.
- Norcross, J. J., S. L. Richardson, W. H. Massmann and E. B. Joseph. 1974. Development of young bluefish (Pomatomus saltatrix) and distribution of eggs and young in Virginian coastal waters. Trans. Am. Fish. Soc. 3:477-497.
- Olla, B. L., W. H. Pearson and A. L. Studholme. 1980. Applicability of behavioral measures in environmental stress assessment, Rapp. P.-V. Reun. Con. Int. Explor. Mer. (accepted).
- Otto, R. G., and J. E. McInerney. 1970. Development of salinity preference in pre-smolt coho salmon, Oncorhynchus kisutch. J. Fish. Res. Bd. Can. 27:793-800.
- Phillips, R. R. 1977. Relationship between social behavior and the use of space in the benthic fish Chasmodes bosquianus Lacepede (Teleostei, Blenniidae): Effects of topography on habitat selection and shelter choice. Behavior 60:1-27.

- Schiewe, M. H. 1974. Influence of dissolved atmospheric gas on swimming performance of juvenile chinook salmon. Trans. Am. Fish. Soc. 103(4):717-721.
- Stauffer, J. R., K. L. Dickson, J. Cairns and D. S. Cherry. 1976. The potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. Wildl. Monogr. 50:5-40.
- Swenson, W. A. 1978. Influence of Turbidity on Fish Abundance in Western Lake Superior. EPA-600/3-78-067. 83 pp.
- Thomas, A. E. 1975. Migration of chinook salmon fry from simulated incubation channels in relation to water temperature, flow and turbidity. Prog. Fish Cult. 73(4):219-223.
- Van Dolah, R. F. 1978. Factors regulating the distribution and population dynamics of the amphipod Gammarus palustris in an intertidal salt marsh community. Ecol. Monogr. 48:191-217.
- Webb, P. W. 1978. Temperature effects on acceleration of rainbow trout, (Salmo gairdneri). J. Fish. Res. Bd. Can. 35:1417-1422.
- Werner, E. E., D. J. Hall, D. R. Laughlin, D. J. Wagner, L. A. Wilsman and F. C. Funk. 1977. Habitat partitioning in a freshwater fish community. J. Fish. Res. Bd. Can. 34:360-370.
- Winn, H. E., and B. L. Olla. 1972a. Behavior of Marine Animals: Current Perspectives in Research. Vol 1: Invertebrates. Plenum Press, New York. 244 pp.
- Winn, H. E., and B. L. Olla. 1972b. Behavior of Marine Animals: Current Perspectives in Research. Vol 2: Vertebrates. Plenum Press, New York. 503 pp.

HABITAT SELECTION

- Arve, J. 1960. Preliminary report on attracting fish by oystershell plantings in Chincoteague Bay, Maryland. Ches. Sci. 1(1):58-65.
- Brewer, G. D. 1978. Reproduction and spawning of the northern anchovy, (Engraulis mordax) in San Pedro Bay, California. Calif. Fish and Game 64(3):175-184.
- Briggs, P. T. 1975a. Shore-zone fishes of the vicinity of Fire Island inlet Great South Bay, New York. N.Y. Fish and Game J. 22(1):1-12.
- Briggs, P. T. 1975b. An evaluation of artificial reefs in New York's marine water. N.Y. Fish and Game J. 22(1):51-56.

- Buchanan, C. C. 1972. A comparison of sport fishing statistics from man-made and natural habitats in the New York Bight. Coastal Plains Cent. Mar. Dev. Serv. Sem. Ser. 1:27-37.
- Buchanan, C. C. 1973. Effects of an artificial habitat on the marine sport fishery and economy of Murrells Inlet, South Carolina. Mar. Fish. Rev. 35(9):15-22.
- Buchanan, C. C., R. B. Stone and R. O. Parker, Jr. 1974. Effects of artificial reefs on a marine sport fishery off South Carolina. Mar. Fish. Rev. 36(11):32-38.
- Carlisle, J. G., C. H. Turner and E. E. Ebert. 1964. Artificial habitat in the marine environment. Calif. Dept. Fish Game, Fish. Bull. 124:1-93.
- Carter, H. H., and S. R. Rives. 1976. An Investigation into the Effect of the Intake Curtain Wall on Forebay Water Quality at Calvert Cliffs. Ches. Bay Inst., Johns Hopkins Univ., Spec. Rep. 51. Reference 76-4.
- Colunga, L., and Richard. 1974. Proceedings of an International Conference on Artificial Reefs held at the Astroworld Hotel in Houston, Texas on March 20-22, 1974. NOAA-75052009. 151 pp.
- Cover, E. C., and R. C. Harrell. 1978. Sequence of colonization diversity biomass and productivity of macroinvertebrates on artificial substrates in a freshwater canal. Hydrobiologia 59(1):81-95.
- Elser, H. J. 1960. A test of an artificial oyster-shell fishing reef, Maryland. Maryland Dep. Res. Educ. 61-16:1-11.
- Gotmsn, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecol. 59(3):507-515.
- Hansen, E. A. 1973. In channel sedimentation basins. A possible tool for trout habitat management. Prog. Fish Cult. 35(3):138-142.
- Hunter, J. R., and C. T. Mitchell. 1967. Association of fishes with flotsam in the offshore waters of Central America. Fish. Bull. 66(1):13-29.
- Hunter, J. R., and C. T. Mitchell. 1968. Field experiments on the attraction of pelagic fish to floating objects. J. Cons. Perm. Int. Explor. Mer. 31(3):427-434.
- Jones, A. N. 1975. Preliminary study of fish segregation in salmon spawning streams. J. Fish Biol. 7(1):95-104.
- Meadows, P. S., and J. I. Campbell. 1972. Habitat selection and animal distribution in the sea: the evolution of a concept. Proc. R.S.E. (B) 73:145 - 157.

- Parker, R. O., R. B. Stone and C. C. Buchanan. 1979. Artificial reefs off Murrells Inlet, South Carolina. Mar. Fish. Rev. September: 12-24.
- Rickards, W. L. 1973. A Bibliography of Artificial Reefs and Other Man-Made Fish Attractants. Univ. North Carolina Sea Grant Program. UNC-56-73-04:1-23.
- Scarratt, D. J. 1968. An artificial reef for lobsters (Homarus americanus). J. Fish. Res. Bd. Can. 25(12):2683-2690.
- Stone, R. B. 1978. Artificial reefs and fishery management. Water Spectrum 10(2):1-6.
- Stone, R. B., H. L. Pratt, R. O. Parker and G. E. Jarvis. 1979. A comparison of fish populations on an artificial and natural reef in the Florida Keys. Mar. Fish. Rev. September 1-11.
- Stroud, R. H. 1961. Artificial saltwater fishing reefs. Sport Fish. Inst. Bull. 121:1-3.
- Stroud, R. H. 1966. Artificial reefs as tools of sport fishery management in coastal marine waters. Sport Fish. Inst. Bull. 170:1-8.
- Turner, C. H., E. E. Ebert and R. R. Given. 1969. Man-made reef ecology. Calif. Dept. Fish. Game Fish. Bull. 146:1-221.
- Unger, I. 1966. Artificial reefs - a review. Am. Litt. Soc. Spec. Publ., 4:1-74.
- Wickham, D. A., and G. M. Russell. 1974. An evaluation of mid-water artificial structures for attracting coastal pelagic fishes. Fish. Bull. 72(1):181-191.
- Wickham, D. A., J. W. Watson, Jr., and L. H. Ogren. 1973. The efficacy of mid-water artificial structures for attracting pelagic sport fish. Trans. Am. Fish. Soc. 102:563-572.

RESPONSE TO STIMULI AT WATER INTAKE STRUCTURE

- Ali, M. A., R. A. Ryder and M. Anctil. 1977. Photoreceptors and visual pigments as related to behavioral responses and preferred habitats of perches (Perca spp.) and pikeperches (Stizostedion spp.). J. Fish. Res. Bd. Can. 34:1475-1480.
- Beitinger, T. L. 1975. Diel activity rhythms and thermoregulatory behavior of bluegill in response to unnatural photoperiods. Biol. Bull. 149:96-108.
- Bigford, T. E. 1979. Ontogeny of light and gravity responses in rock crab larvae (Cancer irroratus). Mar. Biol. 52(1):69-76.

