PNL-40 88

18K

Biological Services Program

FWS/OBS-82/13.2

April 1982

Evaluation of Models for Developing Biological Input for the Design and Location of Water Intake Structures

Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; mineral development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; environmental contaminants; National Wetland Inventory; habitat classification and evaluation; inventory and data management systems; and information management.

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

PNL-4088
UC-97e

EVALUATION OF MOOELS FOR OEVELOPING BIOLOGICAL INPUT FOR THE DESIGN AND LOCATION OF WATER INTAKE STRUCTURES

M. A. Simmons
D. H. McKenzie

December 1981

Prepared for
the U.S. Department of the Interior
Fish and Wildlife Service
Kearneysville, West Virginia 25430
Under FWS Contract Number 14-16-0009-79-1401

Pacific Northwest Laboratory
Richland, Washington 99352

ACKNOWLEDGEMENTS

The authors acknowledge with gratitude the support of the U.S. Fish and Wildlife Service which financed this project. We particularly appreciate the assistance of Paul Rago and Gene Fritz for their helpful comments throughout this project.

Particular thanks are due to Rene Hinds for coordinating the word processing and graphical input and her editorial assistance during all stages of manual preparation.

This document was prepared at the Pacific Northwest Laboratory as PNL-4088/UC-97e.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Water withdrawn for cooling purposes constitutes one of the largest non-consumptive uses of this resource today (EPA 1976). A major area of environmental concern associated with this withdrawal is the entrainment and impingement of aquatic organisms. Entrainment refers to the passage of organisms through the cooling water system, while impinged organisms are held against the screens at the intake by the force of the water. Impact from entrainment and impingement results in the loss of organisms, either directly through exposure to biocides, increased water temperatures and mechanical abrasion, or indirectly through increased susceptibility to predation and disease.

Efforts to reduce entrainment and impingement impact have attempted to incorporate information on fish and shellfish behavior into design modifications of intake structure and operation. One of the first such modifications was to reduce intake velocity. The rationale was that low intake velocities relative to swim speeds would allow fish to avoid the intake current. Other design modifications utilizing behavioral information have included bubble screens, developed to act as a fish barrier, and velocity caps which convert vertical water movement into a horizontal flow. Experiments evaluating these modifications have resulted in conflicting lines of evidence. For example, studies on the effectiveness of velccity caps indicate that the change in flow direction from vertical to horizontal reduces impingement (Weight 1958; Maxwell 1973). However, in an experiment by Hanson et al. (1978), juvenile chinook salmon and bluegill avoided vertical flow fields and had a higher impingement rate under horizontal flow conditions. Similar conflicting experimental results have been obtained in studies on the effectiveness of bubble screens (Bibko et al. 1974; Lieberman and Muessig 1978).

The main premise of utilizing behavioral information to modify the design or location of intake structures to reduce impacts is logically sound. However, several problems have prevented its effective implementation. First, information on the behavioral response of aquatic organisms to parameters associated with intake structures is sparse and sometimes contradictory. Second, most experiments on fish and shellfish behavior evaluate single stimulus/response situations in laboratory settings. A third problem involves the dichotomy which sometimes exists between the response of the individual and population level response. These problems are exemplified in a study of fish distribution in relation to effluent from a pulp and paper mill. Kelso (1977) found high fish densities in the vicinity of a paper mill outfall, though the residency time for individual fish was short. Thus while individual fish exhibited an avoidance reaction in response to the outfall plume, the distribution of the population appeared related to the concentration of benthic invertebrates with little regard to the plume. A partial solution to these problems lies in recognizing that organisms integrate and prioritize a great many stimuli into their behavioral response under natural conditions (Meadows and Campbell 1972). Development of logical criteria for inclusion in the design and location of intake structures will require evaluation of community level response in a multiple stimulus/response framework, as well as prioritization of the stimuli/response relationships.

In an earlier report (Neitzel and McKenzie 1981), the available information on behavior patterns and biological and environmental stimuli which might affect the behavioral response of aquatic organisms in the vicinity of intake structures were reviewed. In that report a flow diagram was assembled to organize this information into a multiple stimulus/response framework. The diagram matched biological input with decisions pertaining to intake location, design and operation (Figure 1).

The objective of this report is to present an approach for assessing multiple stimulus/response relations. The approach will stress stimulus/response relations influencing fish and shellfish distribution. The response of an organism to the stimuli produced by an intake may take the form of a taxis or a change in some physiological parameter such as respiration. However, those responses which result in a change in the temporal and spatial distribution of the organism are of primary concern, since proximity to an intake increases the probability of impingement and entrainment. By concentrating on factors related to the distribution of fish

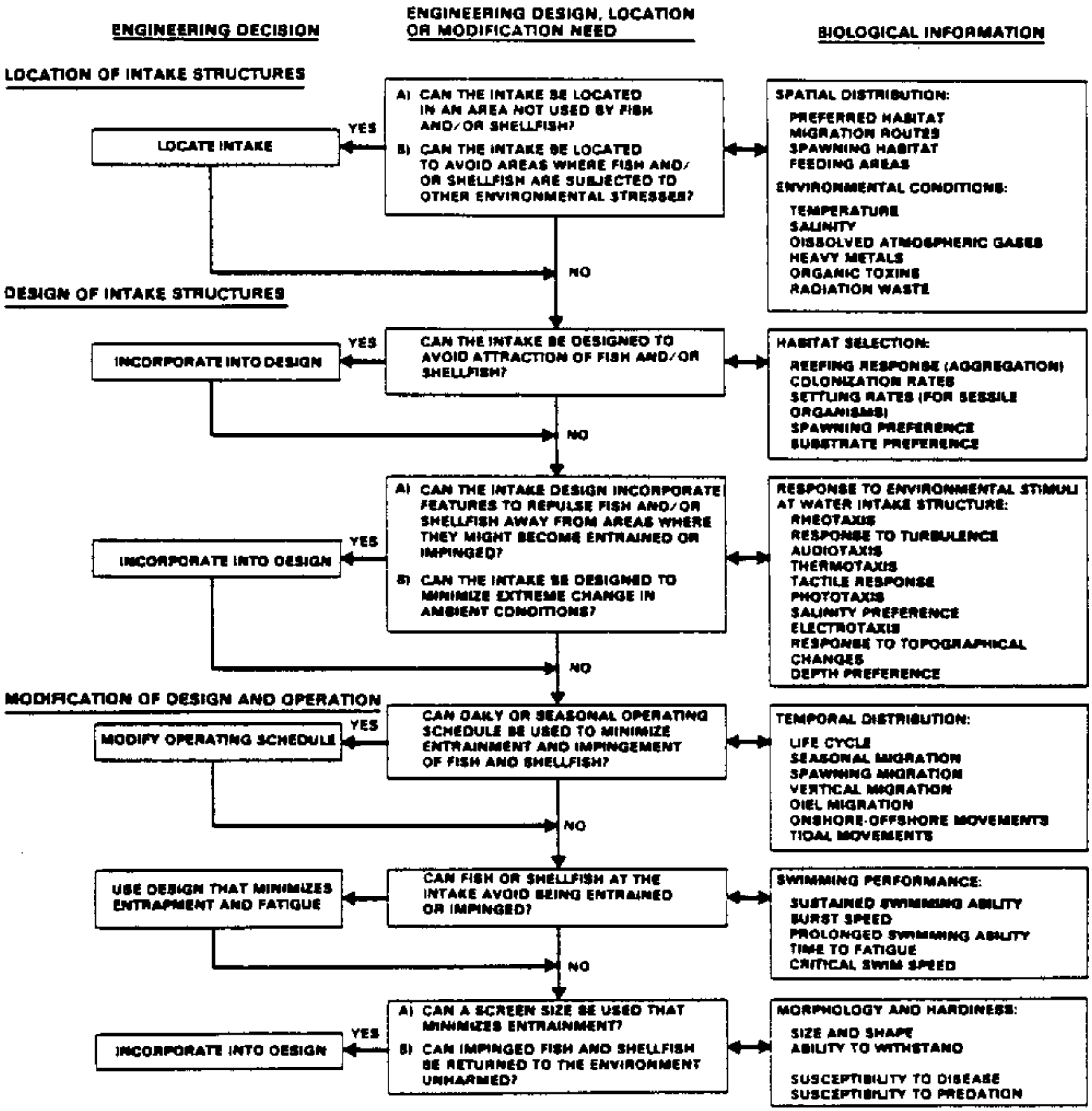

Figure 1. Outline of biological information necessary to answer engineering needs for the design and location of a water intake structure.

and shellfish, we can evaluate the relationship between behavior and intake stimuli on a general level, where intake and environmental stimuli are associated with spatial and temporal distribution categories, and on a more specific functional level, where an attempt is made to define the specific factor(s) controlling the distribution (e.g., evaluating the effect of abiotic and biotic factors on the distribution of selected fish species).

In this report we examine two methods for assessing multiple stimulus/response situations. In the first, a general approach is followed with no attempt to define the relationship for individual stimulus/response situations. Instead, emphasis is placed on temporal and spatial distribution of the population as a behavioral endpoint resulting from the integration of multiple stimuli by a group of organisms. A model is proposed in which species distributions are described quantally within spatial and temporal categories. Categorizing distribution in this manner makes maximum use of available or easily obtained information. It also offers an efficient method for organizing information and documenting the decision process. This approach can provide biological input into engineering questions on intake location and on modification to intake design and operation (Figure 1). It does, however, give a static picture of where fish and shellfish are distributed and is not a predictive model.

The second approach encompasses functional relationships between environmental and biological stimuli and responses such as swim speed and preferences for temperature, salinity, etc. For this approach, mathematical equations are presented which relate the effect of many stimuli to a single response. Examples include the effect of temperature, salinity, dissolved oxygen concentration, or sex and age on swim speed, or the effect of temperature, dissolved oxygen concentration, food habits, and habitat preference on distribution. The development of these relationships requires that biological responses be measured over a range of stimulus levels. This requirement, coupled with the paucity of data available for input into these equations, limits the current applicability of this approach. In spite of the difficulties in using this approach, it does provide information pertinent to understanding and resolving questions relating to impingement and entrainment.

While the two approaches are described separately, it is intended that they be used together. Thus functional relationships can be evaluated to define the distribution of a particular fish or shellfish species. This information can then be used to define the categories and responses in the categorical approach.

APPROACHES FOR ASSESSING MULTIPLE STIMULUS/RESPONSE SITUATIONS

CATEGORICAL APPROACH

Understanding the spatial and temporal distribution of a species requires information on a plethora of physical, chemical and biological parameters. For example, the distribution of fish within a lake is known to be influenced by temperature preferences, dissolved oxygen levels, presence of food and predators, and preferences for depth and substrate (Neill and Magnuson 1974; Wurtsbaugh et al. 1975). It is possible to simplify this description; for example, in a lake, the distribution of fish could be specified according to species presence or absence in the pelagic, littoral or benthic areas of the lake. Temporal categories could be designated as summer, winter, and day, night. Though such broad spatial and temporal categories are not indicative of the cause-effect relationship which determines observed behavior, they allow the consequence of the behavior, the distribution, to be described simply.

Design and operational characteristics of water intake structures can also be defined within broad spatial and temporal categories. These categories provide the basis for developing two matrices, one incorporating information on the biological characteristics of the area, and the other, intake design characteristics. Comparing the matrices using matrix multiplication, measures the coincidence in the area occupied by both fish and shellfish and the intake. This coincidence can be used to assess the potential for impact.

One benefit of this approach is that existing or easily obtained information may be used. Environmental regulations generally require preliminary assessment of resident populations at a proposed water intake site. Thus with little additional effort, information that would aid in assessing the impact of different locations and design chacteristics could be assembled. Further, this approach allows noncommensurate types of information to be included in the same analysis. Additionally, categorical models can be constructed to evaluate various scenarios entailing different hypothetical operating conditions and fish and shellfish distributions.

The primary disadvantage in categorizing distribution using a presence/absence model is the failure to identify the factors (physical, chemical or biological) which control the distribution of fish or shellfish. Thus, a species orginally distributed in an offshore, benthic habitat could be attracted to an inshore intake by preferred currents, food availability, or the presence of a structure (i.e., a reefing response). Because of this deficiency, this method should not be the sole basis for establishing biological criteria for intake siting or operation. However other approaches, such as the functional approach (see next section) can be incorporated with the categorical to ameliorate this deficiency. For example, the effect of current, food availability and reefing response on fish and shellfish distribution can be predicted from the description of these relationships given by the functional relationships. This information can then be used in the categorical approach to evaluate design and location options.