- Blaxter, J. H. S. 1973. Monitoring the vertical movements and light responses of herring and plaice larvae. *J. Mar. Biol. Ass. UK* 53(3):635-647.
- Brooks, A. L. 1971. The effects of underwater sound on marine organisms-- A review. Naval Underwater Systems Center, Newport, Rhode Island. A-400-03-00. 7pp.
- Cada, G. F., A. T. Szluha. 1978. Biological Evaluation of Devices Used for Reducing Entrainment and Impingement Losses at Thermal Power Plants. ORNL CONF-7809109-1.53. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Campbell, K. P. 1971. Influence of light and dark periods on spatial distribution and activity of the white sucker Catostomus commersoni. *Trans. Am. Fish. Soc.* 100(2):333-355.
- Dodson, J. J., and W. C. Leggett. 1974. Role of olfaction and vision in the behavior of American shad (Alosa sapidissima) homing to the Connecticut River from Long Island Sound. *J. Fish. Res. Bd. Can.* 31:1607-1619.
- Forward, R. B., Jr. 1976. A shadow response in a larval crustacean. *Biol. Bull.* 151:126-140.
- Kunesh, W. H., W. J. Freshman, M. Hoehm and N. G. Nordin. 1974. Altering spawning cycle of rainbow trout by control of artificial light. *Prog. Fish Cult.* 36(4):225-226.
- Kwain, W., and R. W. McCauley. 1978. Effects of age and overhead illumination on temperatures preferred by underyearling rainbow trout, Salmo gairdneri, in a vertical temperature gradient. *J. Fish. Res. Bd. Can.* 35:1430-1433.
- Lang, H., R. B. Forward, Jr. and D. C. Miller. 1979. Behavioral response of Balanus improvisus nauplii to light intensity and spectrum. *Biol. Bull.* 157:166-181.
- Latz, M. I., and R. B. Forward, Jr. 1977. The effect of salinity upon phototaxis and geotaxis in a larval crustacean. *Biol. Bull.* 153:163-179.
- Lieberman, J. T., and P. H. Muessing. 1978. Evaluation of an air bubbler to mitigate fish impingement at an electric generating plant. *Estuaries* 1(2):129-132.
- Maxfield, G. H., R. H. Lander and K. Liscom. 1971. Survival, growth and fecundity of hatchery-reared rainbow trout after exposure to pulsating direct current. *Trans. Am. Fish. Soc.* 3:546-552.
- McHugh, J. J., and R. C. Heidinger. 1977. Effects of light on feeding and egestion time of striped bass fry. *Prog. Fish Cult.* 39(1):33-34.
- McHugh, J. J., and R. C. Heidinger. 1978. Effects of light shock and handling shock on striped bass fry. *Prog. Fish Cult.* 40(2):82.

- Ritter, J. A., and H. R. MacCrimmon. 1973. Effects of illumination on behavior of wild brown (Salmo trutta) and rainbow trout (S. gairdneri) exposed to black and white backgrounds. J. Fish. Res. Bd. Can. 30(12):1875-1880.
- Ritz, D. A. 1972. Behavioral response to light of the newly hatched phyllosoma larvae of Panulorus longipes cygnus George (Crustacea: Decapoda: Palinuridae). J. Exp. Mar. Biol. Ecol. 10:105-114.
- Ryder, R. A. 1977. Effects of ambient light variations on behavior of yearling, subadult, and adult walleyes (Stizostedion vitreum vitreum). J. Fish. Res. Bd. Can. 34:1481-1491.
- Stober, Q. J. 1969. Underwater noise spectra, fish sounds and response to low frequencies of cutthroat trout (Salmo clarki) with reference to orientation and homing in Yellowstone Lake. Trans. Am. Fish Soc. 4:652-663.
- Sulkin, S. D. 1975. The influence of light in the depth regulation of crab larvae. Biol. Bull. 148(2):333-343.
- Tavolga, W. N. 1967. Significance of underwater sound in fishes. Office of Naval Research NR 3D1-322. 10pp.
- Vinyard, G. L., and W. J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (Lepomis macrochirus). J. Fish Res. Bd. Can. 33:2845-2849.
- Wickham, D. A. 1973. Attracting and controlling coastal pelagic fish with nightlights. Trans. Am. Fish Soc. 4:816-825.
- Zeitoun, I. H., J. A. Gulvas, and D. B. Roarabaugh. 1981. Effectiveness of fine mesh cylindrical wedge-wire screens in reducing entrainment of Lake Michigan ichthyoplankton. Can. J. Fish Aquat. Sci. 38:120-125.

TEMPORAL DISTRIBUTION

- Alton, M. S., and C. J. Blackburn. 1972. Diel changes in the vertical distribution of the Euphausiids (Thysanoessa spinifera Holmes) and Euphausia pacifica Hansen, in coastal waters of Washington. 1972. Calif. Fish and Game 58(3):179-190.
- Baumann, P. C., and J. F. Kitchell. 1974. Diel patterns of distribution and feeding of bluegill (Lepomis macrochirus) in Lake Wingra, Wisconsin. Trans. Am. Fish Soc. 2:255-260.
- Bohlin, T. 1978. Temporal changes in the spatial distribution of juvenile sea-trout (Salmo trutta) in a small stream. Oikos 30:114-120.

- Chesney, E. J., and J. Iglesias. 1979. Seasonal distribution, abundance and diversity of demersal fishes in the inner Ria de Arosa, Northwest Spain. *Estuarine and Coastal Mar. Sci.* 8:227-239.
- Galloway, B. J., and K. Strawn. 1974. Seasonal abundance and distribution of marine fishes at a hot-water discharge in Galveston Bay, Texas. *Contributions in Mar. Sci.* 18:71-137.
- Jones, D., and J. Clare. 1977. Annual and long-term fluctuations in the abundance of fish species inhabiting an intertidal mussel bed in Morecambe Bay, Lancashire, England. *Zool. Linn. Soc.* 60(2):117-172.
- Kelso, J. R. M., and C. K. Minns. 1975. Summer distribution of the nearshore fish community near a thermal generating station as determined by acoustic census. *J. Fish Res. Bd. Can.* 32(8):1409-1418.
- Long, C. W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. *Fishery Bull.* 66(3):599-609.
- Nishimoto, R. T., and W. F. Herrnkind. 1978. Directional orientation in blue crabs Callinectes sapidus Rathbun: escape responses and influence of wave direction. *J. exp. mar. Biol. Ecol.* 33:93-111.
- McNeely, D. L., and W. D. Pearson. 1974. Distribution and condition of fishes in a small reservoir receiving heated waters. *Trans. Amer. Fish Soc.* 3:518-530.
- Richardson, S. L., and W. G. Pearcy. 1977. Coastal and oceanic fish larvae in an area of upwelling off Yaquina Bay, Oregon. *Fish. Bull.* 75(1):125-145.
- Stauffer, J. R., K. L. Dickson, J. Cairnes, W. F. Calhoun, M. T. Masnik and R. H. Myers. 1975. Summer distribution of fish species in the vicinity of a thermal discharge New River, Virginia. *Arch. Hydrobiol.* 76(3):287-301.
- Venema, S. C., and F. Creutzberg. 1973. Seasonal migration of the swimming crab Macropipus helsatus in an estuarine area controlled by tidal streams. *Netherlands J. Sea Res.* 7:94-102.
- Wurtsbaugh, W. A., R. W. Brocksen and C. R. Goldman. 1975. Food and distribution of underyearling brook and rainbow trout in Castle Lake, California, USA. *Trans. Am. Fish Soc.* 104(1):88-95.

SWIMMING PERFORMANCE

- Beamish, F. W. H. 1966. Swimming endurance of some Northwest Atlantic fishes. *J. Fish. Res. Bd. Can.* 23(3):341-347.
- Blaxter, J. H. S. 1969. Swimming speeds of fish. *FAO (Food Agr Organ UN) Fish Rep.* 62(2):69-100.

- Brett, J. R. 1967. Swimming performance of sockeye salmon (Oncorhynchus nerka) in relation to fatigue time and temperature. J. Fish. Res. Bd. Can. 24(8):1731-1741.
- Collette, B. B., M. A. Ali, K. E. F. Hokanson, M. Nagiec, A. Smirnov, J. E. Thorpe and A. H. Weatherly. Biology of the Percids. EPA-600/03. From the Proceedings of the Percid International Symposium (PERCIS) at Quetico Centre, Ontario. 10pp.
- Foster, J. J. 1969. The influence of fish behavior on trawl design with special reference to mathematical interpretation of observations on the swimming speeds of fish and results of comparative fishing experiments. FAO Fish Rep. (3)62:731-773.
- Greenland, D. C., and A. E. Thomas. 1972. Swimming speed of fall chinook salmon (Oncorhynchus tshawytscha). Trans. Am. Fish. Soc. 4:696-700.
- Greenway, P. 1965. Body form and behavioral types in fish. Experientia. 21:1-10.
- Hunter, J. R. 1972. Swimming and feeding behavior of larval anchovy (Engraulis mordax). Fish. Bull. 70(3):821-837.
- Laurence, G. C. 1972. Comparative swimming abilities of fed and starved larval largemouth bass (Micropterus salmoides). J. Fish. Biol. 4:73-78.
- Malinin, L. K. 1975. The swimming speed of Salmo salar during freshwater anadromous migration. Translated from Zool. Zh. 54(11):1729-1731.
- Phillips, B. F., and L. Olsen. 1975. Swimming behavior of puerulus larvae of the western rock lobster. Aust. J. Mar. Freshwat. Res. 26:415-417.
- Roberts, J. L. 1975. Active branchial and ram gill ventilation in fishes. Biol. Bull. 148:85-105.
- Sasaki, M., W. Heubach and J. E. Skinner. 1973. Some Preliminary Results on the Swimming Ability and Impingement Tolerance of Young-of-the-Year Steelhead Trout, King Salmon and Stripped Bass. Final report for Anadromous Fisheries Act Project, California AFS-13. 31pp.
- Thomas, A. E., and M. J. Donahoo. 1977. Differences in swimming performance among strains of rainbow trout (Salmo gairdneri). J. Fish. Res. Bd. Can. 34:304-306.
- Tsuyuki, H., and S. N. Willisroft. 1977. Swimming stamina differences between genotypically distinct forms of rainbow (Salmo gairdneri) and steelhead trout. J. Fish. Res. Bd. Can. 34:996-1003.
- Vlymen, W. J. 1974. Swimming energetics of the larval anchovy (Engraulis mordax). Fish. Bull. 72(4):885-899.

- Wardle, C. S. 1975. Limit of fish swimming speed. *Nature* 255(5511):725-727.
- Ware, D. M. 1975. Growth, metabolism and optimal swimming speed of a pelagic fish. *J. Fish. Res. Bd. Can.* 32:33-41.
- Ware, D. M. 1978. Bioenergetics of pelagic fish: Theoretical change in swimming speed and ration with body size. *J. Fish Res. Bd. Can.* 35:220-228.
- Webb, P. W. 1975. Hydrodynamics and energetics of fish propulsion. *Fish Res. Bd. Can. Bull.* 190:1-159.
- Webb, P. W. 1975. Acceleration performance of rainbow trout (Salmo gairdneri) and green sunfish (Lepomis cyanellus). *J. Exp. Biol.* 63(2):451-465.
- Webb, P. W. 1976. The effect of size on the fast start performance of rainbow trout (Salmo gairdneri) and a consideration of piscivorous predator prey interactions. *J. Exp. Biol.* 65(1):157-177.
- Weihs, D. 1974. Energetic advantages of burst swimming of fish. *Jour. of Theoretical Biology* 48(1):215-229.
- Weihs, D. 1975. Optimum swimming speed of fish based on feeding efficiency. *Israel J. Tech.* 13:163-167.
- Williams, A. B. 1973. The swimming of crabs of the genus Callinectes (Decapoda: Portunidae). *Fish. Bull.* 72(3):685-798.

APPENDIX B

The species discussed throughout the report were not necessarily species that have been reported as being entrained or impinged at water intakes. For readers interested or needing to know the species that are reported as entrained and/or impinged at water intakes this appendix presents lists showing this and other information.

Table B.1 lists the common names of 55 fish species observed in impingement samples at 83 power plants in the United States. This information is summarized from Surveys of Fish Impingement at Power Plants in the United States Vol. I through III (Sharma and Freeman, 1977; Freeman and Sharma, 1977; Stupka and Sharma, 1977). The name and location of the power plants and the water habitat (i.e., estuarine or coastal, river or reservoir, freshwater lake) are also listed. The above cited references also include lists of over 500 other fish species either entrained, impinged or found near the power plants that were surveyed.

Table B.2 lists the common name for 18 species of invertebrates that may be affected by the location and operation of water intake structures. This list was compiled from species mentioned in the entrainment and impingement literature and from discussions with U.S. Fish and Wildlife personnel.

Also included in this appendix are two lists of journal articles and technical reports. The first list includes entrainment and impingement references. The references are arranged alphabetically, by senior author. Some of the species observed and the study site are noted for most references.

The second list includes references to behavioral and physiological studies for some of the 55 species of fish listed in Table B.1 and 18 species of invertebrates listed in Table B.2. The references are arranged alphabetically, by senior author. The fish and shellfish species discussed are noted.

Table B.1. Summary of the Fish Species Most Frequently Observed in Impingement Samples Collected at Water Intake Structures Throughout the United States (Sharma and Freeman, 1977; Freeman and Sharma, 1977; Stupka and Sharma, 1977). The species are in the order in which they were listed in the text and do not indicate abundance, frequency of impingement or importance.

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
J.P. Pulliam	Freshwater lake	Green Bay, WI	alewife yellow perch black bullhead
Kewaunee	Freshwater lake	WI	alewife rainbow smelt sucker
Point Beach	Freshwater lake	WI	alewife rainbow smelt yellow perch
Port Washington	Freshwater lake	Port Washington, WI	alewife rainbow smelt brown trout
Lakeside	Freshwater lake	St. Francis, WI	alewife slimy sculpin spottail shiner
Oak Creek	Freshwater lake	Milwaukee, WI	alewife rainbow smelt yellow perch
Zion	Freshwater lake	Zion, IL	alewife rainbow smelt slimy sculpin spottail shiner
Waukegan	Freshwater lake	Waukegan, IL	alewife rainbow smelt gizzard shad
State Line	Freshwater lake	Hammond, IN	alewife gizzard shad spottail shiner
Dean H. Mitchell	Freshwater lake	Lake County, IN	alewife gizzard shad yellow perch

Table B.1 (Contd)

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
Bailly	Freshwater lake	Porter County, IN	alewife yellow perch rainbow smelt
Michigan City	Freshwater lake	LaPorte County, IN	alewife yellow perch northern pike
Donald C. Cook	Freshwater lake	Berrien County, MI	yellow perch slimy sculpin alewife spottail shiner
Palisades	Freshwater lake	Van Buren County, MI	slimy sculpin alewife spottail shiner
J.H. Campbell	Freshwater lake	Ottawa County, MI	alewife gizzard shad spottail shiner
Big Rock	Freshwater lake	Charlevoix County, MI	alewife rainbow smelt lake chub
D.E. Karn and J.C. Weadock	Freshwater lake	Bay City, MI	gizzard shad yellow perch spottail shiner
R.E. Ginna	Freshwater lake	Wayne County, NY	alewife rainbow smelt spottail shiner
Nine Mile Point	Freshwater lake	Oswego County, NY	alewife rainbow smelt spottail shiner mottled sculpin
Yankee Atomic	Inland rivers or reservoir	Rowe, MA	rock bass yellow perch rainbow smelt
Connecticut Yankee	Inland rivers or reservoir	Haddam, CT	white perch white catfish

Table B.1 (Contd)

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
Three Mile Island	Inland rivers or reservoir	Harrisburg, PA	spottail shiner tessellated darter spotfin shiner channel catfish
Peach Bottom	Inland rivers or reservoir	PA	bluegill white crappie channel catfish
Allen Station	Inland rivers or reservoir	Charlotte, NC	threadfin shad gizzard shad bluegill
H.E. Robinson	Inland rivers or reservoir	Darlington County, SC	bluegill warmouth yellow perch
Wateree Station	Inland rivers of reservoir	Eastover, SC	threadfin shad channel catfish yellow perch
John Seivier	Inland rivers or reservoir	Rogerville, TN	gizzard shad threadfin shad channel catfish
Bull Run	Inland rivers or reservoir	TN	threadfin shad gizzard shad logperch
Kingston	Inland rivers or reservoir	TN	threadfin shad bluegill freshwater drum
Watts Bar	Inland rivers or reservoir	TN	threadfin shad bluegill freshwater drum
Widows Creek	Inland rivers or reservoir	AL	gizzard shad threadfin shad freshwater drum
Browns Ferry	Inland rivers or reservoir	AL	shad and herring freshwater drum catfish

Table B.1 (Contd)

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
Colbert	Inland rivers or reservoir	AL	threadfin shad gizzard shad skipjack herring
Johnsonville	Inland rivers or reservoir	TN	gizzard shad threadfin shad freshwater drum
Gallatin	Inland rivers or reservoir	TN	gizzard shad threadfin shad freshwater drum
Cumberland	Inland rivers or reservoir	TN	shad freshwater drum silver chub
Paradise	Inland rivers or reservoir	KY	gizzard shad threadfin shad freshwater drum
Shawnee	Inland rivers or reservoir	Paducah, KY	gizzard shad threadfin shad freshwater drum
T.H. Allen	Inland rivers or reservoir	Memphis, TN	gizzard shad threadfin shad freshwater drum
Clifty Creek	Inland rivers or reservoir	Madison, IN	gizzard shad freshwater drum skipjack herring
B.C. Cobb	Inland rivers or reservoir	Muskegon County, MI	northern pike alewife trout perch gizzard shad
Green River	Inland rivers or reservoir	Muhlenberg County, KY	threadfin shad gizzard shad bluegill
Baldwin	Inland rivers or reservoir	Baldwin, IL	gizzard shad freshwater drum flathead catfish

Table B.1 (Contd)

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
Wood River	Inland rivers or reservoir	Madison County, IL	gizzard shad freshwater drum bluegill
Quad-Cities	Inland rivers or reservoir	IL	gizzard shad channel catfish freshwater drum
La Crosse	Inland rivers or reservoir	Mississippi River Mile 678.5	bluegill freshwater drum white crappie
Prairie Island	Inland rivers or reservoir	Goodhue County MN	white bass freshwater drum gizzard shad crappie
Arkansas	Inland rivers or reservoir	Pope County, AR	threadfin shad gizzard shad freshwater drum
Cooper	Inland rivers or reservoir	Nemaha County, NB	river carpsucker gizzard shad freshwater drum
George Neal	Inland rivers or reservoir	Sioux City, IA	gizzard shad freshwater drum bluegill channel catfish
Hanford	Inland waters or reservoir	Benton County, WA	chinook salmon
Marine Yankee	Estuarine or coastal	Wiscasset, ME	threespine stickleback smooth flounder rainbow smelt
Salem Harbor	Estuarine or coastal	Salem, MA	Atlantic menhaden winter flounder northern pipefish threespine stickleback
Mystic	Estuarine or coastal	Everett, MA	winter flounder rainbow smelt alewife