Example

One method for using the categorical approach is to evaluate intake sites with a matrix model. The matrices would contain categories describing both fish and shellfish distribution, as well as intake location and operation. Input for the matrices would generally be zero or one, signifying absence or presence. It also seems possible to include response categories for those factors eliciting a threshold response. These categories can be designated as: attraction (1), no response (0) and avoidance (-1). Figure 2 illustrates three possible types of threshold responses. Response types A and B are examples of possible fish responses to current; for example, depending on the species, low current levels elicit an attraction or avoidance response while at higher levels the fish show no preference. At still higher current levels, the response is again avoidance or attraction. Response type C is respresentative of the response to light, where no response occurs below some threshold, while the organism avoids or is attracted to the light above the threshold.

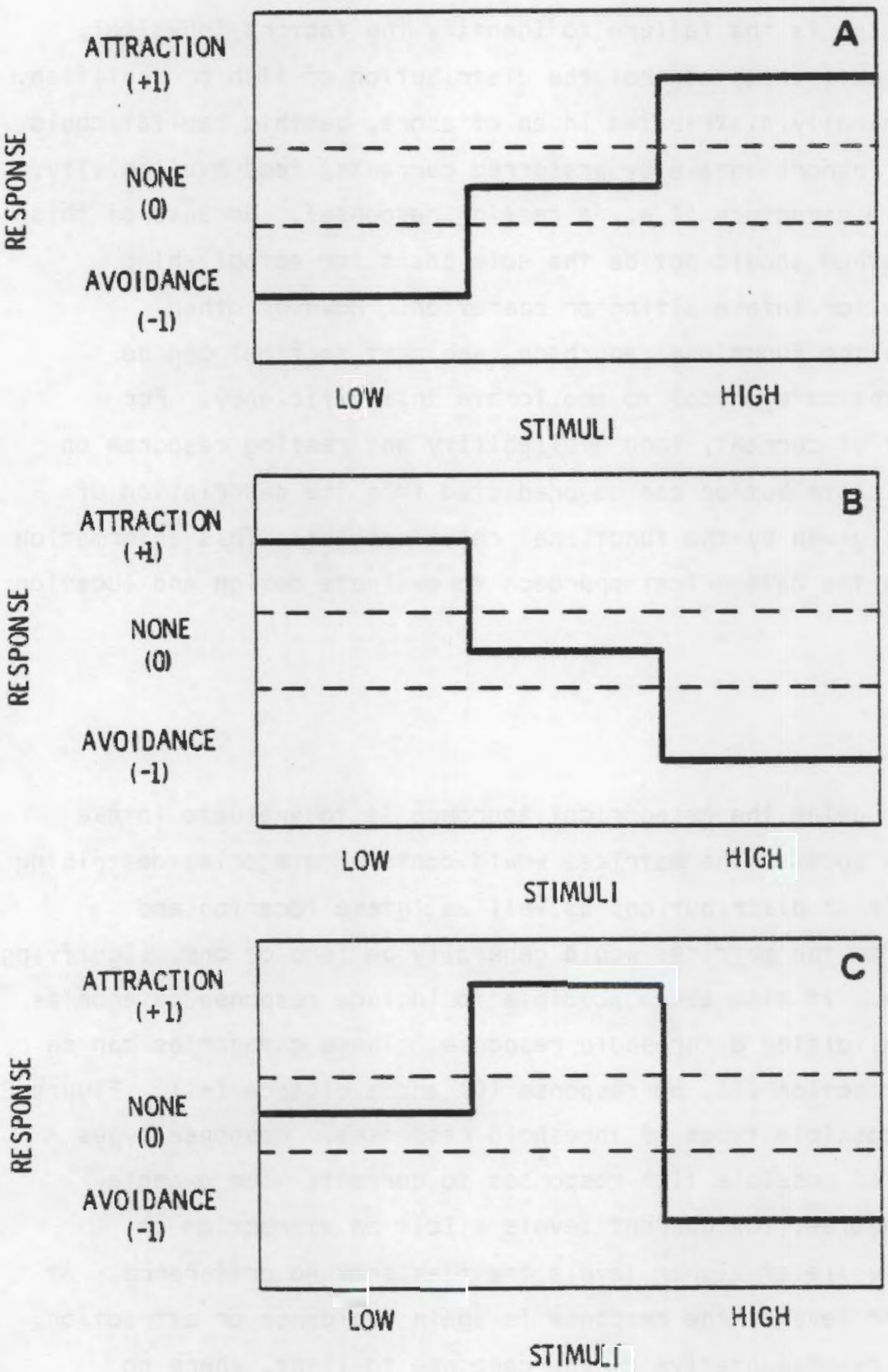

Figure 2. Threshold response types. Examples of stimuli: light, sound, current or intake velocity.

The general form of the matrix for fish and shellfish distribution ($\underline{D}$) is:

$$\underline{D} = \begin{vmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ d_{s1} & d_{s2} & \cdots & d_{sn} \end{vmatrix}$$

with n = parameters associated with distribution

s = life stages

and d = response (0,1).

Zero/one in the matrix signifies absence or presence, respectively. The matrix should include all potentially impacted life stages and important temporal and spatial categories.

In selecting categories for the distribution matrix consideration should be given to features which are broad in scope. Distance from shoreline is a general category which describes the spatial distribution of fish and shellfish. This category encompasses more specific features which affect habitat selection such as depth, substrate type, light intensity and probably temperature ranges. The distance category can be subdivided into top/bottom to accommodate those species which show a preference for depth, and intake structures which withdraw water from different sections of the water column. General temporal categories of season and day/night provide input on the life cycle of fish and shellfish and indicate when certain stages are present. These categories encompass temporal changes occurring in the population due to reproduction, diel rhythms or migrations.

Factors associated with the location of the power plant intake would be contained in a vector ($\underline{P}$). In selecting factors, consideration should be given to the extent of the area disturbed by the intake (e.g. by current), and, if the intake is located at the end of an intake canal, the characteristics of the canal (e.g., relative depth, where the intake water is drawn from). The intake vector ($\underline{P}$) would be:

$$\underline{P} = \begin{vmatrix} p_{11} \\ p_{21} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ p_{n1} \end{vmatrix}$$

where n = parameters associated with intake

and p = relevance to intake (0,1).

Overlap between a species distribution and the zone of influence around the intake could be assessed as:

$$\text{Overlap} = \underline{1} * [\underline{W} * (\underline{D} * \underline{P})]$$

where $\underline{W}$ = s x s matrix of weights assigning importance to various life stages

$\underline{1}$ = 1 x s vector of 1's.

The overlap variable is a number which measures the coincidence between the distribution of fish and shellfish and the spatial and temporal area occupied by the intake. The degree of overlap measures the relative potential for impact.

The weight matrix ($\underline{W}$) provides a means for assigning biological importance to the various life stages and species. One measure of importance could be based on the reproductive value of each life stage in the vicinity of the intake. Another factor to consider in assigning weights is the susceptibility of the various life stages to impingement and entrainment.

For example, spawning adults of many species are very important to the reproductive success of the species, but because of their size are not generally susceptible to impingement. The assignment of weights will necessarily be arbitrary and dependent on knowledge of the biological community. Values for the weights should be based on an ordinal scale, or if possible, a ratio scale incorporating a quantifiable measure.

As an example of how these matrices can be used to evaluate an intake site, consider a hypothetical situation where a power plant is to be constructed along the shore of a river. Four possible intake structures (A-D) will be considered (Figure 3). The intake structures are classified according to distance from the shoreline, i.e., inshore (along the shoreline; shallow depth), midshore (mid-water depth) or offshore (furthest from shoreline; deep water), and whether water is withdrawn from the top or bottom of the water column. The first structure (A) would withdraw water from the entire water column along the shoreline. Intake type B would have an intake duct with the intake port located on the bottom in an offshore location. Intake C would be located at a midshore location and would withdraw water from the bottom. For design D an intake canal would be constructed. The depth of the canal would mimic a midshore location at an inshore site and might incorporate both habitat types. Water for the intake would be withdrawn from the entire water column.

We will compare the effect of each intake design on a hypothetical species with the following life history: a spring upstream migration; spawning along the shore; adults migrating downstream in the fall; and juveniles migrating downstream the following spring. Spatial and temporal factors describing the proposed plant intake and the distribution of the fish could include: season (spring, summer, fall and winter), location within the river [inshore(i-s), midshore(m-s) and offshore(o-s)]; location within the water column[top(t) and bottom(b)]. The resulting distribution matrix ($\underline{D}$) would be:

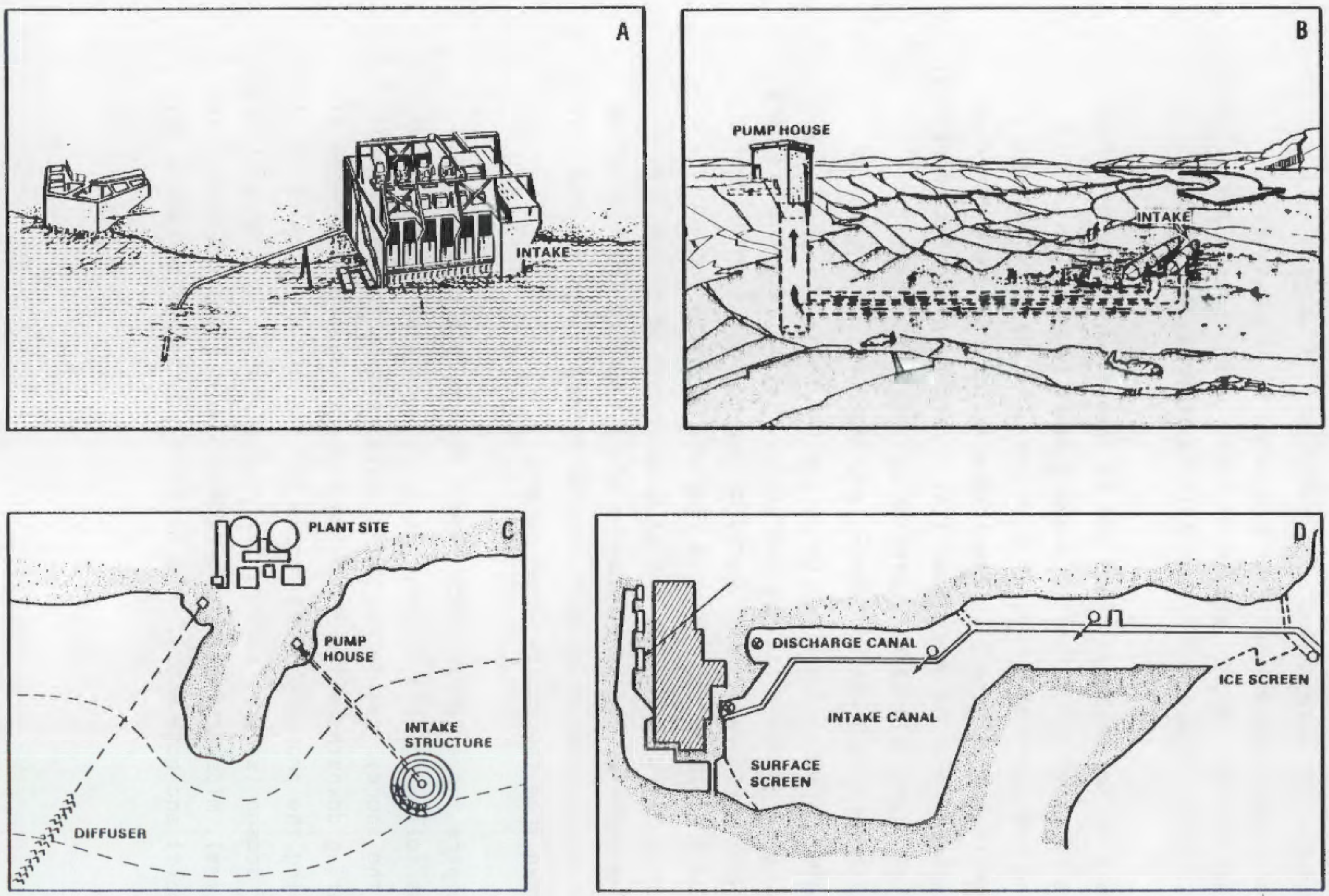

Figure 3. Four types of water intake structures.

	sp	su	fa	w	i-s (t)	i-s (b)	m-s (t)	m-s (b)	o-s (t)	o-s (b)
eggs	1	0	0	0	0	1	0	0	0	0
larvae	0	1	0	0	0	1	0	1	0	0
juveniles	0	1	1	1	0	0	1	1	0	0
adults	1	1	1	0	0	0	0	0	1	1
spawning adults	1	0	0	0	0	1	0	0	0	0

The intake characteristics for each design and location could be quantified as:

	Intake Design*			
	A	B	C	D
spring	1	1	1	1
summer	1	1	1	1
fall	1	1	1	1
winter	1	1	1	1
inshore(t)	1	0	0	1
inshore(b)	1	0	0	1
midshore (t)	0	0	0	1
midshore (b)	0	0	1	1
offshore (t)	0	0	0	0
offshore (b)	0	1	0	0

* see Figure 3.