Table B.1 (Contd)

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
Pilgrim	Estuarine or coastal	Plymouth, MA	Atlantic silverside rainbow smelt
Canal	Estuarine or coastal	Sandwich, MA	cunner blueback herring alewife
Brayton Point	Estuarine or coastal	Somerset, MA	threespine stickleback Atlantic menhaden Atlantic silverside winter flounder
Millstone	Estuarine or coastal	Waterford, CT	Atlantic menhaden winter flounder windowpane
Indian Point	Estuarine or coastal	Buchanan, NY	white perch Atlantic tomcod bay anchovy striped bass rainbow smelt
Northport	Estuarine or coastal	Long Island, NY	Atlantic menhaden winter flounder Atlantic silverside
Astoria	Estuarine or coastal	New York, NY	striped searobin Atlantic silverside blueback herring Atlantic menhaden alewife
Oyster Creek	Estuarine or coastal	Ocean City, NJ	Atlantic silverside winter flounder northern pipefish bay anchovy blueback herring
Edge Moor	Estuarine or coastal	Wilmington, DE	white perch silvery minnow American eel blueback herring

Table B.1 (Contd)

<u>Power Plant</u>	<u>Habitat</u>	<u>Location</u>	<u>Species (common name)</u>
Calvert Cliffs	Estuarine or coastal	Calvert County, MD	bay anchovy Atlantic croaker spot
Surry	Estuarine or coastal	Surry County, VA	blueback herring gizzard shad Atlantic menhaden
Brunswick	Estuarine or coastal	Brunswick County, NC	grey trout Atlantic croaker Atlantic menhaden
A.M. Williams	Estuarine or coastal	Berkeley County, SC	hogchoker threadfin shad blueback herring
Crystal River	Estuarine or coastal	Citrus County, FL	polka-dot batfish pinfish Atlantic threadfin
Willow Glen	Estuarine or coastal	St. Gabriel, LA	gizzard shad blue catfish freshwater drum
Cedar Bayou	Estuarine or coastal	Houston, TX	gulf menhaden Atlantic croaker spot
Barney M. Davis	Estuarine or coastal	Corpus Christi, TX	gulf menhaden bay anchovy tidewater silverside
Trojan	Estuarine or coastal	Prescott, OR	eulachon prickly sculpin American shad
San Onofre	Estuarine or coastal	CA	queenfish walleye surfperch white croaker

TABLE B.2 Common Names of Invertebrates that are Affected by the Location and Operation of Water Intake Structures

oysters	sand crabs
soft shell clams	Dungeness crabs
hard shell clams	Paeneid shrimp
cherrystone clams	rock shrimp
mussels	sea urchins
blue crab	abalone
American lobster	Pismo clams
spiny lobster	Mysids
stone crabs	squid

ENTRAINMENT AND IMPINGEMENT REFERENCES

Barnthouse, L. W., J. B. Cannon, S. G. Christensen, A. H. Eraslan, J. L. Harris, K. H. Kim, M. E. LaVerne, H. A. McLain, B. D. Murphy, R. J. Raridon, T. H. Row, R. D. Sharp and W. Van Winkle. 1977. A Selective Analysis of Power Plant Operation on the Hudson River with Emphasis on the Bowline Point Generating Station. ORNL/TM-5877/V2. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 239 pp.

partial list of species observed: striped bass, white perch, tomcod, alewife, blueback herring, anchovy.

study site: Hudson River, NY.

Dahlberg, M. D. 1979. A review of survival rates of fish eggs and larvae in relation to impact assessment. Marine Fisheries Review 41(3):1-12.

partial list of species discussed: walleye, striped bass, Atlantic herring, northern pike, rainbow smelt, yellow perch, salmon

study site: not specified

Griffith, J. S., and D. A. Tomljanovich. 1975. Susceptibility of Threadfin Shad to Impingement. ORNL CDNF-751066-1. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 26 pp.

species observed: threadfin shad

study site: 13 Tennessee Valley Authority electrical generating facilities.

Grotbeck, L. M., and J. L. Bechthold. 1975. Fish impingement at Monticello Nuclear Plant. Power Division. ASCE 101(1):69-83.

most frequently observed species: black bullhead, black crappie, carp

study site: Monticello Nuclear Plant, Minneapolis, MN.

Kelso, J. R. M., and J. K. Leslie. 1979. Entrainment of larval fish by the Douglas Point generating station, Lake Huron, in relation to seasonal succession and distribution. J. Fish. Res. Board Can. 36:37-41.

species observed: fourhorn sculpin, rainbow smelt, alewife, yellow perch, brook stickleback, slimy sculpin, white sucker

study site: Douglas Point Generating Station, Ontario, Can.

Kumar, K. D., and J. S. Griffith. 1977. Temporally stratified sampling programs for estimation of fish impingement. ORNL CONF-771231-2. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 24 pp.

species observed: threadfin shad

study site: Arkansas Unit One, AR and Browns Ferry Nuclear Plant, AL.

Mathur, D., P. G. Heisey, and N. C. Magnusson. 1977. Impingement of fishes at Peach Bottom Atomic Power Station, Pennsylvania. Trans. Am. Fish. Soc. 106(3):258-267.

most frequently observed species: channel catfish, white crappie, bluegill

study site: Peach Bottom Atomic Power Station, PA.

McFarlane, R. W., R. F. Frietsche, and R. D. Miracle. 1978. Impingement and Entrainment of Fishes at the Savannah River Plant: An NPDES 316b Demonstration. Prepared for the U.S. Dept. of Energy under Contract AT(07.2) 1 by E.I. du Pont de Nemours and Company, Aiken, South Carolina. 68 pp.

most frequently observed species: bluespotted sunfish, warmouth, channel catfish, yellow perch

study site: Savannah River, SC.

Schubel, J. R., and B. C. Marcy, Jr. (eds.). 1978. Power Plant Entrainment--A Biological Assessment. Academic Press. New York. 271 pp.

Zawacki, C. S., and P. T. Briggs. 1976. Fish investigations in Long Island Sound at a nuclear power station site at Shoreham, New York. New York Fish and Game Journal 23(1):34-50.

species observed: Atlantic silverside, Atlantic menhaden

study site: Shoreham, NY.

The reader interested in the entrainment and impingement of a species or the impacts at a particular site should also refer to the references listed below.

Carrier, R. F., and E. H. Hannon. 1979. Entrainment: An annotated bibliography. EPRI EA-1049. Electric Power Research Institute, Palo Alto, California. 193 pp.

Over 600 annotated references are presented in this bibliography. Published and unpublished literature covering the years 1947 through 1977 is presented. The bibliography includes references on monitoring studies at power plant sites, laboratory studies of physical and biological effects on entrained organisms, engineering strategies for the mitigation of entrainment effects and selected theoretical studies concerned with the methodology for determining the ultimate significance of entrainment effects to populations and ecosystems.

Uziel, M. S., and E. H. Hannon. 1979. Impingement: An annotated bibliography EPRI EA-1050. Electric Power Research Institute, Palo Alto, California. 193 pp.

Over 600 annotated references on impingement of aquatic organisms at intake structures of thermal power plant cooling systems are compiled from the published and unpublished literature. The bibliography includes references from 1928 to 1978 on impingement monitoring programs, impingement impact assessment; applicable law; location and design of intake structures, screens, louvers, and other barriers; fish behavior and swim speed as related to impingement susceptibility; and the effects of light, sound, bubbles, currents, and temperature on fish behavior.

BEHAVIORAL AND PHYSIOLOGICAL REFERENCES

Adams, W. J., D. J. Behmer and W. O. Weingarten. 1972. Recovery of shocked common shiner (Notropis cornutus) related to electric energy. Trans. Am. Fish. Soc. 101(3):552-555.

shiner

Allen, K. O, and J. W. Avault, Jr. 1971. Notes on the relative salinity tolerance of channel catfish and blue catfish. Prog. Fish-Cult. 33(3):135-137.

blue catfish

channel catfish

Amundrud, J. R., D. J. Faber and A. Keast. 1974. Seasonal succession of free swimming perciform larvae in Lake Opinicon, Ontario, Canada. J. Fish. Res. Board Can. 31(10):1661-1665.

yellow perch

Anctil, M. 1967. Ecological Implications of the Retinal Structure in Some Marine Teleosts of the St. Lawrence Gulf, Canada. Sta. Biol. Mar. Grande-Riviere Que Rapp. Annu. pp. 67-73.

rainbow smelt

Atema, J. 1969. The role of taste in the behavior of the catfish (Ictalurus natalis). Amer. Zool. 9(4):1077.

catfish

Atema, J., and D. G. Engstrom. 1971. Sex pheromone in the lobster (Homarus americanus). Nature 232(5308):261-263.

American lobster

Atema, J., S. Jacobson and J. Todd. 1973. The importance of chemical signals in stimulating behavior of marine organisms effects of altered environmental chemistry on animal communication. pp. 177-197. In: G. E. Glass (ed.), Bioassay Techniques and Environmental Chemistry. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

American lobster

alewife

horse-shoe crab

Atema, J., and L. S. Stein. 1974. Effects of crude oil on the feeding behavior of the lobster (Homarus americanus). Environ. Pollut. 6(2):77-86.