We weighted egg and larvae loss as +1, spawning adult loss as +2, juvenile loss as +4, and adult loss as 0. These weights combined information on reproductive value and the probability of being impinged and entrained. For the eggs and recently hatched larvae, the chances of being entrained are small since the eggs stay attached to the bottom and the larvae remain in the vicinity of the hatch until the yolk-sac is absorbed. Impingement of adult fish was considered negligible; however, the loss of any spawning adults is critical to the population. Juvenile loss through entrainment and impingement represented the greatest impact for this species. Our weight matrix (W) is:

eggs	1	0	0	0	0
larvae	0	1	0	0	0
juveniles	0	0	4	0	0
adults	0	0	0	0	0
spawning adults	0	0	0	0	2

We can now evaluate the potential effect of intake designs A, B, C, and D on our fish species. The vectors resulting from the matrix multiplication [W * (D * P)] are:

	Intake Design*			
	A	B	C	D
eggs	2	1	1	2
larvae	2	1	2	3
juvenile	12	12	16	20
adults	0	0	0	0
spawning adults	4	2	2	4

*see Figure 3.

The overlap index is 20 for design A, 16 for design B, 21 for design C and 29 for D. Decisions on intake design can now be made based on the relative impact to this one species. To extend this analysis, distribution matrices would have to be prepared for all ecologically and commercially important fish and shellfish species, including those with a high potential for impact (e.g., alewife in lakes). Differential weights can be assigned in matrix W so that more emphasis is accorded to species of critical concern such as endangered species or species in demand for sport or commerical fisheries. The sum of the overlap indices computed for all these species would then provide an indication of the relative potential for impact to the entire system.

FUNCTIONAL APPROACH

Establishing biological criteria for the design, operation and location of water intake structures will first require information on the types of stimuli produced by the intake or occurring in its vicinity, and on the response of fish and shellfish to these stimuli. Neitzel and McKenzie (1981) documented the possible stimulus/response situations associated with an intake (Figure 1). Next, a procedure for quantitatively evaluating these relationships in a multiple stimulus/response framework must be developed. These quantitative evaluations attempt to explain how fish and shellfish distribute themselves within the environment. The procedure serves as a communication link for transferring information on the biological community to those in charge of the design and location of intake structures. The previous section explored a procedure which evaluated the result of multiple relationships using a categorical model. In this section several procedures for combining functional relationships into models that evaluate multiple stimulus/response situations are illustrated. Mathematical equations describe the relationship between stimuli and response. Preparation of such descriptions can provide insight into the mechanisms responsible for the relationships, suggest new areas for research, and predict the response of fish and shellfish over a range stimuli levels.

The difficulty with this approach is the lack of data needed to develop the functional relationships. A majority of the stimulus/response relationships listed in Figure 1 are unstudied or only described qualitatively. Also, mathematical models of complex ecological systems can be criticized for being too simplified and therefore unrealistic. Box and Jenkins (1976) suggest that in developing models for ecology, two ideas should be considered: 1) the principle of parsimony, which states that if several models that adequately represent the system are available, the model with the smallest number of parameters should be selected; and 2) the idea that incomplete understanding of biological processes makes the selection of an adequate model an iterative process.

We selected two examples from the approaches available for describing stimulus/response relationships. In the first, deterministic functions defining a single stimulus/response relationship are combined to evaluate the response interaction. For this example, functions which evaluate the relation between swim speed and various biological and environmental stimuli are presented. This example was chosen because of the amount of information available. Similar relationships could also be developed for response variables more pertinent to intake design, especially preferences for temperature and current. Unfortunately, in this case data comparable to those obtained for swim speed are lacking. The second model uses probability functions to describe the distribution of fish in response to various stimuli. The stimuli in the example are temperature, dissolved oxygen concentration, food distribution and habitat preference. The response is fish movement, which results in a distribution pattern for the fish population.

At their present state of development, these models are useful for planning experiments to examine the mechanisms and consequences of behavioral regulation. They are useful for evaluating field distributions as well. (Behavioral regulation is defined by Neill (1979) as the behavioral adaptations of an organism to environmental stimuli.) Information from laboratory and field experiments can be used to define mechanisms and parameterize the models further. Because the model is provisional, its application as the only basis for assessing water intake design, operation and location is premature. Information needed for the development of these models, however, will increase our ability to predict the response of aquatic organisms to water intake structures.

<u>Examples</u>

1. A deterministic model for swim speed will illustrate a procedure for combining single stimulus/response relationships into a multiple stimulus/response model. The model describes the influence of physiological and environmental variables on fish swim speed. Most studies on swim speed are generally of the single stimulus/response type. Integrating a number of these stimulus/response relationships into one model allows an evaluation of which factors have the greatest effect on swim speed and may improve the accuracy of estimating swim speed for a particular species.

Swim speed is constrained by physiological factors, such as the organism's size (which indirectly indicates age and sex) and the health and reproductive state of the organism. It is also affected by environmental factors such as temperature, salinity, dissolved oxygen, and toxicants (Beamish 1978). The general form of the swim speed model is:

$$V = (aL^b) * f(T, SAL, DO, TOX, CF)$$

where V = swim speed (cm/sec)

L = organism size (length)

a,b = parameters

and $f(\ )$ = functions describing the effect of the following on swim speed:

T (temperature)

SAL (salinity)

DO (dissolved oxygen)

TOX (toxic compounds)

CF (physiological factor- e.g.,sex,disease,schooling,etc.).

If a multiplicative relationship between the various environmental and physiological factors is assumed, the model becomes:

$$V = (aL^b) * f_1(T) * f_2(SAL) * f_3(DO) * f_4(TOX) * f_5(CF)$$

where $0<f_i(\bullet)<1$ for all i.

Functions for temperature, salinity, etc. were developed so that at preferred or optimum levels for these factors, swim speed was related only to fish size (e.g., $f_1(T) = 1$). At other than optimal conditions, the effect of temperature, salinity, etc., was to proportionately reduce swim speed (e.g., $f_1(T) < 1$). Each factor can be weighted according to its importance in determining swim speed; the physiological factor (CF) provides input describing the effects of sex, disease, reproduction and schooling on swim speed.