American lobster

Atema, J. 1976. Sublethal effects of petroleum fractions on the behavior of the lobster (Homarus americanus) and the mud snail (Nassarius obsoletus). pp. 302-312. In: M. Wiley (ed.), Estuarine Processes. Vol. 1. Academic Press, New York.

American lobster

Baldes, R. J., and R. E. Vincent. 1969. Physical parameters of micro habitats occupied by brown trout in an experimental flume. Trans. Amer. Fish Soc. 98(2):230-238.

brown trout

Beamish, F. W. H. 1969. Photographic observations on reactions of fish ahead of otter trawls. FAO (Food Agr. Organ UN) Fish Rep. 3(62):511-521.

cod
sculpin

Becker, C. D., and R. G. Genoway. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. Environ. Biol. Fishes. 4(3):245-256.

coho salmon
pumpkin seed

Biahm, T. H., and R. J. McConnell. 1971. Mortality of adult eulachon (Thaleichthys pacificus) subjected to sudden increases in water temperature. Northwest Sci. 45(3):178-182.

eulachon

Block, R. M. 1977. Physiological responses of estuarine organisms to chlorine. Chesapeake Sci. 18(1):158-160.

white perch
Atlantic menhaden
eastern oyster
blue crabs

Block, R. M., J. C. Rhoderick and S. R. Gullans. 1977. Physiological response of white perch (Morone americana) to chlorine. ASB (Assoc. Southeast Biol.) Bull. 24(2):37.

white perch

Boaze, J. J., and R. T. Lackey. 1972. Winter mortality of the landlocked alewife (Alosa pseudoharengus) in Clayton Lake, Virginia. Va. J. Sci. 23(3):109.

alewife

Brett, J. R. 1971. Energetic responses of salmon to temperature, a study of some thermal relations in the physiology and fresh water ecology of sockeye salmon (Oncorhynchus nerka). Amer. Zool. 11(1):99-113.

sockeye salmon

Brown, B. E., I. Inman and A. Jerald, Jr. 1970. Schooling and shelter seeking tendencies in fingerling channel catfish. Trans. Amer. Fish Soc. 99(3):540-545.

channel catfish

Bryan, C. F., and T. R. Sopher. 1969. New northern record for the threadfin shad (Dorosoma petenese) in coastal waters of California USA fishery stocking. Calif. Fish Game 55(2):155-156.

threadfin shad

Burbidge, R. G. 1969. Age growth length weight relationship sex ratio and food habits of American smelt (Osmerus mordax) from Gull Lake, Michigan. Trans. Amer. Fish. Soc. 98(4):631-640.

American smelt

Cairns, J. Jr., R. E. Sparks and W. T. Waller. 1973. The relationship between continuous biological monitoring and water quality standards for chronic exposure. pp. 383-401. In: G. E. Glass (ed.), Bioassay Techniques and Environmental Chemistry. XI+499p. Illus. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.

bluegill

Cameron, J. N. 1969. Growth respiratory metabolism and seasonal distribution of juvenile pinfish (Lagodon rhomboides) in Redfish Bay, Texas. Contrib. Mar. Sci. 14:19-36.

pinfish

Campbell, K. P. 1971. Influence of light and dark periods of spatial distribution and activity of the white sucker (Catostomus commersoni). Trans. Amer. Fish Soc. 100(2):353-355.

white sucker

Caprio, J. 1978. Olfaction and taste in the channel catfish on electrophysiological study of the response to amino acids and derivatives. J. Comp. Physiol. and Sens. Neural. Behav. Physiol. 123(4):357-372.

channel catfish

Chao, L. N. 1973. Digestive system and feeding habits of the cunner (Tautoglabrus adspersus) a stomachless fish. U.S. Natl. Mar. Fish Serv. Fish. Bull. 71(2):565-586.

cunner

Chiszar, D., R. Rudisill and J. Windell. 1972. Variables influencing predatory behavior in bluegill sunfish. J. Colo-Wyo. Acad. Sci. 7(2-3):89-90.

bluegill

Chittenden, M. E., Jr. 1972. Salinity tolerance of young blueback herring (Alosa aestivalis). Trans. Am. Fish Soc. 101(1):123-125.

blueback herring

Clark, S. H., and B. E. Brown. 1977. Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, North Carolina, USA, 1963-1974 as determined from research vessel survey data. U.S. Natl. Mar. Fish Ser. Fish Bull. 75(1):1-21.

squid

Cobb, J. S. 1971. The shelter related behavior of the lobster (Homarus americanus). Ecology 52(1):108-115.

American lobster

Coble, D. W. 1973. Influence of appearance of prey and satiation of predator on food selection by northern pike (Esox lucius). J. Fish Res. Board Can. 30(2):317-320.

northern pike

Cooper, R. A. 1970. Retention of marks and their effects of growth, behavior, and migration of the American lobster (Homarus americanus). Trans. Am. Fish Soc. 99(2):409-417.

American lobster

Coutant, C. C. 1973. Effect of thermal shock on vulnerability of juvenile salmonids to predation. J. Fish Res. Board Can. 30(7):965-973.

chinook salmon
rainbow (steelhead) trout

Cramer, J. R., and G. R. Marzolf. 1970. Selective predation of zooplankton by gizzard shad. Trans. Amer. Fish Soc. 99(2):320-332.

gizzard shad

Crawford, R., J. H. Shaddy and D. A. Kangas. 1977. Ecology of 6 species of fish in an oxbow pond in Missouri. Trans. Mo. Acad. Sci. (10/11):236.

white crappie	crap
gizzard shad	largemouth bass
channel catfish	bluegill

Cvancara, V. A., S. F. Stieber and B. A. Cvancara. 1977. Summer temperature tolerance of selected species of Mississippi River acclimated young of the year fishes. Comp. Biochem. Physiol. A Comp. Physiol. 56(1):81-85.

gizzard shad	largemouth bass
bluegill	black bullhead
northern pike	freshwater drum
white bass	carpsucker

Davies, W. D. 1973. The effects of total dissolved solids, temperature and pH on the survival of immature striped bass: A response surface experiment. Prog. Fish-Cult. 35(3):157-160.

striped bass

Davis, J. R., and D. E. Louder. 1971. Life history and ecology of the cyprinid fish (Notropis petersoni) in North Carolina waters. Trans. Am. Fish Soc. 100(4):726-733.

shiner

Davis, W. J., G. J. Mpitsos and J. M. Pinneo. 1974. The behavioral hierarchy of the mollusk *Pleurobrenchaea*, Part 1. The dominant position of the feeding behavior. J. Comp. Physiol. 90(3):207-224.

mollusks

Dawley, E. M., and W. J. Ebel. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steelhead trout. U.S. Natl. Mar. Fish Serv. Fish. Bull. 73(4):787-796.

chinook salmon
rainbow (steelhead) trout

Dawson, M. A., E. Gould, F. P. Thurberg and A. Calabrese. 1977. Physiological response of juvenile striped bass (Morone saxatilis) to low levels of cadmium and mercury. Natl. Mar. Fish. Serv., Northeast Fish. Cent., Milford Lab., Milford, Conn. Chesapeake Sci. 18(4):353-359.

striped bass

Dovel, W. L. 1968. Predation by striped bass as a possible influence on population size of the Atlantic croaker. Trans. Amer. Fish Soc. 97(4):313-319.

striped bass
Atlantic croaker

Dovel, W. L., J. A. Mihursky and A. J. McErlean. 1969. Life history aspects of the hogchoker (Trinectes maculatus) in the Patuxent River estuary, Maryland. Chesapeake Sci. 10(2):104-119.

hogchoker

Dunhan, A. E., G. R. Smith and J. N. Taylor. 1979. Evidence for ecological character displacement in Western American catostomid fishes. Evolution 33(3):877-896.

suckers

Ebel, W. J., D. L. Park and R. C. Johnson. 1973. Effects of transportation on survival and homing of Snake River chinook salmon and steelhead trout. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 71(2):549-563.

chinook salmon
rainbow (steelhead) trout

Ellgaard, E. G., K. S. Bloom, A. A. Malizia, Jr., G. E. Gunning and R. E. Jensen. 1975. The locomotor activity of fish, an analogy to the kinetics of an opposed first-order chemical reaction. Trans Am. Fish. Soc. 104(4):752-754.

bluegill

Ennis, G. P. 1975. Behavioral responses to changes in hydrostatic pressure and light during larval development of the lobster (Homarus americanus). J. Fish. Res. Board Can. 32(2):271-282.

American lobster

Faber, D. J. 1970. Ecological observations on newly hatched lake whitefish in South Bay, Lake Huron, pp. 481-500. In: C. C. Lindsey, C. S. Woods, (eds.). Biology of Coregonid Fishes. Symposium. 560 p. Illus. University of Manitoba Press, Winnipeg, Canada.

lake whitefish

Fay, R. R., and A. N. Popper. 1975. Modes of stimulation of the teleost ear. J. Exp. Biol. 62(2):379-387.

channel catfish

Flores, E. E. C., S. Igaroshi, T. Mikami and K. Kobayashi. 1976. Studies on squid behavior in relation to fishing on the handling of squid (Todarodes pacificus) for behavior study. Bull. Fac. Fish. Hokkaido Univ. 27(3-4):145-151.

squid

Flores, E. E. C., S. Igaroshi and T. Mikami. 1979. Studies on squid behavior in relation to fishing. Part 3 on the opto-motor response of squid (Todarodes pacificus) to various colors. 29(2):131-140.

squid

Fickeisen, D. H., and J. C. Montgomery. 1978. Tolerances of fishes to dissolved gas super saturation in deep tank bioassays. Trans. Am. Fish. Soc. 107(2):376-381.

sucker

Finucane, J. H., and W. Campbell. 1968. Ecology of American oysters in old Tampa Bay, Florida, USA. Quart. J. Fla. Acad. Sci. 31(1):37-46.

American oysters

Freadman, M. A. 1977. Swimming metabolism of striped bass (Morone saxatilis) and bluefish (Pomatomus saltatrix) in relation to active branchial and ram gill ventilation. Am. Zool. 17(4):958.

striped bass
bluefish

Gallepp, G. W, and J. J. Magnuson. 1972. Effects of negative buoyancy on the behavior of the bluegill (Lepomis macrochirus). Trans. Am. Fish. Soc. 101(3):507-512.

bluegill

George, R. Y. 1976. Salient ecological and physiological aspects of deep sea benthos off North Carolina. J. E. Mitchell (ed). Sci. Soc. 92(2):82-83.

blue crab

Girsa, I. I. 1969. The photo response of a number of fresh water fish during ontogenesis and other physiological states. VO² Ikhtiol 9(1):172-183.

northern pike
carp

Gleeson, R. A. 1974. Pheromone mediated behavior in the blue crab (Callinectes sapidus). Am. Zool. 16(2):197.

blue crab

Glova, G. J, and J. E. McInerney. 1977. Critical swimming speeds of coho salmon (Oncorhynchus kisutch) fry to smolt stages in relation to salinity and temperature. Inst. Anim. Resour. Ecol., Univ. B.C., Vancouver, B.C. V6T 1W5, Can. J. Fish. Res. Board Can. 34(1):151-154.

coho salmon

Gruffydd, L. D., R. A. Rieser and D. Machin. 1975. A comparison of growth and temperature tolerance in the larvae of the lobsters (Homerus gammarus) and (H. americanus).

American lobster

Gusar, A. G., and V. S. Kupriyanov. 1975. Use of underwater television to study the behavior of fishes in light fields. J. Ichthyol. 15(3):519-521.

squid

Hansen, D. J. 1970. Food growth migration reproduction and abundance of pinfish (Lagodon rhomboides) and Atlantic croaker (Micropogon undulatus) near Pensacola, Florida, 1963-1965. U.S. Fish Wildl. Serv. Fish. Bull. 68(1):135-146.

pinfish

Atlantic croaker

Hazel, C. R., W. Thomsen and S. J. Meith. 1971. Sensitivity of striped bass and stickleback to ammonia in relation to temperature and salinity. Calif. Fish. Game 57(3):138-153.

striped bass

Heins, D. C, and G. H. Clemmer. 1975. Ecology foods and feeding of the longnose shiner (Notropis longirostris) in Mississippi, USA. Am. Midl. Nat. 94(2):284-295.

shiner

Helfman, G. S. 1979. Twilight activities of yellow perch (Perca flavescens). J. Fish. Res. Board Can. 36(2):173-179.

perch

Henry, M. G., and G. J. Atchison. 1979. Behavioral changes in bluegill (Lepomis macrochirus) as indicators of sublethal effects of metals. Environ. Biol. Fishes. 4(1):37-42.

bluegill

Hoffman, R. S., P. J. Dunham and P. V. Kelly. 1975. Effects of water temperature and housing conditions upon the aggressive behavior of the lobster (Homarus americanus). J. Fish Res. Board Can. 32(5):713-718.

American lobster

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.

walleye
yellow perch

Houde, E. D. 1969. Sustained swimming ability of larvae of walleye (Stizostedion vitreum vitreum) and yellow perch (Perca flavescens). J. Fish Res Board Can. 26(6):1647-1659.

walleye
yellow perch

Howard, H. C., and R. E. Thomas. 1970. Behavior of northern pike fry as related to pond culture. 1970. Progr. Fish-Cult. 32(4):224-226.

northern pike

Humphries, E. T., and K. B. Cumming. 1972. Food habits and feeding selectivity of striped bass fingerlings in culture ponds. Proc. Ann. Conf Southeast Assoc. Game Fish Comm. 25:522-536.

striped bass

Huntsman, G. R., R. L. Kroger and R. L. Dryfoos. 1971. Movement of juvenile Atlantic menhaden tagged in New England waters. Chesapeake Sci. 12(2):114-115.

Atlantic menhaden

Hurley, A. C. 1976. Feeding behavior, food consumption, growth and respiration of squid (Loligo opalescens) raised in the laboratory. U.S. Natl. Mar. Fish. Ser. Fish. Bull. 74(1):176-182.

squid

Hurley, A. C. 1977. Mating behavior of the squid (Loligo opalescens). Mar. Behav. Physiol. 4(3):195-203.

squid

Jacobson, S., and J. Atema. 1976. Dominance and territoriality in juvenile lobsters (Homarus americanus). Am. Zool. 16(2):208.

American lobster

Jachowski, R. L. 1974. Agonistic behavior of the blue crab (Callinectes sapidus). Behaviour 50(3-4):232-253.

blue crab

Jester, D. B., and B. L. Jensen. 1972. Life history and ecology of the gizzard shad (Dorosoma cepedianum) with reference to Elephant-Butte Lake. N. M. Agric. Exp. Stn. Res. Rep. 218:5-56.

gizzard shad

Jester, D. B. 1972. Life history ecology and management of the river carpsucker (Carpionides carpio) with reference to Elephant Butte Lake. N. M. Agric. Exp. Stn. Res. Rep. 243:5-120.

river carpsucker

Jennings, J. B., and S. R. Gelder. 1976. Observations on the feeding mechanism diet and digestive physiology of (Histiobdella homari) an aberrant polychaete symbiotic with North American and European lobsters. Biol. Bull. 151(3):489-517.

American lobster

Johnson, F. H. 1969. Environmental and species associations of the walleye in Lake Winnibigoshish, Minnesota and connecting waters including observations on food habits and predator prey relationships (Stizostedion vitreum), (Notropis hudsonicus), (Notropis volucellus), (Pimephales notatus), (Perca flavescens), (Boleosoma N. igrum) diet insectivorous. Minn. Fish Invest. (5):5-36.

walleye
shiner
yellow perch

Kelly, H. D. 1969. The production and management of striped bass (Morone saxatilis) in Alabama. J. Ala. Acad. Sci. 40(1):7-10.

striped bass

Kennedy, V. S., and D. H. Steele. 1971. The winter flounder (Pseudopleuronectes americanus) in long-pond Conception Bay, Newfoundland. J. Fish. Res. Board Can. 28(8):1153-1165.

winter flounder

Kjelson, M. A., and G. N. Johnson. 1976. Pinfish (Lagodon rhomboides) and spot (Leiostomus xanthurus). U.S. Natl. Mar. Fish. Serv. Fish. Bull. 74(2):423-432.

pinfish

spot

Kjelson, M. A., D. S. Peters, G. W. Thayer and G. N. Johnson. 1975. The general feeding ecology of post larval fishes in the Newport River Estuary, North Carolina. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 73(1):137-144.

Atlantic menhaden

pinfish

spot

Kleerekoper, H. 1972. Orientation through chemoreception in the channel catfish (Ictalurus punctatus). Tex. J. Sci. 23(4):577.

channel catfish

Kleerekoper, H. 1972. Orientation through chemoreception in fishes. NASA Sp. 262:459-468.

channel catfish

Klyashtorin, L. B., and A. A. Yarzhombek. 1975. Some aspects of the physiology of the striped bass (Morone saxatilis). J. Ichthyol (Engl. Transl. Vopr Ikhtiol). 15(6):985-989.

striped bass

Kowalski, K. T., J. P. Schubauer, C. L. Scott, and J. R. Spotila. 1978. Interspecific and seasonal differences in the temperature tolerance of stream fish. J. Therm. Biol. 3(3):105-108.

shiner

sculpin

Krekorian, C. O., D. C. Sommerville and R. F. Ford. 1974. Laboratory study of behavioral interactions between the American lobster (Homarus americanus) and the California spiny lobster (Panulirus interruptus) with comparative observations on the rock crab (Cancer antennarius). U.S. Natl. Mar. Fish. Serv. Fish. Bull. 72(4):1146-1159.

American lobster
spiny lobster
rock crab

Kroger, R. L., and J. F. Guthrie. 1973. Migrations of tagged juvenile Atlantic menhaden. Trans. Am. Fish. Soc. 102(2):417-422.

Atlantic menhaden

Kroger, R. L., and R. W. Brocksen. 1978. Respiratory metabolism of striped bass (Morone saxatilis) in relation to temperature. J. Exp. Mar. Biol. Ecol. 31(1):55-66.

striped bass

Lackey, R. T. 1970. Seasonal depth distributions of landlocked Atlantic salmon, brook trout, landlocked alewives and American smelt in a small lake. J. Fish. Res. Board Can. 27(9):1656-1660.