The relation between temperature and swim speed, applicable to a multiplicative model, is simiiar to that postulated for temperature and ingestion rates (Kitchell et al. 1974) where:

$$T = T_r^{t_x} * e^{t_x(1-T_r)}$$

where $T_r = (T_u - t) / (T_u - T_{opt})$

$t_x = T_1^2[1 + (1 + 40 / T_2)^{.5}]^2$

$T_1 = \ln T_Q(T_u - T_{opt})$

$T_2 = \ln T_Q(T_u - T_{opt} + 2)$

and T_u = upper temperature limit at which swimming stops

T_{opt} = preferred or optimum temperature

T_Q = Q_{10} (rate of change per 10^oC) for swim speed

t = ambient or test temperature.

The form of this relationship is illustrated in Figure 4.

The relation between swim speed and dissolved oxygen concentration can be characterized by a threshold effect (Dizon 1977), with swim speed unaffected at dissolved oxygen concentrations above the threshold and reduced at concentrations below the threshold. This relation is described by an exponential of the form:

$$DO = 1 - e^{D_x d}$$

where $D_x = \ln (1 - V_c / V_m) / D_c$

and V_m = maximum swimming speed (cm/sec)

D_c = dissolved oxygen concentration threshold

V_c = swim speed at D_c

d = ambient dissolved oxygen concentration.

Similar functions can be developed for salinity and toxicants when needed. The model may contain several physiological constraining factors, most of which can be described by discrete functions. For example:

CF = 1.0 if no disease

= V_{dis} / V_m if disease is present

where V_{dis} = swim speed of diseased fish

V_m = maximum swim speed.

All these functions are size dependent. To evaluate the swim speed for all life stages of a particular species would require multiple inputs for maximum swim speed (V_m) and preferred temperatures (T_{opt}).

The swim speed model was evaluated for the fry of two fish species: Micropterus salmoides (largemouth bass) and Oncorhynchus kisutch (coho salmon). Assuming natural (unpolluted) conditions, the swimming speed for the two species was defined by fish size, temperature, dissolved oxygen concentration, and for salmon, disease. The effect of salinity on O. kisutch fry was assumed to be negligible (Giova and McInerney 1977). Figure 4 illustrates the effect of temperature and dissolved oxygen on M. salmoides swim speed, and the effect of temperature, dissolved oxygen and disease on the swim speed of O. kisutch. Parameter values were taken from the literature (Beamish 1978). Output from the model suggests that the decrease in swim speed at sub-optimal conditions is especially precipitcus at

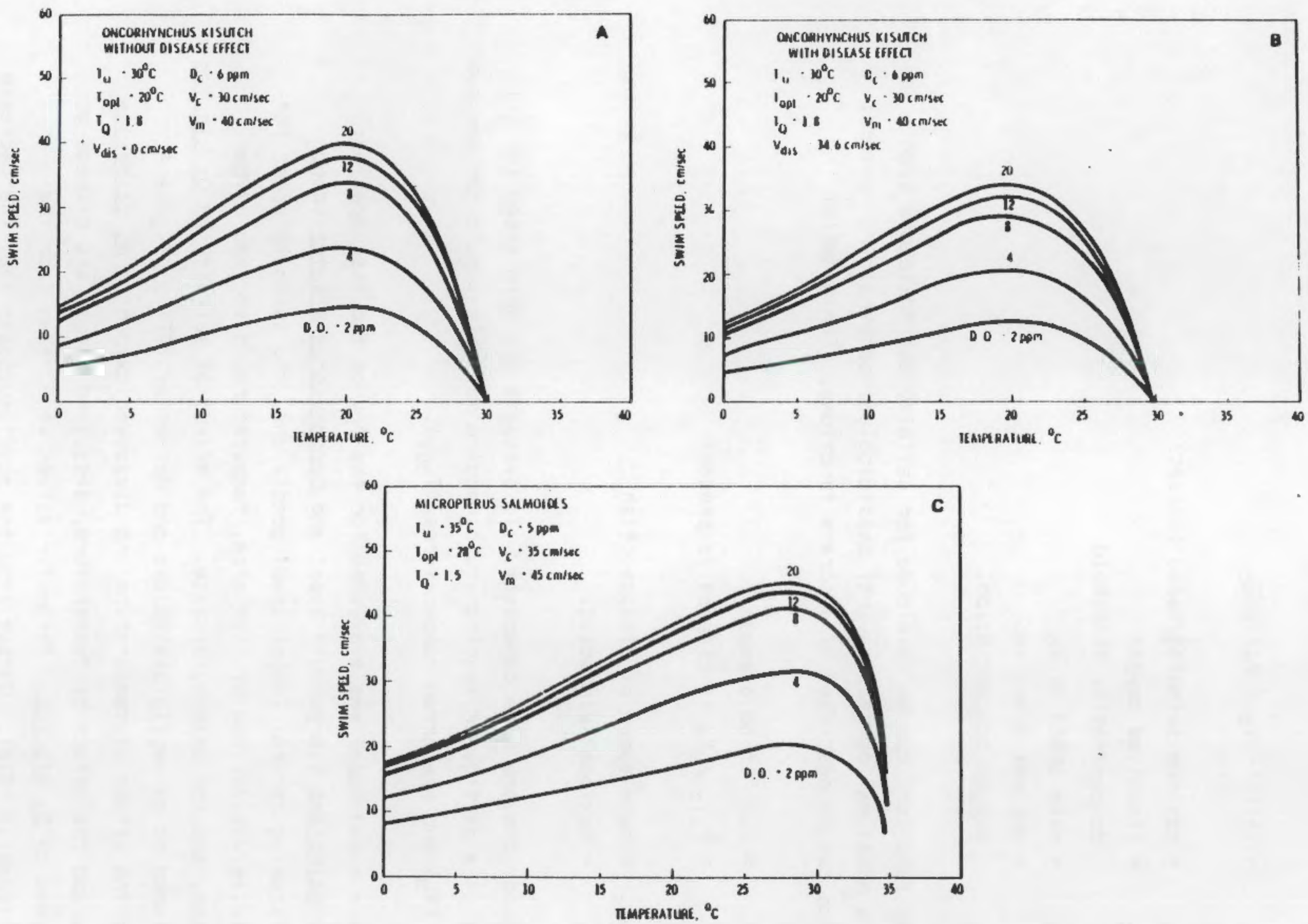

Figure 4. Predicted swim speed for <u>Oncorhynchus</u> <u>kisutch</u> and <u>Micropterus</u> <u>salmoides</u> as a function of temperature, dissolved oxygen concentration and disease. Size: 8mm.

temperatures above optimum and dissolved oxygen concentrations below threshold.