Atlantic salmon
brook trout
alewife
American smelt

Lal, K., R. Lasker, and A. Kuljis. 1977. Acclimation and rearing of striped bass larvae. Calif. Fish Game. 63(4):210-218.

striped bass

Larson, G. L., F. E. Hutchins and L. P. Lamperti. 1977. Laboratory determination of acute and sublethal toxicities of inorganic chloramines to early life stages of coho salmon (Oncorhynchus kisutch). Dep. Fish. Wild., Ore. State Univ., Corvallis, Oregon. Trans. Am. Fish. Soc. 106(3):268-277.

coho salmon

Lee, R. M., M. R. Robbins and R. Palovcik. 1974. Pleurobranchaea behavior food finding and other aspects of feeding. Behav. Biol. 12(3):297-316.

squid

Lewis, R. M., and E. P. H. Wilkens. 1971. Abundance of Atlantic menhaden larvae and associated species during a diel collection at Beaufort, North Carolina. Chesapeake Sci. 12(3):185-187.

Atlantic menhaden

Libosvsky, J. 1976. On the ecology of spawning migration of brown trout. Zool. Listy. 25(2):175-182.

brown trout

Liscom, K. L. 1971. Orifice placement in gatewells of turbine intakes for bypassing juvenile fish around dams. Trans. Amer. Fish. Soc. 100(2):319-324.

rainbow trout
chinook salmon
sockeye salmon

Long, C. W. 1968. Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes (Oncorhynchus tshawytscha), (Oncorhynchus nerka), (Salmo gairdneri), (Lampetra tridentata). U.S. Fish Wildlife Serv. Fish. Bull. 66(3):599-609.

chinook salmon
sockeye salmon
rainbow trout
lamprey

Loos, J. J. 1977. Comparative early life histories of representatives of the cyprinid subgenera hydrophlox and notropis. ASB (Assoc Southeast Biol). Bull. 24(2):67.

shiner

Mahood, R. K., M. D. McKenzie, D. P. Middaugh, S. J. Bollar, J. R. Davis, and D. Spitsbergen. 1970. A Report on the Cooperative Blue Crab Study South Atlantic States. U.S. Department of Interior Bureau of Commercial Fisheries 01678. 32 pp.

blue crab

Mahon, R., and E. K. Balon. 1977. Ecological fish production in long pond at lakeshore lagoon on long point Lake Erie, Canada. Environ. Biol. Fishes 2(3):261-284.

shiner
minnow
bluegill
pumpkinseed

yellow perch
carp
bass
trout

Matthews, W. J., and L. G. Hill. 1977. Tolerance of the red shiner (Notropis lutrensis) cyprinidae to environmental parameters. Southwest Nat. 22(1):89-98.

Matthews, W. J., and L. G. Hill. 1970. Critical thermal maxima, oxygen tolerances, and success of cyprinid fishes in a southwestern river. Am. Midl. Nat. 102(2):374-377.

cyprinidae

Matthews, W. J., and J. T. Styron, Jr. 1978. Comparative tolerance of head water and mainstream fishes for abrupt change in pH dissolved oxygen and temperature. Va. J. Sci. 29(2):65.

shiner

McCann, J. A., and K. D. Carlander. 1970. Mark and recovery estimates of fish populations in Clear Lake, Iowa 1958 and 1959. Iowa State J. Sci. 44(3):369-403.

walleye
largemouth bass
crappie
perch

bullhead
pile
bluegill

McCarraher, D. B., and R. E. Thomas. 1972. Ecological significance of vegetation to northern pike (Esox lucius) spawning. Trans. Am. Fish. Soc. 101(3):560-563.

northern pike

McErlean, A. J., and H. J. Brinkley. 1971. Temperature tolerance and thyroid activity of the white perch (Roccus) equals (Morone americanus). J. Fish. Biol. 3(1):97-114.

white perch

McLeese, D. W., R. L. Spraggins, A. K. Bose and B. N. Pramanik. 1977. Chemical and behavioral studies of the sex attractant of the lobster (Homarus americanus). Mar. Behav. Physiol. 4(3):219-232.

American lobster

Mercer, M. C. 1970. On the northern limits of the squid (Loligo pealei). Natur. Can. 97(6):823-824.

squid

Mesnil, B. 1977. Growth and life cycle of squid (Loligo pealei) and (Illex illecebrosus) from the Northwest Atlantic. Int. Comm. Northwest Atl. Fish. Sel. Pap. (2):55-69.

squid

Morgan, E. L., J. Cairns, Jr. and R. E. Sparks. 1975. Swimming response of bluegill (Lepomis macrochirus) to harmful zinc concentrations after long-term exposure to safe concentrations. ASB (Assoc. Southeast Biol.) Bull. 22(2):69.

bluegill

NOAA (Natl. Ocean. Atmos. Adm.). 1974. Physiological response of the cunner (Tautogolabrus adspersus) to cadmium. Natl. Oceanic Atmos. Adm. Natl. Mar. Fish. Serv. Tech Rep. NMFS (Natl. Mar. Fish Serv.) SSRF (Spec. Sci. Rep. Fish.). 681:1-33.

cunner

Neill, S. R. S., and J. M. Cullen. 1974. Experiments on whether schooling by their prey affects the hunting behavior of cephalopods and fish predators. J. Zool. Proc. Zool. Soc. Lond. 172(4):549-569.

squid

Neill, W. H., and J. J. Magnuson. 1974. Distributional ecology and behavioral thermo regulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. Trans. Am. Fish. Soc. 103(4):663-710.

yellow perch
sculpin
pumpkinseed
bluegill

carp
bullhead
bass

Nicholson, W. R. 1972. Population structure and movements of Atlantic menhaden (Brevoortia tyrannus) as inferred from back calculated length frequencies. Chesapeake Sci. 13(3):161-174.

Atlantic menhaden

Noble, R. L. 1970. Evaluation of the Miller high speed sampler for sampling yellow perch and walleye fry. J. Fish. Res. Bd. Can. 27(6):1033-1044.

yellow perch
walleye

Nordeng, H. 1971. Is the local orientation of anadromous fishes determined by pheromones. *Nature (Lond)* 233(5319):411-413.

pink salmon

Nursall, J. R., and M. E. Pinsent. 1969. Aggregations of spottail shiners and yellow perch. *J. Fish. Res. Bd. Can.* 26(6):1672-1676.

shiner
yellow perch

O'Brien, W. J., N. A. Slade and G. L. Vinyard. 1976. Apparent size as the determinant of prey selection by bluegill sunfish (Lepomis macrochirus). *Ecology* 57(6):1304-1310.

bluegill

O'Connor, J. M. 1972. Tidal activity rhythm in the hogchoker (Trinectes maculatus). *J. Exp. Mar. Biol. Ecol.* 9(2):173-177.

hogchoker

Olla, B. L., R. Wickland and S. Wilk. 1969. Behavior of winter flounder in a natural habitat. *Trans. Amer. Fish. Soc.* 98(4):717-720.

winter flounder

Otto, R. G., and J. O. Rice. 1974. Swimming speeds of yellow perch (Perca flavescens) following an abrupt change in environmental temperature. *J. Fish. Res. Bd. Can.* 31(11):1731-1734.

yellow perch

Otto, R. G., and J. O. Rice. 1977. Responses of a fresh water sculpin (Cottus cognatus gracilis) to temperature. *Trans. Am. Fish. Soc.* 106(1):89-94.

sculpin

Outten, L. M. 1977. Comparative studies of cyprinid fishes in the southeast USA. *ASB (Assoc. Southeast Biol.) Bull.* 24(2):74.

shiner

Park, D. L. 1969. Seasonal changes in downstream migration of age group 0 chinook salmon in the upper Columbia River. *Trans. Amer. Fish. Soc.* 98(2):315-317.

chinook salmon

Parker, J. C. 1971. The biology of the spot (Leiostomus xanthurus) and Atlantic croaker (Micropogonias undulatus) in 2 Gulf of Mexico nursery areas. Diss. Abstr. Int. B. Sci. Eng. 32(3):1380-B.

spot
Atlantic croaker

Pearson, W. H., and B. L. Olla. 1977. Chemo reception in the blue crab (Callinectes sapidus). Biol. Bull. 153(2):346-354.

blue crab

Pearson, W. H., P. C. Sugarman and D. L. Woodruff. 1979. Thresholds for detection and feeding behavior in the Dungeness crab (Cancer magister). J. Exp. Mar. Biol. Ecol. 39(1):65-78.

Dungeness crab

Peeke, H. V. S., and A. Veno. 1973. Stimulus specificity of habituated aggression in the stickleback (Gasterosteus aculeatus). Behav. Biol. 8(3):427-432.

stickleback

Perez, K. T. 1969. An orthokinetic response to rates of salinity changes in two estuarine fishes. Ecology 50(3):454-457.

spot
Atlantic croaker

Pringle, J. D., and R. E. Semple. 1976. A preliminary assessment of the ecological impact of an experimental chondrus Irish moss harvester off coastal Prince Edward Island. Can. Fish. Mar. Ser. Resour. Dev. Branch Maritime Reg. Tech. Rep. Ser. Mar-T 76(1):1-28.

American lobster

Randolph, K. N., and H. P. Clemens. 1976. Home areas and swimways in channel catfish culture ponds. Trans. Am. Fish. Soc. 105(6):725-730.

channel catfish

Reed, J. R. 1969. Alarm substances and fright reaction in some fishes from the southeastern U.S. Trans. Amer. Fish. Soc. 98(4):664-668.

bluegill
shiner
spotted bass

Reed, J. R., W. Wieland and T. D. Kimbrough. 1972. A study of the possible effects of various drugs as instigators of a fright reaction in fish. Va. J. Sci. 23(3):115.

shiner

Reigle, N. J., Jr. 1969. Bottom trawl explorations in southern Lake Michigan U.S. Fish. Wildlife Serv. Circ. 301:1-35.

alewife

yellow perch

rainbow smelt

Reynolds, W. W., and M. E. Casterlin. 1979. Behavioral thermo regulation and activity in Homarus americanus. Comp. Biochem. and Physiology 64(1):25-28.

American lobster

Reynolds, W. W., M. E. Casterlin and J. B. Covert. 1979. Comparative thermo regulatory and febrile behavior of aquatic ectothermic vertebrates and arthropods. Fed. Proc. 38(3):1053.

American lobster

bluegill

horse-shoe crab

Richkus, W. A. 1971. Correlative relationships between environmental parameters and upstream migration of the anadromous alewife (Alosa pseudoharengus). Am. Zool. 11(4):630.

alewife

Roye, D. B. 1979. The physiological basis for pitch induced antennuli movements in the blue crab (Callinectes sapidus). Comp. Biochem. and Physiology 62(2):475-484.

blue crab

Rudisill, R., D. Chiszar and J. Windell. 1972. A descriptive analysis of predatory behavior in the bluegill sunfish. J. Colo. Wyo. Acad. Sci. 7(2-3):89.

bluegill

Rulifson, R. A. 1977. Temperature and water velocity effects on the swimming performances of young of the year striped mullet (*Mugil cephalus*), spot (*Leiostomus xanthurus*) and pinfish (*Lagodon rhomboides*). J. Fish. Res. Bd. Can. 34(12):2316-2322.

spot
pinfish

Saila, S. B., T. T. Polgar, D. J. Sheehy and J. M. Flowers. 1972. Correlations between alewife activity and environmental variables at a fishway. Trans. Am. Fish Soc. 101(4):583-594.

alewife

Sastry, A. N., and S. L. Vargo. 1977. Variations in the physiological responses of crustacean larvae to temperature, pp. 401-423. In: J. F. Vernberg (ed.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York.

crabs
American lobster

Schultz, R., and M. Norberg. 1970. The effects of blindness on bluegill (*Lepomis macrochirus*) activity. Psychonomic Sci. Soc. Anim. Physiol. Psychol. 18(3).

bluegill

Sheri, A. N., and G. Power. 1969. Vertical distribution of white perch (*Roccus americanus*) modified by light. Can. Field Natur. 83(2):160-161.

white perch

Sheri, A. N., and G. Power. 1972. Effect of density on the growth of white perch (*Roccus americanus*) in the Bay of Quinte, Lake Ontario. Pak. J. Zool. 4(2):109-132.

white perch

Singer, J. 1969. What fish smell clues to community status. Wards Bull. 8(61):2.

chinook salmon

Slatick, E. 1970. Passage of adult salmon and trout through pipes. U.S. Fish. Wildl. Serv. Spec. Sci. Rep. Fish. 592:1-81.

chinook salmon
coho salmon

sockeye salmon
rainbow trout

Slatick, E. 1971. Passage of adult salmon and trout through an inclined pipe. Trans. Am. Fish Soc. 100(3):448-455.

chinook salmon
sockeye salmon

rainbow trout
coho salmon

Smith, S. H. 1968. That little pest the alewife. Limnos. 1(2):12-20.

alewife

Spirito, C. P. 1972. An analysis of swimming behavior in the portunid crab (Callinectes sapidus). Mar. Behav. Physiol. 1(3):261-276.

crab

Squires, H. J. 1969. Lobster (Homarus americanus) fishery and ecology in Port Au Port Bay, New Foundland 1960-1965. Proc. Nat. Shellfish Ass. 60:22-39.

American lobster

Stewart, J. E., G. W. Horner and B. Arie. 1972. Effects of temperature, food, and starvation on several physiological parameters of the lobster (Homarus americanus). J. Fish. Res. Bd. Can. 29(4):439-442.

American lobster

Stickney, R. R., and B. A. Simco. 1971. Salinity tolerance of catfish hybrids. Trans Am. Fish. Soc. 100(4):790-794.

channel catfish
blue catfish

Stockley, C. 1967. Chinook salmon passage at dams Columbia River U.S. migratory season. Wash. Dept. Fish Ann. Rep. 77:42.

chinook salmon

Sutterlin, A. M., K. J. Jokola and B. Holte. 1979. Swimming behavior of salmonid fish in ocean pens. J. Fish. Res. Bd. Can. 36(8):948-954.

Atlantic salmon
rainbow trout
pink salmon

Sylvester, J. R. 1972. Effect of thermal stress on predator avoidance in sockeye salmon. J. Fish. Res. Bd. Can. 29(5):601-603.

sockeye salmon

Symons, P. E. K. 1971. Spacing and density in schooling three-spined sticklebacks (Gasterosteus aculeatus) and mummichog (Fundulus heteroclitus). J. Fish. Res. Bd. Can. 28(7):999-1004.

stickleback
munnichog

Tagatz, M. E. 1969. Some relations of temperature acclimation and salinity to thermal tolerance of the blue crab (Callinectes sapidus). Trans. Am. Fish. Soc. 98(4):713-716.

blue crab

Tamm, G. R., and J. S. Cobb. 1978. Behavior and the crustacean molt cycle changes in aggression of Homerus americanus. Science 200(4337):79-81.

American lobster

Thompson, C. S. 1970. Effect of flow on performance and behavior of chinook salmon in fishways. U.S. Fish. Wildl. Serv. Spec. Sci. Rep. Fish (601):1-11.

chinook salmon

Thunberg, B. E. 1969. Olfaction in parent stream selection by the alewife (Alosa pseudoharengus). Amer. Zool. 9(4):1074-1075.

alewife

Trent, L., and W. W. Hassler. 1968. Gill net selection migration size and age composition, sex ratio harvest efficiency and management of striped bass in the Roanoke River, North Carolina. Chesapeake Sci. 9(4):217-232.

striped bass

Tsai, C. F. 1970. Changes in fish populations and migration in relation to increased sewage pollution in Little Patuxent River, Maryland. Chesapeake Sci. 11(1):34-41.

catfish
sucker
crappie

perch
bass
bluegill

Tyler, A. V. 1971. Surges of winter flounder (Pseudopleuronectes americanus) into the inter tidal zone. J. Fish. Res. Bd. Can. 28(11):1727-1732.

winter flounder

Van Derwalker, J. G. 1971. Responses of fingerling coho and chinook salmon to modified flows in a simulated turbine intake. Gov. Rep. Announce. 71(6):31 COM-71-00180.

coho salmon
chinook salmon

Van Hyning, J. M. 1973. Factors affecting the abundance of fall chinook salmon in the Columbia River. Res. Rep. Fish. Comm. Oreg. 4(1):1-87.

chinook salmon

Verheijen, F. J., and H. J. Reuter. 1969. The effect of alarm substance on predation among cyprinids. Anim. Behav. 17(3):551-554.

northern pike

Wagner, W. C. 1972. Utilization of alewives by inshore piscivorous fishes in Lake Michigan. Trans. Am. Fish. Soc. 101(1):55-63.

alewife

Wallace, C. R. 1972. Spawning behavior of (Ictalurus natalis). Tex. J. Sci. 24(3):307-310.

yellow bullhead

Weaver, R. O., and C. D. Ziebell. 1976. Ecology and early life history of largemouth bass and bluegill in Imperial Reservoir, Arizona. Southwest Nat. 21(2):151-160.

largemouth bass
bluegill

Weiss, B. A., W. F. Strother and G. M. Hartig. 1969. Auditory sensitivity in the bullhead catfish (Ictalurus nebulosis). Proc. Nat. Acad. Sci. U.S.A. 64(2):552-556.

brown bullhead

Werner, R. G. 1969. Ecology of limnetic bluegill (Lepomis macrochirus) fry in Crane Lake, Indiana. Amer. Midland Natur. 81(1):165-181.

bluegill

White, S. T., and D. C. Wallace. 1973. Diel changes in the feeding activity and food habits of the spotfin shiner (Notropis spilopterus). Am. Midl. Nat. 90(1):200-205.

shiner

Wilkins, E. P. H., and R. M. Lewis. 1971. Abundance and distribution of young Atlantic menhaden (Brevoortia tyrannus) in the White Oak River estuary, North Carolina. U.S. Fish Wildl. Serv. Fish. Bull. 69(4):783-789.

Atlantic menhaden

Williams, A. B. 1976. Distinction between a Gulf of Mexico and a Carolinian Atlantic species of the swimming crab (Ovalipes). Proc. Biol. Soc. Wash. 89(14):205-214.

crab

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