Information from this particular model could be used to better predict swim speed based on the range of temperatures, dissolved oxygen levels, etc. in the vicinity of the intake; the swim speeds could also be compared to intake velocities predicted to occur during intake operation. The categorical approach could be used for the comparison between swim speed and intake velocities.

II. Another approach for evaluating an organism's distribution in relation to environmental or intake stimuli is with a Monte Carlo mathematical model. In such a model the stimulus/response relation is assigned a probability which is dependent upon stimuli preferences. This type of model can include noncommensurate variables similar to the categorical approach so that it is possible, for example, to evaluate the distribution response to both temperature and habitat cover. DeAngelis (1978) developed such a model for predicting fish movement and distribution. The model assumes that fish detect and respond to gradients in temperature and dissolved oxygen, and are attracted to areas which provide food and a preferred habitat. The direction of movement of a "fish" placed within its habitat is randomly selected with conditions closer to preferred producing a bias in favor of movement in that direction. A "forward inertia" is also assumed (i.e., the tendency to continue moving in the same direction).

In the model, a simulated, 2-dimensional habitat is divided into a grid. Values for temperature, dissolved oxygen, food availability and a measure of habitat preference are assigned to each point in the grid. These values are based on gradients, either measured or assumed, for the habitat being evaluated. The response probability of fish to the gradients can be weighted so that temperature preference is more important than food availability, for example. Weighting here would assure that fish in the model do not become trapped in areas with high food availability at lethal temperatures. Modification of the weighting scheme could also be used to compare the effect of the individual factors on the distribution. For example, model distributions where all factors are given equal weight could be compared to distributions where higher weights are assigned to the biological parameters of habitat and food, or where higher weights are assigned to physical and chemical factors.

Such a model offers the potential for describing the distribution of fish and shellfish in relation to stimuli produced by the intake. For example, the distribution variables for fish in the vicinity of a proposed riverine intake site could include preferences for current, depth, and temperature, as well as predator/prey interactions. For shellfish, distribution variables could include temperature, salinity, light and substrate type. The area near a proposed intake could be simulated using values for physical and chemical parameters calculated from engineering models for the various intake designs. Assignment of the biological components to the habitiat, e.g., distribution of food items, could be based either on known distribution patterns or assumed scenarios. Then distribution patterns for selected fish and shellfish species could be simulated under the various scenarios to predict the range of possible behaviors.

However, as with the swim speed model, most of the stimulus/response relations still need to be quantified. It would appear to be a formidable task to collect the information necessary to evaluate the distribution of several species near a proposed intake site. A possible solution would be to include data into the model as they are collected. The distribution predicted from the model could then be compared to the known distribution. This iterative procedure would continue until an adequate distribution was predicted from the model. The adequacy of the model would be subjective and dependent on time and money considerations. A model which accounted for a majority of the distribution for a fish or shellfish species, though, would seem adequate given the present state-of-the-art in determining the actual distribution.

DISCUSSION

Reducing the impact of water intake facilities on fish and shellfish communities will require better siting of the facilities and/or improved intake designs. To attain this goal, information on the biological community will have to be incorporated into engineering decisions. Such information will require decisions as to which members of the community are at risk and what biological factors are important in mitigating entrainment and impingement. In a previous report the biological information pertinent to the question of impact were identified and reviewed (Neitzel and McKenzie 1981). The approach for selecting biological information focused on a stimulus/response relation with fish and shellfish behavior and physiology as the response to intake stimuli. The analysis of multiple stimulus/response relations was considered to yield more realistic information, while fish and shellfish distribution appeared to be the response of greatest utility.

The next step was the development of a quantitative procedure to describe the stimulus/response relation and to assist in the decision process. However, such a procedure is limited by a paucity of information on stimulus/response relations, particularily on multiple stimulus/response relations. Additionally, an abundance of factors may need to be considered. In spite of these limitations, the need for this information is immediate. The hazards of not providing input into engineering decisions on intake siting and design include the potential for impact on the aquatic community, as well as the expenditure of additional money for intake redesign. The proposed procedures attempt to circumvent the data shortage by making maximum use of the available information to make decisions, and combining information from single stimulus/response experiments into a multiple stimulus/response framework.

The categorical approach allows for comparison of water intake characteristics with the distribution of the biotic community. The structure of the model emphasizes organization of the available data and indicates what information is missing. Decisions can then be made regarding the importance of various species, life stages and categories through the use of numerical measures of coincidence. Limited model predictions are useful as a method of evaluating the potential for impact of alternative water intake designs, locations or operating schedules.

Several types of functional models designed to study the stimulus/response mechanism (Figure 5) were examined. A swim speed model demonstrated how to link deterministic functions describing stimuli/response relationships among swim speed and the various environmental and biological stimuli. Stochastic elements in the DeAngelis model simulated fish distribution and the model explored the effect of multiple interactions between stimuli on fish distribution. Presently such models serve primarily as tools for hypothesis testing. For example, different weighting schemes in the DeAngelis model could be used to prioritize the factors responsible for fish and shellfish distribution.

Information needed for the categorical and functional approaches should ideally come from experiments designed to study multiple stimulus/response situations relating to habitat selection. However, research on habitat selection encompasses a broad spectrum of biological and environmental factors, many of which have been identified as important for the development of criteria to protect fish and shellfish (Figure 1). Collecting this information or even part of it would be expensive both in time and money. Also, given the difficulty in designing, implementing and analyzing multiple stimulus/response experiments, the task may yield little useful information. One solution is to utilize the approaches presented in this report as part of a procedure for generating needed information. For example, the categorical approach would be used to make preliminary decisions, organize the available information and suggest areas for research. The functional approach used in conjunction with laboratory and field experiments would assist in the interpretation and organization of the data. Finally, information generated by the experimentation and analysis step would be used by the categorical approach for additional analysis. This procedure is iterative, and attempts to develop a systematic approach to data collection.

Several research areas deserving special consideration include current preferences and the reefing phenomena. Relatively few studies have examined the response of fish and shellfish to current or fish ability to detect changes in current (Bibko et al. 1974; Richkus 1975). Current preferences and the ability to distinguish the intake plume from any background current could be a critical factor affecting impingement and entrainment rates in rivers and tidal areas.

The reefing response has been studied with respect to attracting commercially important fish and shellfish to artificial structures (Klima and Wickham 1971; Scarret 1968). The results indicated that aquatic species are not only attracted to these structures, but also exhibit preferences for structure shape. Solid, structurally simple devices attract more fish than open frame designs do. This phenomenon may be an important determinant in habitat selection and in attracting fish and shellfish to water intake structures.

Utilizing the categorical and functional approaches in an iterative process will ultimately lead to the development of specific biological criteria for evaluating intake siting and design. In the short term, these approaches satisfy a more immediate goal of providing biological input to the design engineer, and of developing a systematic approach for evaluating potential criteria.

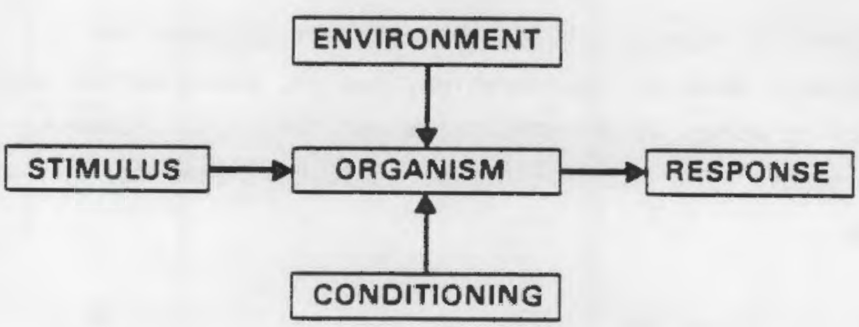

Figure 5. Stimulus/response mechanisms and environmental factors affecting the mechanism.

REFERENCES

Beamish, F.W.H. 1978. Swimming capacity. Pages 101-187. in Hoar, W.S. and D.J. Randall ed. Fish Physiology Vol VII. Locomotion. Academic Press, New York.

Bibko, P.N., L. Wirtenan, and P.E. Kueser. 1974. Preliminary studies on the effects of air bubbles and intense illumination on the swimming behavior of the striped bass (*Morone saxitalis*) and the gizzard shad (*Dorosoma cepedianum*). Pages 293-304. in Jensen, L.D. ed. Proceedings of the second workshop on entrainment and intake screening. Electric Power Research Institute, Palo Alto, California.

Box, G.E.P., and G.M. Jenkins. 1976. Time series analysis: forcasting and control. Holden-Day Publishers, San Francisco.

DeAngelis, D.L. 1978. A model for the movement and distribution of fish in a body of water. ORNL/TM-6319. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 61 pp.

Dizon, A.E. 1977. Effect of dissolved oxygen concentration and salinity on swimming speed of two species of tunas. Fish. Bull. 75:649-653.

Environmental Protection Agency. 1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. EPA 440/1-76/015-A. U.S. Environmental Protection Agency. 263 pp.

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. J. Fish. Res. Board Can. 34:151-154.

Hanson, C.H., L. Decker and H.W. Li. 1978. Response of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and bluegill (*Lepomis macrochirus*) to vertical and horizontal water withdrawals. Pages 120-141.

_in_ Hanson, C.H., and H.W. Li ed. A research program to examine fish behavior in response to hydraulic 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.

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. Board Can. 34:879-885.

Kitchell, J.F., J.F. Koonce, R.V. O'Neill, H.H. Shugart, J.J. Magnuson, and R.S. Booth. 1974. Model of fish biomass dynamics. Trans. Am. Fish. Soc. 103:786-798.

Klima, E.F., and D.A. Wickham. 1971. Attraction of coastal pelagic fishes with artificial structures. Trans. Am. Fish. Soc. 100:86-99.

Lieberman, J.T., and P.H. Muessig. 1978. Evaluation of an air bubbler to mitigate fish impingement at an electric generating plant. Estuaries 1:129-132.

Maxwell, W.A. 1973. Fish diversion for electrical generating station cooling systems a state-of-the-art report. Southern Nuclear Engineering, Inc. Report SNE-123. NUS Corporation, Dunedin, Florida. 78 pp.

Meadows, P.S., and J.I. Campbell. 1972. Habitat selection by aquatic invertebrates. Adv. Mar. Biol. 10:271-382.

Neill, W.H. 1979. Mechanisms of fish distribution in heterothermal environments. Am. Zool. 19:305-317.

———, and J.J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fish in relation to heated effluent from a power plant in Lake Monona, Wisconsin. Trans. Am. Fish. Soc. 103:663-710.

Neitzel, D.A., and D.H. McKenzie. 1981. Procedure for developing biological input for the design, location or modification of water intake structures. A report for the U.S. Fish and Wildlife Service done by Pacific Northwest Laboratory, Richland, Washington.

Richkus, W.A. 1975. The response of juvenile alewives to water currents in an experimental chamber. Trans. Am. Fish. Soc. 104:88-95.

Scarratt, D.J. 1968. An artificial reef for lobsters (Homarus americanus). J. Fish. Res. Board Can. 25:2683-2690.

Weight, R.H. 1958. Ocean cooling water system for 800 MW power station. J. Power Div., Proc. Amer. Soc. Civil Eng., Proc. Paper No. 1888:1-23.

Wurtsbaugh, W.A., R.W. Brocksen, and C.R. Goldman. 1975. Food and distribution of underyearling brook and rainbow trout in Castle Lake, California. Trans. Am. Fish. Soc. 104:88-95.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. FWS/OBS-82/13.2	2.	3. Recipient's Accession No.

4. Title and Subtitle	5. Report Date
Evaluation of Models for Developing Biological Input for the Design and Location of Water Intake Structures	April 1982
	6.
7. Author(s) M. A. Simmons and D. H. McKenzie	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Pacific Northwest Laboratory Battelle Blvd. Richland, Washington 99352	10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U. S. Fish and Wildlife Service Kearneysville, West Virginia 25430	13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

An approach for assessing multiple stimulus/response relations between fish and water intake structures is presented in this report. The approach stresses stimulus/response relations influencing fish and shellfish distribution and is made up of two methods. The first places emphasis on spatial and temperal distributions of populations; information is presented in the form of a non-predictive model, which allows for organizing information and documenting review processes. The second approach encompasses functional relationships between environmental and biological stimuli and responses of organisms. By using the two methods together, functional relationships can be evaluated to define the distribution of a fish or shellfish species. This information can then be used to resolve questions relating to impingement and entrainment.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce