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DEFINING AND DETERMINING THE SIGNIFICANCE OF IMPACTS: CONCEPTS AND METHODS*

Sigurd W. Christensen, Webster Van Winkle and Jack S. Mattice

Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ABSTRACT

The term "impact" is conceptually and mathematically defined to be the difference in the state or value of an ecosystem with versus without the source of impact. Some resulting problems associated with the measurement of impacts based on comparisons of baseline and operational data are discussed briefly. The concept of a "significant" adverse impact on a biological system is operationally defined in terms of an adverse impact which, according to a proposed "decision-tree," justifies rejection of a project or a change in its site, design, or mode of operation.

A gradient of increasing difficulty in the prediction of impacts exists as the scope of the assessment is expanded to consider long-term, far-field impacts with respect to higher levels of biological organization (e.g., communities or ecosystems). The analytical methods available for predicting short-term, near-field impacts are discussed. Finally, the role of simulation modeling as an aid to professional judgment in predicting the long-term, far-field consequences of impacts is considered, and illustrated with an example.

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I. Introduction

The organizers of this "Workshop on the Biological Significance of Environmental Impacts" have shown considerable foresight in providing this timely opportunity for an exchange of ideas in the relatively new field of environmental impact analysis. Most scientists in attendance will have had practical experience in this field, and many will have faced the rigors of defending their predictions or conclusions in public forums or in adjudicatory hearings. Thus, they will be cognizant of the limitations and frailties associated with impact analyses, and of the benefits to be gained from assessing the concepts and the practical methodologies which represent the basic "tools of the trade."

Our experience has been gained in the preparation of Environmental Impact Statements for the U.S. Nuclear Regulatory Commission (USNRC). Specifically, we have been concerned with evaluating the non-radiological effects of nuclear power stations, either proposed or under construction, on aquatic environments. Thus, when we speak of a proposed or existing project as a source of impact, we have in mind a power plant, producing a benefit (electricity) during a 30-40 year period of time, and having some effect (generally adverse) on an aquatic ecosystem. While the generalized concepts we develop are not restricted to power plants, some would require modification for projects having an indefinite expected lifetime, such as dams.

This paper will discuss three main topics: the conceptual definition of "impact", definitions of "significance", and the prediction of impacts. Measurement of impacts will be mentioned briefly, but space limitations preclude more than a cursory treatment of this subject.

II. Definition of Impact

The primary goal of impact analysis is to provide information on which to base responsible decisions about a project. The fundamental questions are related to whether the project will have an acceptable impact, whether use of an alternative design or site (at increased cost but with reduced impact) is necessary or justifiable, and ultimately, whether the project should be approved. Other questions, concerning additional information needed to perform the analysis, and monitoring necessary to confirm compatability of the project with the environment, also need to be answered. An understanding of what is meant by the term "impact" is fundamental to being able to answer such questions.

Conceptually, an ecosystem can be characterized as an N-dimensional hypervolume [Hutchinson 1958; Shugart (in press)] or space in terms of N state variables which are of interest to man in defining the value, or the state, of the ecosystem potentially affected by the proposed project. These variables would represent, for example, biological parameters (numbers of individuals in each of many species), and any physical and chemical characteristics which are of interest in and of themselves (for example, heated discharges could make parts of a lake more suitable for swimming). The N state variables, each a function of time (t), can be denoted as $[X_{1,0}(t), X_{2,0}(t), X_{3,0}(t), \ldots, X_{N,0}(t)]$, where the subscript zero indicates the situation without the project. $\underset{\sim}{X}_0(t)$ then can be defined as the vector (or point) denoting the state of the environment in the N-dimensional hypervolume at a fixed point in time without the project. We can also conceptually define a similar vector to represent the state of the ecosystem, but this time with the project. The state variables are now $[X_{1,p}(t), X_{2,p}(t), X_{3,p}(t), \ldots, X_{N,p}(t)]$, and they define a vector $\underset{\sim}{X}_p(t)$ at any fixed point in time. We next introduce a set of weighting factors as $(W_1, W_2, W_3, \ldots, W_N) = \underset{\sim}{W}$. Each weighting factor represents a conversion of the correspondingly subscripted state variable (e.g., number of individuals of species X_5) to units of value (e.g., worth in dollars for species X_5). An index of impact at year t [I(t)] can now be defined as

$$I(t) = \underset{\sim}{W}^T \underset{\sim}{X}_p(t) - \underset{\sim}{W}^T \underset{\sim}{X}_o(t)$$

$$= \sum_{i=1}^{N} W_i X_{i,p}(t) - \sum_{i=1}^{N} W_i X_{i,o}(t) \qquad (1)$$

$$= V_p(t) - V_o(t)$$

where

$\underset{\sim}{W}^T$ = transpose of the vector of constant weighting factors,

$V_p(t)$ = index of value for the ecosystem with the project at year t.

$V_o(t)$ = index of value for the ecosystem without the project at year t.

If it is anticipated that any of the weighting factors will vary significantly with time or will not be the same with versus without the project, such variations should be taken into account.

This index of impact measures the change in value of the ecosystem at any point in time, due to the plant. Of course, the index of value either with $[V_p(t)]$ or without $[V_o(t)]$ the plant could also be obtained by summing the product of each of the state variables and its associated weighting factor, as implied by Eq. (1).

At this point, the N-dimensional hypervolume has been transformed or mapped into an index of impact (or index of value), and the index of impact (or value) can be plotted as a function of time.

Figure 1a is a graph of the index of value versus time for a hypothetical ecosystem, with (lower line) and without (upper line) a hypothetical plant. Construction of the plant (point C) begins to affect the environment in year 6. Operation (point O) begins in year 10 and continues until decommissioning (point D) in year 50. The vertical distance between the two lines corresponds to the index of impact, [I(t) in Eq. (1)]. The impact in this example has ended by year 65 (point E).

Attempts to measure the impact illustrated in Fig. 1a by comparing baseline data (taken prior to year 6) with post-construction data (taken sometime after year 6) will be confounded by two factors in addition to sampling error: (a) natural fluctuations, and (b) any overall change in the ecosystem not attributable to the plant. While in our hypothetical example we have depicted only relatively long-term fluctuations, shorter-term components of factor (a) (natural fluctuations) will also be substantial in real-world situations, particularly for the individual state variables. An example is available from Conowingo Pond, the lowermost reservoir on the Susquehanna River in Pennsylvania. Year-class strengths of white crappie (a dominant species), estimated from the mean catch of young per trawl haul in each of six years, varied over more than two orders of magnitude, with the strongest year class in 1969 appearing two years after the Muddy Run Pumped-Storage Reservoir began operation (Robbins and Mathur 1973). It was correctly concluded that operation of the pumped-storage reservoir had not had a measurable impact on the white crappie population. In our view, however, there would be small hope of detecting (much less measuring) even a substantial impact on such a varying population by comparing estimates of year-class strengths. Fortunately, most populations of "representative and important species" (RIS; see later discussion) are less variable than the white crappie. Still, the example points out the need for either many years of pre-operational data or the identification and measurement of relevant parameters which show little annual variation.

With respect to factor (b) (any overall change in the ecosystem which is not due to the plant), the "without plant" line (Fig. 1a) indicates a decline in ecosystem value, which it would be unfair to attribute to the plant. In other words, the ecosystem value prior to plant construction does not correspond to the "zero impact" value ("without plant" line in Fig. 1a) after operation begins. The proper statistical test, based on field studies, would be between the "without plant" and the "with plant" situation at various points in time. This test is, in the strict sense, not possible in the real world, where only one of the two situations can exist. Only rarely are there suitable nearby reference areas with similar ecological characteristics which approximately meet the requirements for a comparison.

The Delaware River is a real-world example of a system in which preoperational data might be inappropriate as the baseline for an attempt to measure an impact. In this case, the "zero line" (without plant) would probably indicate an increase in value with time, in contrast to the decrease in value with time illustrated in Fig. 1a. Pollution in the vicinity of Philadelphia has been blamed for the drastic decline in the American shad fishery in the Delaware system since the late nineteenth century (Chittenden 1974; Sykes and Lehman 1957) and for a reduction in striped bass populations (Chittenden 1971). Efforts are underway to restore water quality in this region, and it is hoped that stocks of such anadromous fish will improve considerably. For the purpose of either predicting or measuring the impact of a new project on the Delaware system, these pollution abatement efforts would need to be factored into the analysis. A second example of possible confounding ecosystem change can be illustrated by considering the inadvertent introduction of the gizzard shad into Conowingo Pond in 1972 (Robbins and Mathur 1974) shortly before two large (2130 MWE total) nuclear power stations using once-through cooling began operation. Again, for the purpose of either predicting or measuring the impact of these two power stations on the Conowingo Pond ecosystem, the introduction of the gizzard shad into this ecosystem must be factored into the analysis.

In Fig. 1b, the index of impact due to the plant [again, I (t) in Eq. (1)] is plotted against time, using an expanded vertical scale. The "zero change" horizontal reference line here corresponds to the "without plant" curve on the upper graph. This figure is more useful for examining the impact of the plant itself. In the hypothetical example shown, a lag time is apparent between the beginning of operation and the time when the full impact is apparent. This lag time might, for example, be caused by the time required for cropping of eggs and larvae of a highly-valued fish species to be fully reflected in reduced yield to a fishery. A similar lag time is apparent following decommissioning of the plant. In this example, the impact is not irreversible in the long-term sense, since the two lines converge at point E.

The shaded area between the curves in either Fig. 1a or 1b provides an index of the total impact, according to the expression

$$I_T = \int_C^E I(t)dt \qquad (2a)$$

$$= \int_C^E V_p(t)dt - \int_C^E V_o(t)dt \qquad (2b)$$

where C and E are the times of the onset and the end of the impact, respectively. This total impact could be depicted as a point on a one-dimensional "impact-line" (Fig. 2), since time is no longer a variable. The zero point here corresponds to $I_T = 0$, which could occur if $V_o(t) = V_p(t)$ for each year during the period C to E or if the index of value of the ecosystem summed over the period C to E were the same with and without the plant [(see Eq. (2b)].

Obviously, this approach is simply a conceptual framework. Quantification of all of the state variables which would characterize the ecosystem with the plant is virtually impossible. Further, complete agreement about the appropriate values for the weighting factors is a nebulous goal, and the solution to Eq. (1) requires knowledge about a hypothetical world (one without the plant). Nonetheless, when reduced to a plot of the index of value or impact versus time (Fig. 1a or 1b) or to an impact-line (Fig. 2), the concept is useful in clarifying what an "impact" means. This is a necessary step in being able to talk about how to measure or predict the extent of an impact, and how to determine whether it is "significant" or not.

III. Operational Definition of a Significant Impact on a Biological System

As evidenced by its inclusion in the title of this workshop, "significance," is an important concept in impact analysis. Unfortunately, the word "significance," (as well as others such as irreversible, irreparable, irreplaceable, irrecoverable, irrevocable and irretrievable) is often used without clear definition. The problem of definition is recognized in the guidelines of the Council of Environmental Quality (CEQ), where it is stated that "...a precise definition of environmental 'significance,' valid in all contexts, is not possible..." (CEQ 1973, section 1500.6). Earlier in section 1500.6, however, it is stated that "The Act [NEPA 1969] also indicates that adverse significant effects include those that degrade the quality of the environment, curtail the range of beneficial uses of the environment, and serve short-term, to the disadvantage of long-term, environmental goals." Significant" in the above quotations is used in the context of determining whether a major Federal action requires the preparation of an Environmental Impact Statement, but not in the context of necessarily indicating a need for mitigating measures.

It is relatively easy to provide conceptual definitions for no impact, for a reversible impact, and for an irreversible impact using the characterization, developed in Section II, of an ecosystem as an N-dimensional hypervolume.

<u>No Impact</u>

$$\underset{\sim}{X}_p(t) - \underset{\sim}{X}_o(t) \approx \underset{\sim}{0} \tag{3}$$

for all time t greater than C, the start of construction of the project (see Fig. 1).

<u>Reversible Impact</u>

$$\underset{\sim}{X}_p(t) - \underset{\sim}{X}_o(t) \approx \underset{\sim}{0} \tag{4a}$$

for all time t starting a reasonab e time (T) after the project is decommissioned at time D (see Fig. 1). Alternatively,

$$\lim_{T \to \infty} \int_{D+T}^{T} [\underset{\sim}{X}_p(t) - \underset{\sim}{X}_o(t)]dt \approx \underset{\sim}{0} \tag{4b}$$

<u>Irreversible Impact</u>

Failure to satisfy Eqs. (4a) and (4b).

The definition of "significance" is more elusive, however, since the word "significant" implies a value judgment. An ecosystem cannot make value judgments, and therefore cannot tell us when a significant impact has taken place. Significance must be determined from the viewpoint of the entity making the decision. Humans must, therefore, exercise judgment as to what constitutes a significant impact. In recognition of this requirement for a value judgment, we prefer the phrase "significant impact on a biological system" to the phrase "biologically significant impact." Also, in the context of this paper, we consider biological, ecological, and environmental to be essentially interchangeable terms.

Figure 3 shows a decision-tree relating to the making of decisions concerning the acceptability of a proposed project with respect to its impact on a biological system; the biological system may be a population, community, or ecosystem. At this time the state of the art of impact analysis is such that selected single populations are the biological systems commonly evaluated. A brief discussion of each of the decision points will lead to a clarification of the range of issued involved in attempting to determine the significance of an impact.

1. Is the impact of the project on the biological system beneficial? This decision point reflects a difference in the decision process for beneficial as opposed to adverse impacts. A beneficial impact would be located to the right of the zero point of an impact-line such as in Fig. 2 (i.e., $I_T > 0$).

2. Is the impact of the project on the biological system reversible? Equations (4a) or (4b) give a conceptual definition of a reversible impact. The impact of a project is considered reversible if, following operation of the project for the planned period of time, the biological system which it affects would return to essentially the same state it would have had if the project had never been built.

3. Is the biological system (or component thereof), which is irreversibly affected, trivial? A conceptual definition of an irreversible but trivial long-term impact is:

$$V_p(t) - V_o(t) \simeq 0 \qquad (5)$$

for all time t starting some reasonable time after the project ceases to operate. $V_p(t)$ and $V_o(t)$ are values of the ecosystem with and without the plant, respectively [Eq. (1)]. Value judgments are involved in the selection of the weighting factors needed to convert the state variables [$X_i(t)$] into value variables [V(t)] and in determining how close to zero the difference in Eq. (5) needs to be.

4. Is the socioeconomic benefit of the project greater than the socioeconomic cost of the impact or the biological system? This is a benefit-cost comparison, involving both quantitative (e.g., dollars) and qualitative (e.g., preservation and conservation ethic) considerations. The conservation ethic might be included in a dollar benefit-cost analysis by assigning an infinite cost to the predicted interim reduction of one or more populations below some arbitrary level, even if the reduction would not be irreversible. Society would need to consider the maintainance of populations above this arbitrary level to be of sufficient value to override a strictly monetary benefit-cost ratio of less than 1.0 for selection of any mitagating alternative design. Such levels have not been established, and their selection would be a controversial process. In their absence, incorporation of conversion-ethic considerations at this decision point is necessarily a qualitative and judgmental process.

5. Does the impact of the project on the biological system satisfy legal standards? Relevant laws, such as the National Environmental Policy Act of 1969 (NEPA 1969) and the Federal Water Pollution Control Act Amendments of 1972 (FWPCA 1972), contain qualitative goals relating to maintaining or enhancing environmental quality, consistent with other national priorities. Legal standards, designed to restrict, minimize, or eliminate the impact of a project on a biological system, have been established in some instances. Decision point (5) recognizes these standards.

6. Is an alternative to the project available? This decision point allows for corrective action if it is needed. In general, the best time to consider such alternatives is during the early design stages. By the time a proposed project reaches a regulatory agency for review, the sponsor of the project has usually made a considerable financial investment in both the proposed site and the proposed design. Involvement of regulatory agencies either prior to a project's conception (by designating appropriate sites and designs) or during the earliest planning stages would likely be both economically and ecologically beneficial, and could avoid some of the contention which often surrounds regulatory activities.

7. Is the present design (including mode of operation) of the project optimally cost-effective with respect to minimizing the damage to (or enhancing the value of) the biological system? This decision point reflects the fact that there is a potential value in minimizing adverse effects or enhancing the environment even though an impact may be "acceptable" otherwise. To some extent, established standards will require good designs, but further improvement may be justifiable. A second factor to consider, besides the cost-effectiveness aspect (does a dollar spent on an improved design yield at least that much in damage prevented or enhanced value?) is the question of whether a proposed project, without further mitigative measures, may be excluding future use of the region by other projects.

This decision-tree (Fig. 3) suggests that a significant adverse impact on a biological system can be operationally defined as an adverse impact which justifies rejection of the project or a change in its site, design, or mode of operation. Since only the impacts of the project on the biological system have been included in this decision-tree, other impacts (e.g., non-biological socioeconomic impacts; safety) need to be considered, and a final benefit-cost comparison (including the costs of these other impacts) needs to be made.

Let us now consider some of the implications of these criteria, particularly from an ecologist's point of view. First, it is not always obvious whether an impact will be desirable [decision point (1)] or not (USAEC 1973, pp. XIII-10 to XIII-13), and some short-term benefits (e.g., enhanced fishing because of heated discharges) may carry a risk of long-term adverse effects. Second, with respect to the question of reversibility [decision point (2)], it is obviously not possible to predict exactly what level of stress would be required to destroy the ability of an ecosystem to return to the baseline state. Rather, it is necessary to speak of the probability, or risk, of irreversible damage. This risk is related not only to the characteristics of the ecosystem, but also to the total stress imposed on it by man's activities. This requires that not only the proposed project, but also the other pre-existing sources of impact, be considered in the analysis. It also implies that decisions about the project, if based on the criterion of irreversibility, will need to be made on the basis of professional judgment of the risk involved, since we do not know enough to quantify the probability of irreversibility associated with a typical impact. Third, answers to the philosphical question of how much of "the environment" should be for sale to sources of impact, and the practical question of how to assign monetary value to various kinds and levels of impact on biota are needed for many of the decision points. To answer these questions (as well as is possible), interdisciplinary input and discussion is required. In order to improve the technical soundness of this aspect of the decision-making process, however, the ecologist must supply quantitative estimates of the impact on biological systems.

This decision-tree suggests criteria to apply in determining "significance," in analyzing impacts on biological systems, and in making management decisions. These criteria indicate areas where further attention is needed. They also establish a very real challenge to those charged with performing impact analyses. It is not practical to make quantitative estimates of the magnitude of impact on all the state variables of an ecosystem. Rather, only one, or at most a few, representative and important species (RIS) (Coutant 1975) can receive detailed attention. Even then, estimates of the probability of irreversible damage remain a matter of judgment or opinion. Also, predictions of quantitative impact for benefit-cost purposes (e.g., reduced yield to the fishery in pounds of fish) may span orders of magnitude even before the problem of setting a value is dealt with, because of the considerable uncertainties which are almost always involved (Christensen et al. 1975). Thus, while we believe that these criteria are valuable conceptual guidelines, we do not mean to imply that they can always be formally invoked in the decision-making process. Qualitative judgments on the part of professionals in various disciplines remain very much a necessity in the field of impact assessment.

IV. Prediction of Impacts

A. Some general considerations

The preparation of Environmental Impact Statements generally requires that the effects of a proposed project be predicted, as opposed to measured, because the project does not exist, or has not operated long enough for measurable effects to have occurred. Even in the case of established projects, prediction will usually be involved in an impact analysis, since it will seldom be possible to assess the impact using data comparisons alone. As pointed out in Section II, natural fluctuations will tend to mask the effects of the project, even though the impact may be "significant" as defined in Section III. Irreversible damage may or may not become apparent in time for corrective action to be taken, especially for species with long generation times. Thus, consideration of the prediction, or extrapolation, of impact is relevant to the analysis of either proposed or existing projects. We will now consider the problem of predicting impacts of power plants in some detail, with emphasis on the analytical methods available rather than on the acquisition and interpretation of site-specific data.

A helpful beginning point is to recognize certain gradients of difficulty in the process of analyzing impacts, as illustrated in Fig. 4. The difficulty of either predicting or measuring effects increases (a) as one moves from a short time frame to a long time frame, (b) as one move from considering effects in the immediate vicinity of a point source of impact to considering effects far removed from the source, and (c) as the scope of the investigation is expanded from effects on individual organisms, to populations of a single species, to communities, and to ecosystems. The specific difficulties which increase are related to the cost, the time, and the level of effort required both to obtain and to analyze the needed information. Most unfortunately, the uncertainty also increases as one moves toward long-term, far-field predictions involving more and more species.

The direct impact from a power plant on an ecosystem will be manifested as short-term, near-field effects on individuals of many species. Far-field effects, of increasing importance over a longer time frame, should persist primarily for mobile species having a long generation time and life span, particularly if their reproductive activity is concentrated spatially in the vicinity of the source of impact. A logical way to analyze an impact, then, is to begin at the left-hand side of the gradients for time, space, and level of biological organization (Fig. 4) where the impact will be most amenable to prediction via the quantitative application of laboratory and field studies. Consideration of the right-hand side of these gradients, for which we have found simulation modeling to be an important added tool, can then follow for appropriate species.

B. Analysis of near-field, short-term impacts

A steam-electric power plant affects an aquatic ecosystem by withdrawing water (and therefore organisms) from a water body, and subsequently returning the water (altered in temperature and in chemical composition) to the water body. The location of the plant and the relevant information about its construction and operating characteristics (e.g., volume of water withdrawn, amount of temperature increase, size of the thermal plume, chemical composition of the discharge, etc.) will be specified or can be estimated or predicted by professionals in various disciplines. Physical information about the water body, such as water flow and temperature regimes, will also be available. Biological information in each of the following four categories is fundamental to predicting the consequences of operation (Goodyear et al. 1974, p. 30):

1. The species composition of the affected area must be known and the relationships between various species must be understood.
2. The spatial and temporal distribution of the species in the area must be known.
3. The relationships between each species and its physical environment must be understood.
4. The sensitivity of the various species to alterations in their chemical and physical habitat must be known.

Data available from site-specific sampling programs will generally address the first part of item (1), and, to varying degrees, item (2). The remaining items, which necessarily are only partially achievable goals, are no less essential. In recent years, substantial progress has been made in identifying and summarizing the available literature on thermal [e.g., Coutant et al. 1974a, Raney et al. (undated)] and chemical (Becker and Thatcher 1973) effects, and in devising empirical models for predicting the potential for mortality from various stresses [Committee on Water Quality Criteria 1972; Coutant 1972, and in press; Mattice and Zittel (in preparation); Morgan et al. 1973; USAEC 1974]. Such work forms a foundation for impact analysis.

Figure 5 shows, as an example, data on the thermal tolerance of Corbicula manilensis, the Asiatic clam. The usual way to estimate thermal tolerance is to measure the percent mortality over time following exposure of clams (acclimated to various temperatures) to a series of test temperatures. When percent mortality on a probit scale is plotted against log time a straight line frequently results over the middle range of mortality

(Fig. 5). Data such as these enable prediction of the extent of mortality resulting from specific power plant operational procedures or environmental conditions. For example, if the ambient temperature were 20°C and an Asiatic clam were exposed to a temperature of 36°C for about 3.5 hours, 40% of the organisms would be predicted to die as a result (Fig. 5). The manner of presentation of the data is, however, important. Figure 6 summarizes data of the type in Fig. 5 in a tolerance parallelogram. The lines represent exposures causing 50% mortality at 36°C, but the figure contains no information about the duration of exposure necessary to produce this result, and thus has limited utility in assessing power plant impacts.

Similar types of analyses can be applied to toxic chemicals, and perhaps even to factors involved in mechanical damage such as shear forces (Morgan et al. 1973). Information on most toxicants is too scanty for extensive analysis, but staff members of the Environmental Sciences Division and the Environmental Statements Project at Oak Ridge National Laboratory have developed a procedure for site-specific estimation of chlorine toxicity based on dose-time exposures involved in plant passage and discharge plume dilution [Mattice and Zittel (in preparation)]. Similar procedures need to be developed for other toxicants.

Still, death simply represents the breaching of the last of an organism's "lines of defense." There is, in reality, a continuum of effects due to sublethal stresses arising from habitat modifications. These can represent significant impacts. In response to increasing levels of stress, successive "lines of defense" in general are: embryonic development, reproduction, growth, and finally mortality (Coutant 1972).

A change in production is perhaps the most sensitive criterion for determining habitat modification. For example, the sensitivity of production to temperature is dependent on the combined sensitivities of growth and reproduction, which have been shown generally to decrease at temperatures both higher and lower than some optimum. Since growth and reproduction often have similar temperature optima, production can be expected to demonstrate a similar relationship with temperature. If data are available on production as a function of temperature, it is possible to predict a resultant percentage change in production for a given temperature change. For example, an increase in temperature from 15°C (the optimum) to 20°C would cause an approximate 45-50% decrease in production of the pulmonate gastropod mollusk Lymnaea obrussa Say (Fig. 7).

The direct mortality (or "cropping") of fish and shellfish impinged on the intake screens of power plants, or of small organisms (especially ichthyoplankton) entrained through the intake screens and subjected to the multiple stresses of passage through the plant, is of obvious importance in impact analysis. The percentage of entrained organisms of various species which will be killed has been estimated in field (e.g., New York University 1974) and laboratory (Kedl and Coutant 1975) studies. Once again, however, sublethal stresses can have significant effects on survivors of entrainment, or on organisms in the vicinity of the discharge. Studies of predation on juvenile largemouth bass and catfish by adult largemouth bass have indicated that exposure of the juveniles to cold shock increases their vulnerability to the predator (Coutant et al. 1974b). This increased vulnerability to predation may actually occur in the field following entrainment of fish during the winter or rapid winter shutdown of the plant. Regardless of the cause, the end result would be an increase in cropping impact.

Effects falling in the category of "habitat modification" can also cause what are effectively cropping impacts. If, for example, thermal discharges block fish spawning migrations, or induce spawning in a location which is not favorable to the early life-stages, success of the spawn could be reduced as effectively as though the ichthyoplankton had been directly killed by entrainment. These and other effects, relating to the behavior of mobile organisms, deserve further experimental attention.

C. Extrapolation of Near-field, Short-term Impacts

Interpretation of the significance of near-field, short-term impacts, such as losses of individuals or changes in physiological rates, is an integral part of impact analysis. Such interpretation generally involves extrapolating near-field, short-term impacts at the individual organism or population level to expected far-field, longer-term impacts at the population, community or ecosystem level. Such extrapolations commonly cannot be based entirely on an empirical assessment but rather involve using professional judgment to make predictions or forecasts based on comparable experiences elsewhere and on simulation models. The number of simulation models applicable to impact analysis and resource management is increasing rapidly; and it is our opinion that the results from such simulation models, properly used and properly interpreted, are a valuable aid in impact evaluation.

Some models are of value primarily in forecasting the long-term effects of increased cropping on a particular population. For example, Jensen (1971; also see Beland 1974) evaluated the possible effect of increased mortality on the young in a population of brook trout using a simulation model for yield. The analysis showed that even a 5% increase in mortality of the 0 age group decreased the yield of the trout fishery and that with a 50% increase in mortality the population was theoretically driven to extinction, even though the effect of the increased mortality did not become apparent for several years. Waller et al. (1971) used a simulation model to evaluate the effects of reduced reproduction due to pollutants on populations of fathead minnows, assuming that the parent-progeny relationship is of the form proposed by Ricker (1954, 1958). Their model included a random error term to simulate the effect of random environmental fluctuations on the relationship between spawners and subsequent recruits. In general, their results are compatible with the recommendation of the U.S. Committee on Water Quality Criteria (Anon. 1968) that the maximum concentration of zinc to which fish could be continuously exposed should not exceed 1/100 of the 96-hr TL 50 (median tolerance limit) - a concentration that caused a 50% reduction in the mean number of eggs laid per female by fathead minnows in a laboratory study. Miller and Botkin (1974) used simulation models for endangered populations (whopping cranes and sandhill cranes) to illustrate the outcomes of various management alternatives. The results of this analysis, in comparison with those for fish populations, indicate a difference between K-selected (low fecundity, care of young, stable environment) populations (such as cranes), and r-selected (high fecundity, no care of young, unstable environment) populations (such as fish) with respect to ability to tolerate and recover from increases in cropping.

Other models, such as that of Kitchell et al. (1974), are particularly appropriate for forecasting long-term but sublethal effects, such as those resulting from thermal enrichment. They developed their model of fish biomass dymamics based on principles of physiology, population biology, and trophic ecology. The model is designed to incorporate measurable parameters for simulating seasonal changes in a natural fish population. Model simulations for a bluegill population indicated that changes in temperature of +3°C and +10°C over ambient caused a decrease in biomass and extinction of the population, respectively.

The above four models deal with forecasting the effects of impacts at the population level, and as such they accurately reflect the current emphasis in the role of simulation modeling as applied to assessing impacts on aquatic ecosystems. However, the generalized simulation model developed by Park et al. (1974) for lake ecosystems is an example of the type of model which should find increasing applicability in providing at least semi-quantitative indications of the ecosystem effects of such impacts as nutrient enrichment and thermal alterations.

The above discussion provides a brief overview of the range of applications of simulation models in impact evaluation. We turn now to a detailed discussion of an impact assessment with which we have been involved for several years and which involves the use of simulation models as an aid in determining the significance of an impact.

D. An Example: Determining the Significance of Entrainment and Impingement on the Hudson River Striped Bass Population

The Problem

Figure 8 illustrates the lower Hudson River from the dam at Troy to the Battery where the river drains into New York Bay, a distance of approximately 150 miles. Also indicated are the locations of seven existing power plants and one proposed project, the Cornwall pumped-storage facility. The concentration of power plants between mile points (MP) 38 and 65 is of particular concern, due primarily to the cumulative water withdrawal from the Hudson River by these plants (Fig. 9). From 1950 through 1972 there was a steady but gradual increase in water withdrawal as Indian Point Unit 1 and the various relatively small units at Lovett and Danskammer came on line. Since 1972 there has been a rapid and large increase in the cumulative water withdrawal as relatively large units at Bowline, Roseton and Indian Point have come on line. Water withdrawal in future years is in question and depends on the fate of the proposed Cornwall pumped-storage facility, the installation of closed-cycle cooling at Bowline, Roseton, and Indian Point Units 2 and 3, and the construction of additional power plants in this middle region of the lower Hudson River.

Although the cumulative effects of thermal and chemical discharges from these plants clearly require monitoring because of potential habitat alteration, the primary concern has been the direct cropping impact on fish populations due to impingement on the intake screens and entrainment in the water passing through the plants. In response to this concern, the three utilities involved (Consolidated Edison Company of New York, Inc., Orange and Rockland Utilities, Inc., and Central Hudson Gas and Electric Corporation) have supported a steadily escalating research program that somewhat parallels the water withdrawal curve in Fig. 9 and that now involves expenditures exceeding $5 million per year.

Entrainment and impingement data indicate that the fish species having the greatest potential for being adversely effected by the operation of these power plants are striped bass, white perch, tomcod, alewife, blueback herring, and anchovy (USNRC 1975, pp. V-125 to V-183). For several reasons, however, the impact assessment has concentrated on one of these species, the striped bass. The striped bass is a "representative and important species" (RIS) (Coutant 1975) in that it is the object of an intensive sport and commercial fishery, it is a representative anadromous species (returning to fresh water to spawn), and it is one of the top carnivores in the fish community in the Hudson River Estuary. Secondly, the spawning distribution of striped bass in the Hudson River is in and immediately above the region in which the plants are concentrated, while the major nursery area for young-of-the-year striped bass is in Haverstraw Bay and Tappen Zee Bay immediately below Bowline, which is below most of the other plants (Figs. 8 and 10). Data (USNRC 1975, Appendix B, pp. B-2 to B-31; B-72 to B-73; B-113 to B-120) indicate that the majority of young-of-the-year striped bass which survive to reach this major nursery area move past these power plants at an entrainable size (i.e., less than 50 millimeters long). Finally, considerably more information is available for striped bass than for any of the other five fish species of concern, thus permitting a more detailed and accurate assessment. In terms of the N state variables introduced in Section II, the determination of the significance of the impact of these power plants on the Hudson River ecosystem has focused on one dimension of that hypervolume, namely that for the Hudson River striped bass population. The assessment has been at the population level, as opposed to either the individual organism level or the fish community or ecosystem level.

Although our assessment was carried out in the course of the licensing procedure for a single power plant (Indian Point Unit 3), young-of-the-year striped bass are subjected to entrainment and impingement impacts from the entire complex of power plants on the Hudson River. Consequently, a multi-plant or regional assessment of the impact was necessary.

Use of Simulation Models

As an aid in determining the significance of the entrainment and impingement impact on the Hudson River striped bass population, we have developed two simulation models Fig. 11): a young-of-the-year population transport model [Eraslan et al. (in press)] and a life-cycle population model (Van Winkle et al. 1974). Other simulation models for the Hudson River striped bass population have been developed by Clark (1972), Lawler (1972), and Texas Instruments (1974). [A similar pair of simulation models has been developed at the University of Rhode Island and applied as an aid in assessing the potential impact of the Millstone Point Nuclear Power Station on the winter flounder population spawning in the Niantic Bay area (Hess et al. 1975)].

Our striped bass young-of-the-year model [Eraslan et al. (in press)] considers six life stages (egg, yolk-sac larva, post yolk-sac larva, and three juvenile stages), and it includes dependence of spawning rate, mortality rates, growth rates, apparent survival probabilities and maximum swimming speeds on temperature, salinity and population densities. The transport of these life stages in the Hudson River is formulated in terms of a daily transient (tidal-averaged), longitudinally one-dimensional (cross-section-averaged) hydrological transport scheme. The major features of the model are represented schematically in Figs. 12 and 13. The validation procedure for this model involves comparing simulated and observed weekly standing crop values in the Hudson River for each of the young-of-the-year life stages (Fig. 14).

From the striped bass young-of-the-year population model, we obtain forecasts of the percent reduction in the number of striped bass surviving their first year, due to mortality at the power plants. This percent reduction value provides input to the striped bass life-cycle population model (Fig. 15) (Van Winkle et al. 1974). The life-cycle model is designed to evaluate the long-term impact on the striped bass population of changes in mortality in the youngest age class. The general question concerns what happens to a fishery when new, density-independent sources of mortality which act on the young-of-the-year are added to already existing sources of mortality. This model considers all age classes of striped bass from young-of-the-year to fifteen-year-olds and older. The model is strictly time-dependent and, unlike the young-of-the-year model, does not include spatial considerations. In the model the striped bass population is presently assumed to be regulated in the long-term time frame by fishing mortality which varies with the weight of fish available to the fishery in a compensatory (density-dependent) manner.

Typical but hypothetical results from the life-cycle model are illustrated in Figs. 16 and 17 for two designs. Design 2 involved an annual reduction of 50% for each of the first 35 years in the number of striped bass surviving their first year, due to mortality at the power plants, and then no power-plant impact for the next 65 years. Design 1 involved an annual reduction of 50% for the first five years, followed by an annual reduction of 10% for the next 30 years, and then no power-plant impact for the next 65 years. Relative yield (Fig. 16) is defined as the ratio of the yield to the fishery with a power-plant impact to the yield with no power-plant impact. RELTOTP (Fig. 17) is defined as the ratio of the size of the legally fishable population with a power-plant impact to the size of the legally fishable population with no power-plant impact.

Figure 16, which is similar to Fig. 1b except that pounds of fish rather than value is depicted, and that the line of no impact corresponds to a horizontal line through Relative Yield = 1.0 instead of I(t) = 0.0, can serve as a basis for an economic benefit-cost analysis (USNRC 1975, pp. XI-76 to XI-107). The hatched area in Fig. 16 represents an index of the difference in the expected impact on the striped bass fishery from the two power plant designs.

Figure 17 can serve as a basis for calculating an index of rish of irreversible damage to the striped bass population. This index of risk, calculated as $\sum_i (0.5 - RELTOTP_i)$ for all years i such that RELTOTP < 0.50, corresponds to the hatched area in Fig. 17. This index takes into account both the number of years and the extent to which the relative size of the population is depressed below 0.5 of its original steady-state size. The choice of a "critical value" of one-half of the original size of the population is somewhat arbitrary, but in light of presently available information, our judgment is that 0.5 seems reasonable but not conservative for a fish species subjected to an intensive sport and commercial fishery. Analyses for striped bass have also been made using 0.75 (Fig. 17) as the critical value for the relative size of the population (USNRC 1975, Appendix B, pp. B-182 to B-188). For a species that is not heavily fished, a lower critical value (Fig. 17) might be appropriate for calculating the index, in order to reflect the expectation of a lower risk of irreversible damage with a given level of cropping.

The results of our assessment of the potential impact of the power plants on the striped bass population spawning in the Hudson River provides an example of how biological information can be analyzed to aid in the decision-making process (Fig. 3). In the case of the striped bass, it has been possible to identify a non-trivial adverse impact as having a reasonable, albeit unquantifiable, probability of being irreversible [decision points (2) and (3)], although changing the existing plant to substantially reduce this risk is probably not cost-effective [part of decision points (4) and (7)] if the impact would indeed be reversible.

With reference to the gradients of increasing difficulty in Fig. 4, the striped bass young-of-the-year model, on the one hand, simulates relatively short-term, near-field phenomena, i.e., phenomena occurring within a year in the Hudson River. The life-cycle model, on the other hand, deals with relatively long-term, far-field phenomena, i.e., phenomena occurring over a 100 year period not only in the Hudson River but wherever adult Hudson River striped bass may migrate along the Atlantic Coast. The gradients of increasing cost, time required, and uncertainty diagramed in Fig. 4 are reflected by the design of the research program [which focuses primarily on the young-of-the-year striped bass and short-term (i.e., annual) studies] supported by the utilities which have plants on the Hudson River. In turn, these gradients are reflected in the nature of the validations for the two simulation models. Validation of the young-of-the-year model involves comparing simulated and observed temporal and longitudinal distributions for each of the life stages (e.g., Fig. 14), whereas validation of the life-cycle model is more on a qualitative basis involving trends and direction of change in variables such as population size and age distribution that are in agreement with expectations (USNRC 1975, pp. V-151 to V-153 and Appendix B, pp. B-179; B-182 to B-184). Similar comments apply to the independent striped bass simulation models developed by contractors for Consolidated Edison Company of New York, Inc. (Lawler 1972; Texas Instruments 1974).

At each step in a sequential assessment, it is possible, and perhaps appropriate, to ask, "So what?" Direct counts of the number of striped bass impinged at each power plant are available and estimates of the number of each life stage killed by entrainment at each plant can be made. But how do we judge the significance of these numbers? What fraction of the young-of-the-year striped bass population does this loss represent? The young-of-the-year model [Eraslan et al. (in press)] and other models (e.g., Lawler 1972) provide answers to this question in terms of an annual percent reduction in the number of striped bass surviving their first year, due to the power plants. But what does a 10%, 30%, 50%, or 70% annual reduction in the first year class mean for the total striped bass population over the lifetime of the power plants and beyond? The life-cycle model attempts to provide an answer to this question in terms of reductions in relative yield and in relative population size and changes in the age structure of the population. But what is the significance of an index or risk of 1.04 (Fig. 17) or the significance of depressing the striped bass population for 10, 20 or 40 years below one-half of the size it would have been without the impact? Our point is that there is no logical final step in the sequence at which time the question of significance is clearly answered. However, provided that new data are factored into each additional step of such a sequential assessment, then the information gained at each step contributes to the basis for making a judgment as to whether an impact is "significant" (i.e., in Fig. 3, whether it justifies rejection of a project or selection of an alternate design).

Simulation models are but one tool in the kit of techniques for assessing environmental impacts. They have the advantage of providing a unifying analytical framework for diverse field and laboratory data and of focusing attention on questions where further information is needed. At the same time the uncertainties, the assumptions, and the weaknesses in the data base used to estimate input parameters and validate the model must be appreciated and the model results interpreted and weighed accordingly in making a judgment as to the significance of a given impact. It was with these considerations in mind that the U.S. Nuclear Regulatory Commission Staff relied in part on the results from the striped bass young-of-the-year model [Eraslan et al. (in press)] and life-cycle model (Van Winkle et al. 1974) in reaching the conclusion that: "Operation of Indian Point Unit No. 3 with the once-through cooling system will be permitted during an interim period, the termination date for which will be September 15, 1980. Thereafter,...the Plant shall be operated with an approved closed-cycle cooling system....If the Licensee believes that the empirical data collected during this interim operation justify an extension of the interim operation period, or other relief, it may make an application to the Atomic Energy Commission (USNRC 1975, pp. xviii-xx).

V. Concluding Thoughts

Early in this paper, we mentioned that the primary goal of impact analysis is to provide information on which to base responsible decisions about a project. We have discussed a conceptual framework for impact analysis, and several kinds of analytical methods which we have found to be useful, and in some cases necessary, for achieving this goal. In the sense of an overview of this material, several points are worth stressing:

1. There is a need for common agreement about the meaning of such often-used terms as impact, insignificant, significant, and irreversible.
2. As man's activities impinge more and more on ecological systems, it is becoming increasingly important to consider individual projects in the context of related existing and proposed sources of environmental stress, rather than merely as isolated sources of possible damage. As such, a priori planning (e.g., "designated site" studies) have clear advantages over a posteriori analyses.
3. Simulation models provide a useful forecasting technique for impact analysis. There is a continuing need to develop and generalize such models, so that they can be used more routinely in the analysis of impacts. Still, models cannot be perfect representations of reality. There will always be a need for qualitative judgments by professionals in the building, application, and interpretation of the results of models, and in dealing with questions that are not amenable to being modeled. In addition, judgments by people in various disciplines will continue to be required in deciding what action, if any, is appropriate in a given case,

considering the range of possible impacts that can reasonably be expected to occur.

In the broadest sense, the analysis of biological impacts is but one step in a more or less sequential process which begins with the collection of field data and ends with a decision based only partly on ecological considerations. The entire process will benefit as more communication is established between practitioners at all levels, and as the state of the art at each level is advanced. Workshops such as this represent an opportunity not only to clarify our own roles, but hopefully to suggest directions of progress to others who are involved in the application of biological impact analysis.

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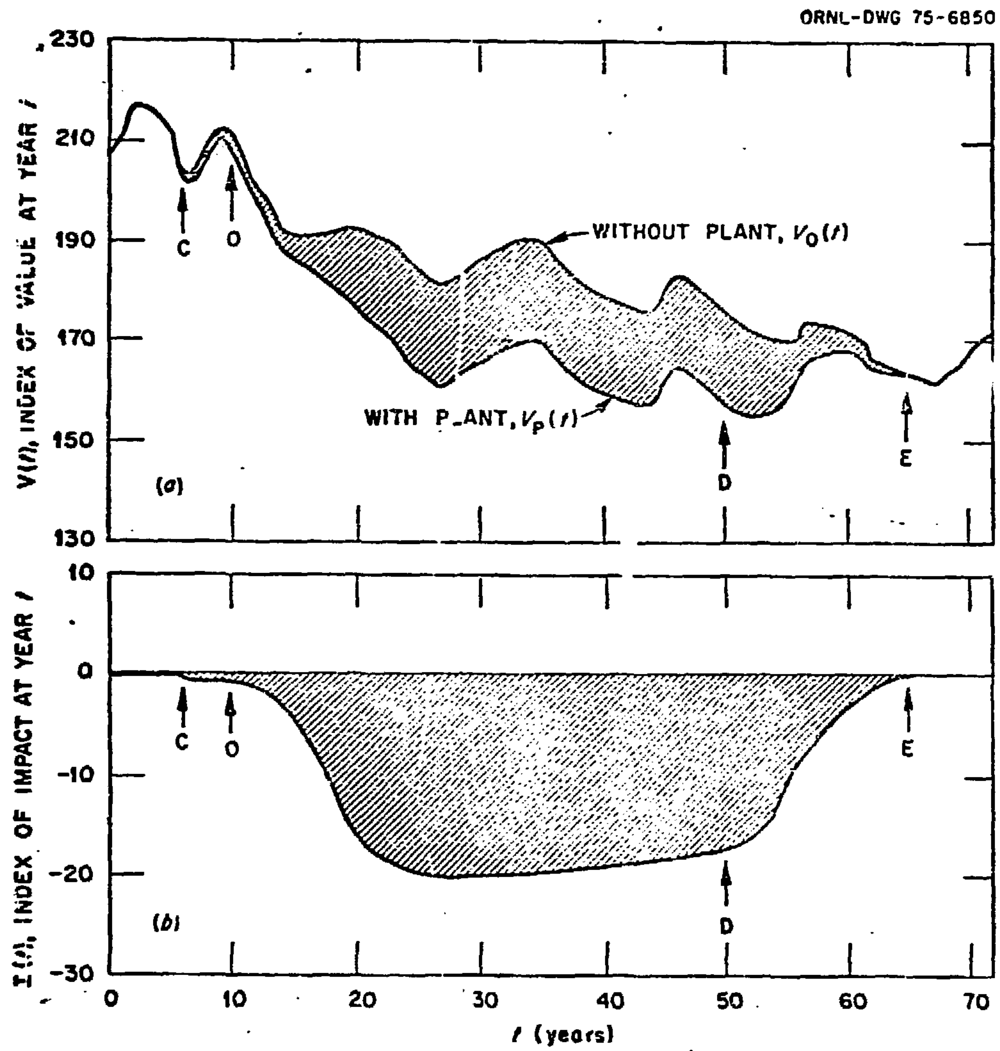
Fig. 1. (a) Index of value of an ecosystem versus years, with and without a hypothetical plant. (b) Index of impact of the plant on the ecosystem $[I(t) = V_p(t) - V_o(t)]$ versus years. Key for both Figs. 1a and 1b: C denotes beginning of construction impact; O denotes beginning of operational impact; D denotes decommissioning (end of operation); and E denotes end of impact.

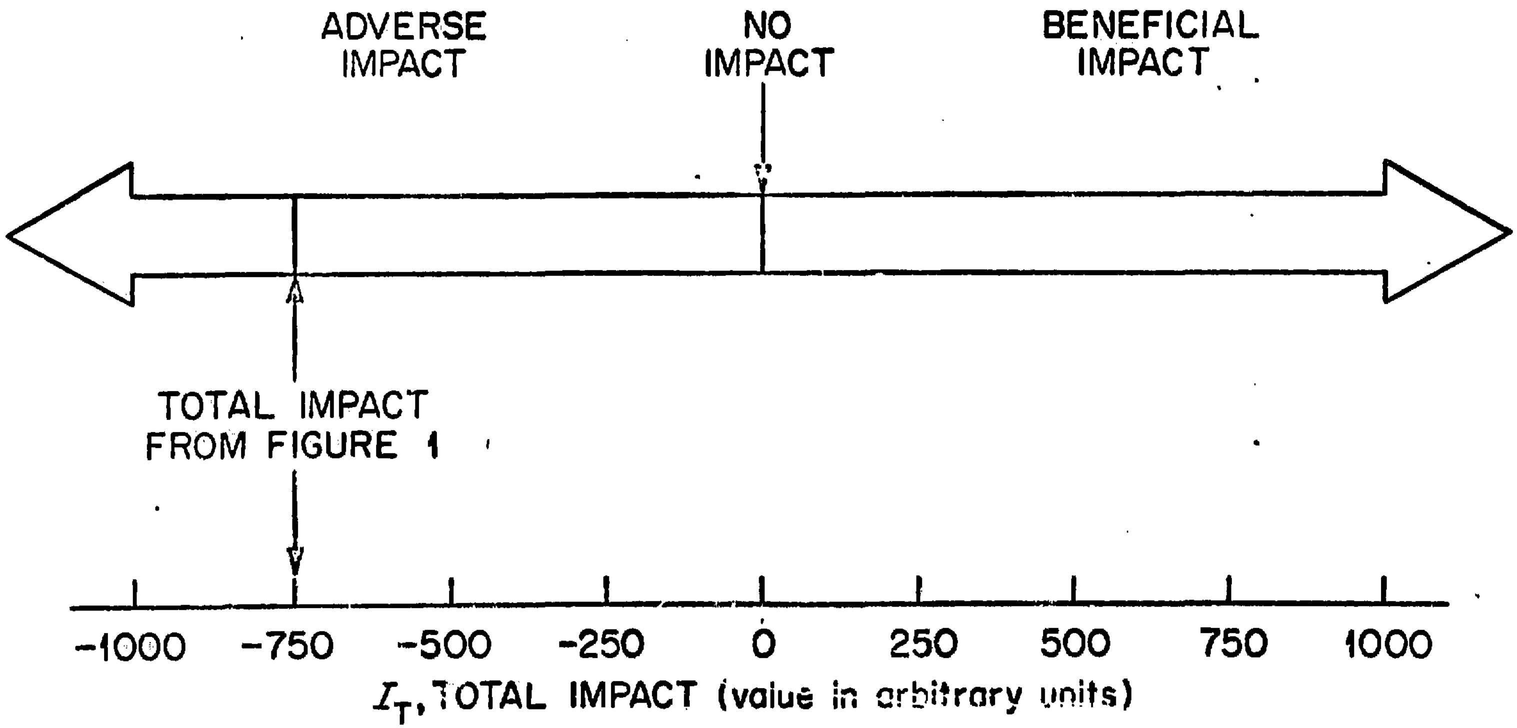
[Fig. 1]



ORNL-DWG 75-6850
V(t), INDEX OF VALUE AT YEAR t
230
210
190
170
150
130
WITHOUT PLANT, V0(t)
WITH PLANT, Vp(t)
C
O
D
E
(a)
I(t), INDEX OF IMPACT AT YEAR t
10
0
-10
-20
-30
(b)
0
10
20
30
40
50
60
70
t (years)

Fig. 2. Impact-line representation of the total impact (I_T) of the hypothetical plant dealt with in Fig. 1.

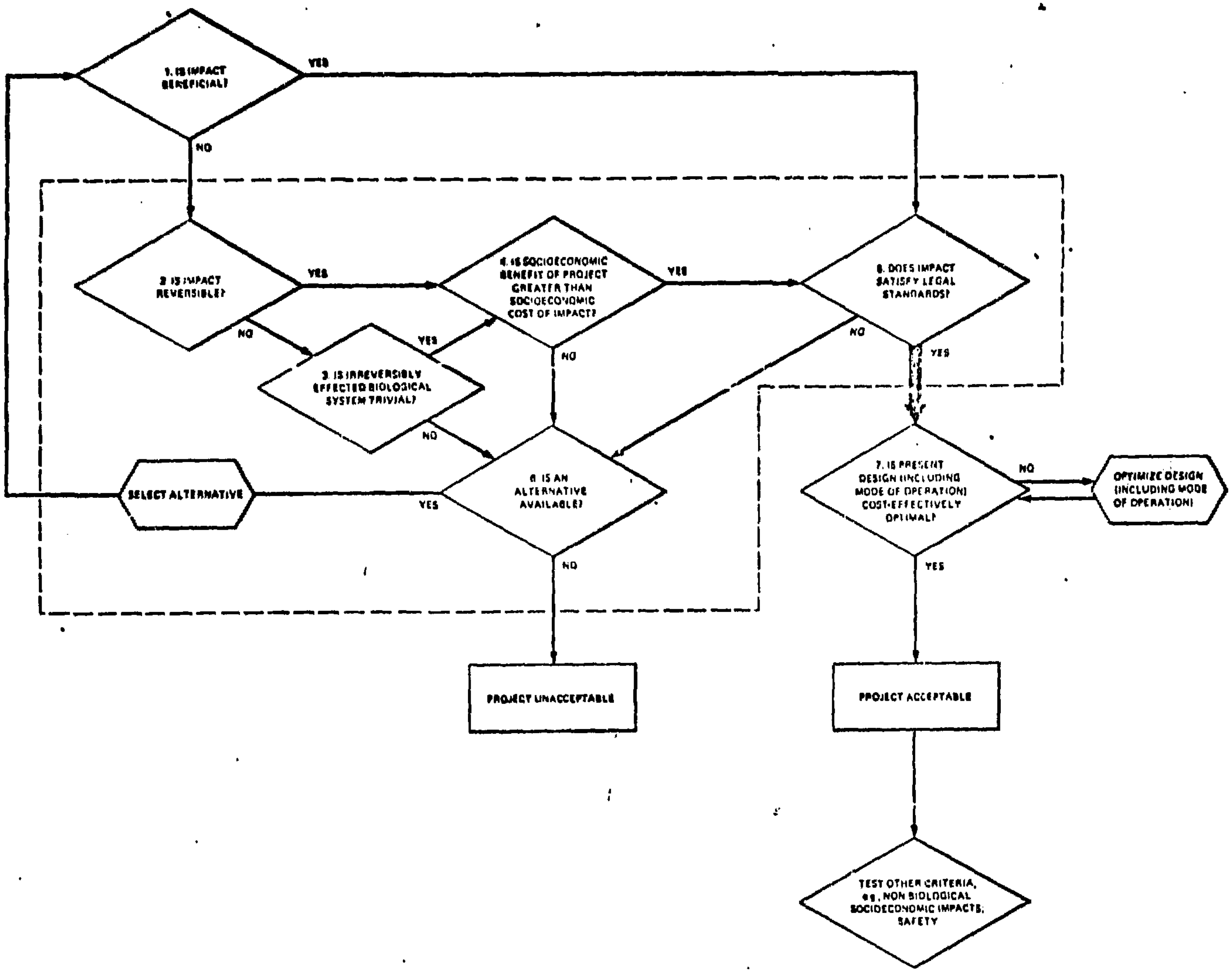
ORNL-DWG 75-6849



[Fig. 2]

Fig. 3. Decision-tree for determining the acceptability of a project with respect to its impact on a biological system. The dashed box indicates the region where the project may be rejected for lack of a suitable alternative. The heavy arrow leaving the dashed box shows the point at which the project is assured of eventual acceptability (although further changes may still be needed).

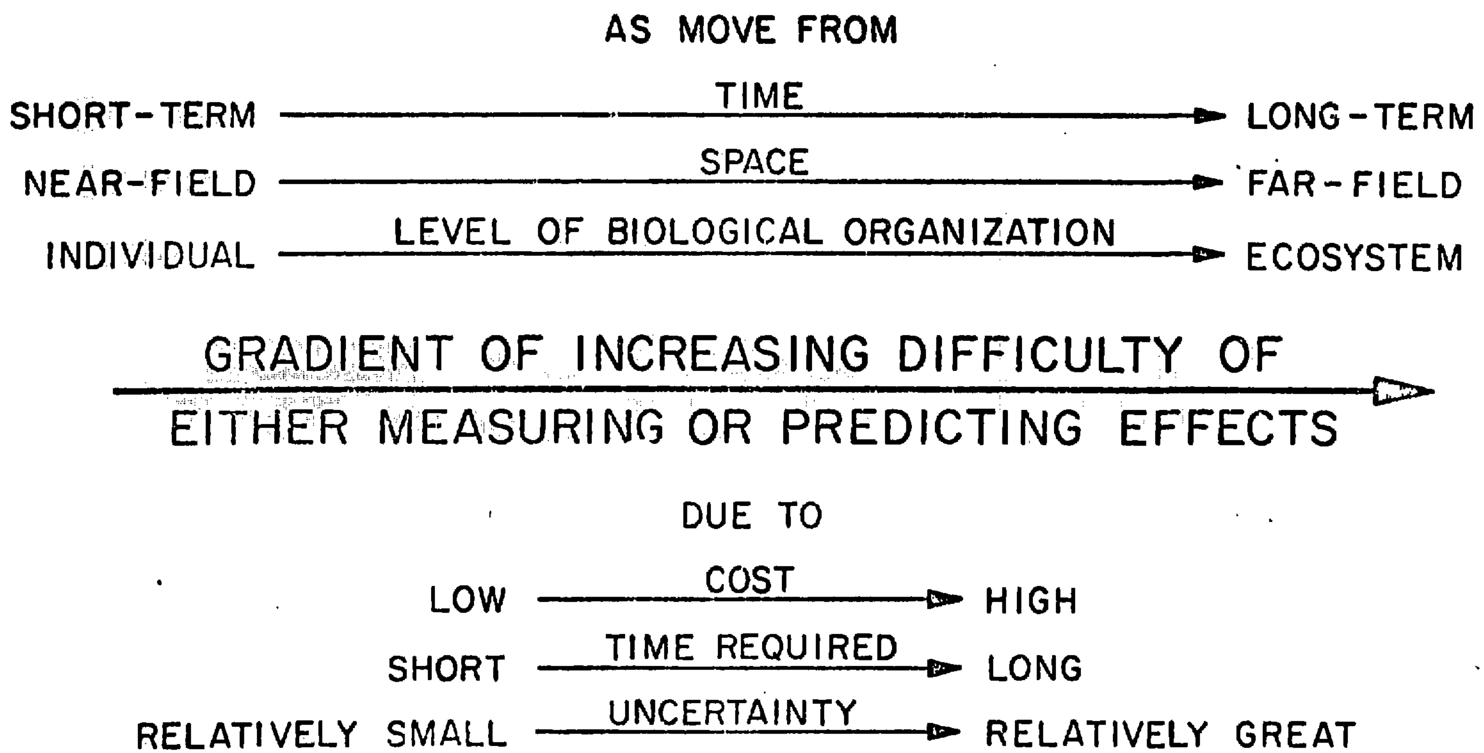
ORNL-DWG 78-7110



[Fig. 3]

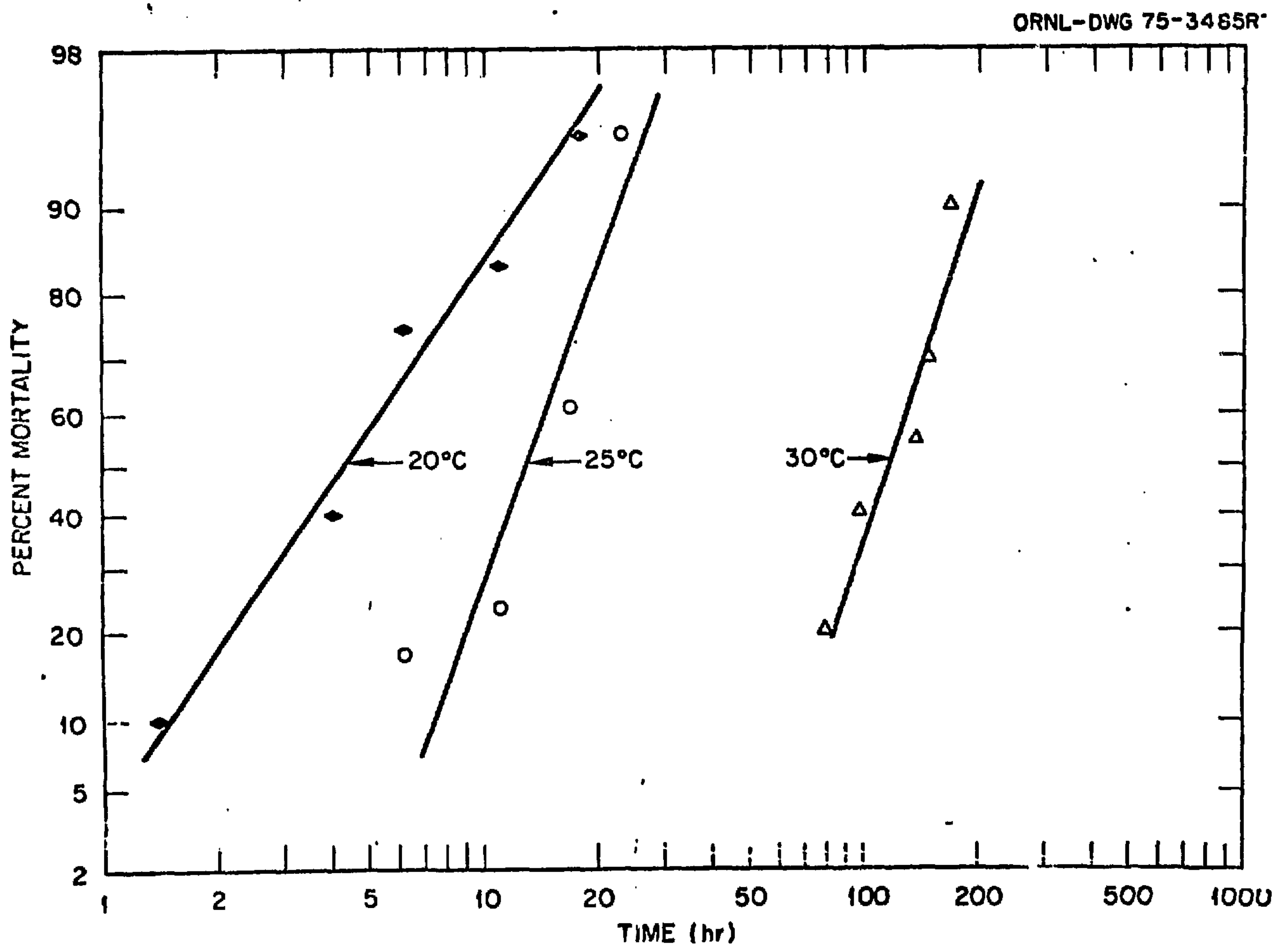
Fig. 4. Gradients associated with analyzing impacts.

ORNL-DWG 75-6901



[Fig. 4]

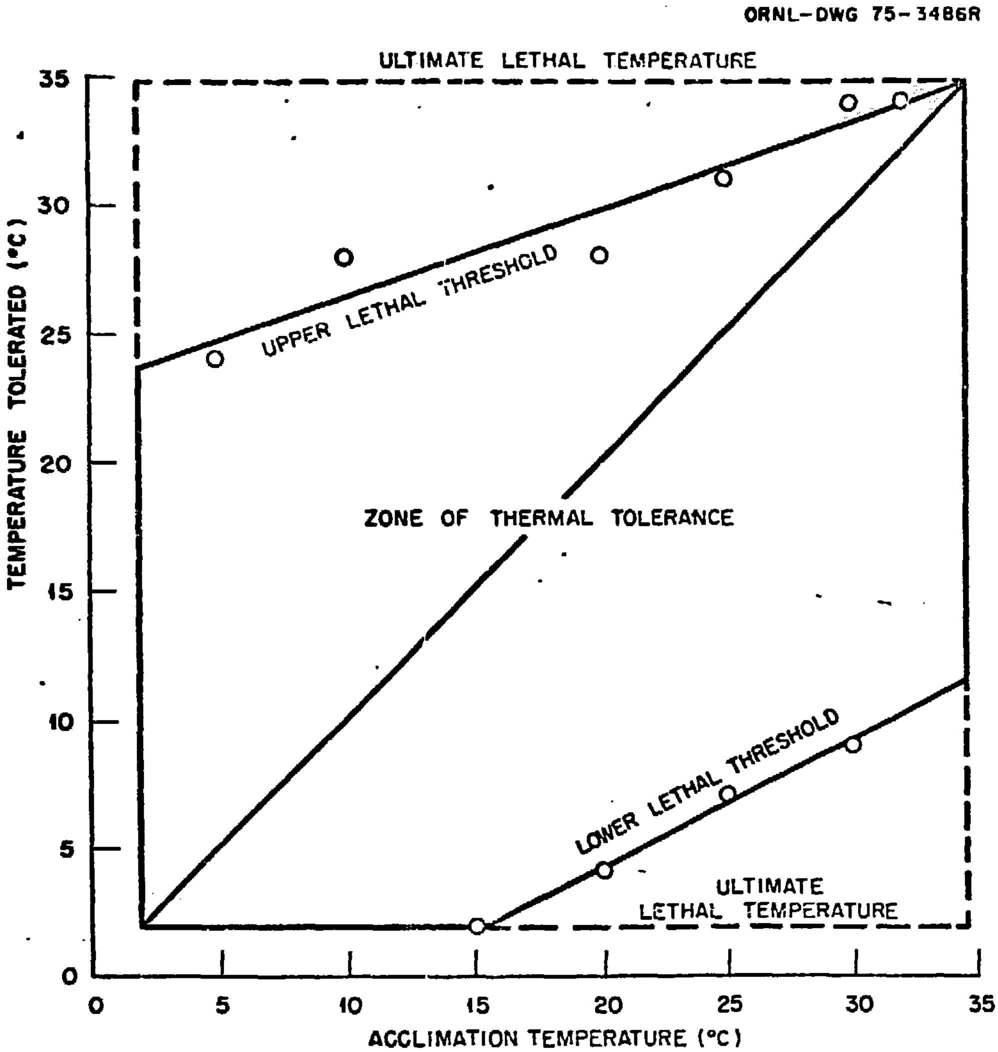
Fig. 5. Data on the thermal tolerance of *Corbicula manilensis*, the Asiatic clam, illustrating percent mortality as a function of exposure time at 36°C using groups of clams acclimated to different temperatures. (Modified from Mattice and Dye 1975).


ORNL-DWG 75-3465R
PERCENT MORTALITY
98
90
80
60
40
20
10
5
2
1
2
5
10
20
50
100
200
500
1000
TIME (hr)
20°C
25°C
30°C

[Fig. 5]

Fig. 6. Thermal tolerance parallelogram for Corbicula manilensis, the Asiatic clam, based on 50% mortality values obtained from Fig. 5 and similar data for other acclimation temperatures. (Modified from Mattice and Dye 1975).

[Fig. 6]



ORNL-DWG 75-3486R
ULTIMATE LETHAL TEMPERATURE
UPPER LETHAL THRESHOLD
ZONE OF THERMAL TOLERANCE
LOWER LETHAL THRESHOLD
ULTIMATE
LETHAL TEMPERATURE
TEMPERATURE TOLERATED (°C)
ACCLIMATION TEMPERATURE (°C)
0
5
10
15
20
25
30
35

Fig. 7. Total production during the reproductive period of the pulmonate gastropod mollusk Lymnaea obrussa Say as a function of temperature for two sizes of snails. [Modified from Mattice (in press)].

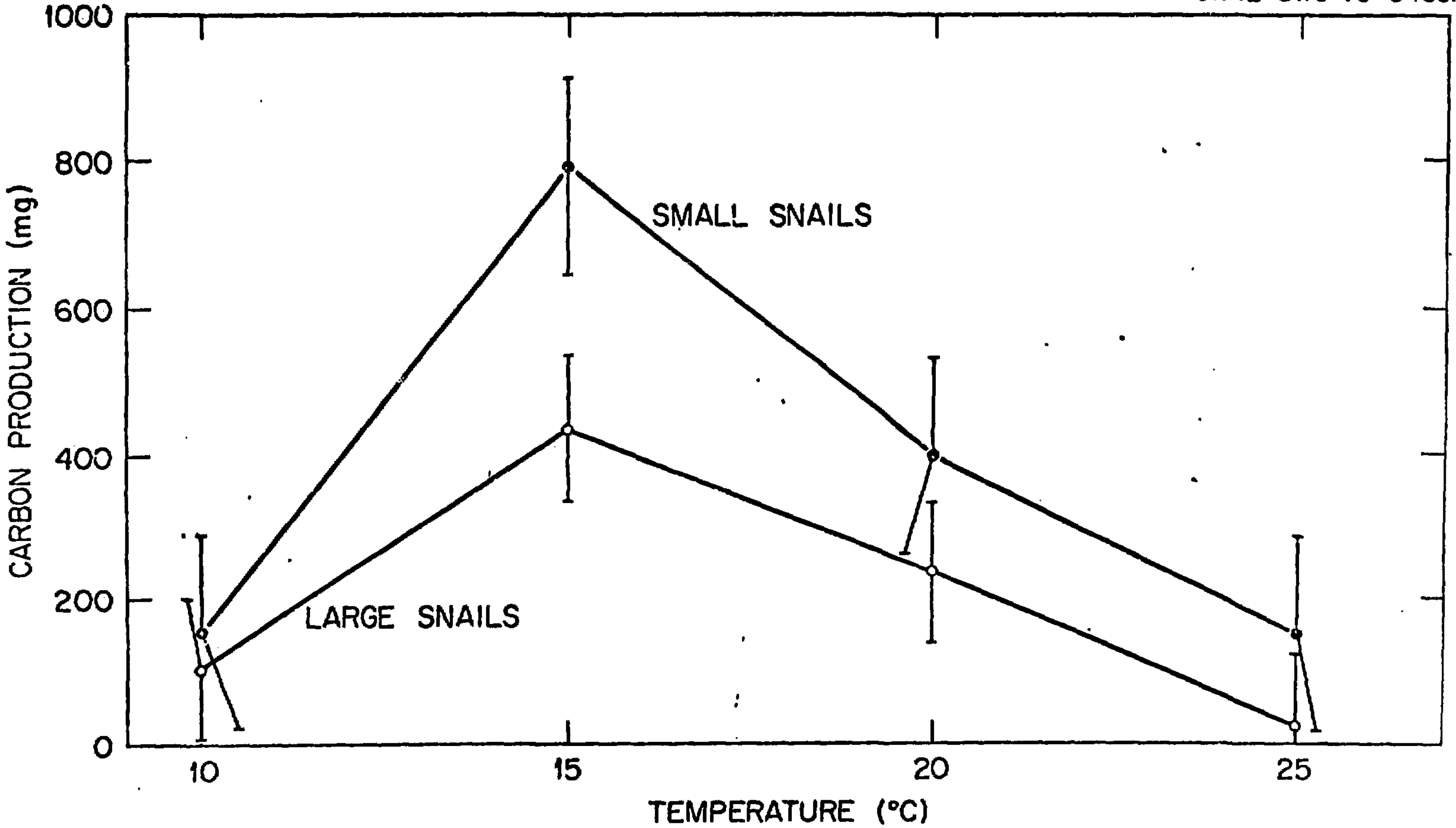

1000
800
600
400
200
0
CARBON PRODUCTION (mg)
SMALL SNAILS
LARGE SNAILS
10
15
20
25
TEMPERATURE (°C)

Fig. 7

Fig. 8. The Hudson River showing major existing and planned power generating plants (USNRC 1975, Appendix B, p. B-57).

[Fig. 8]

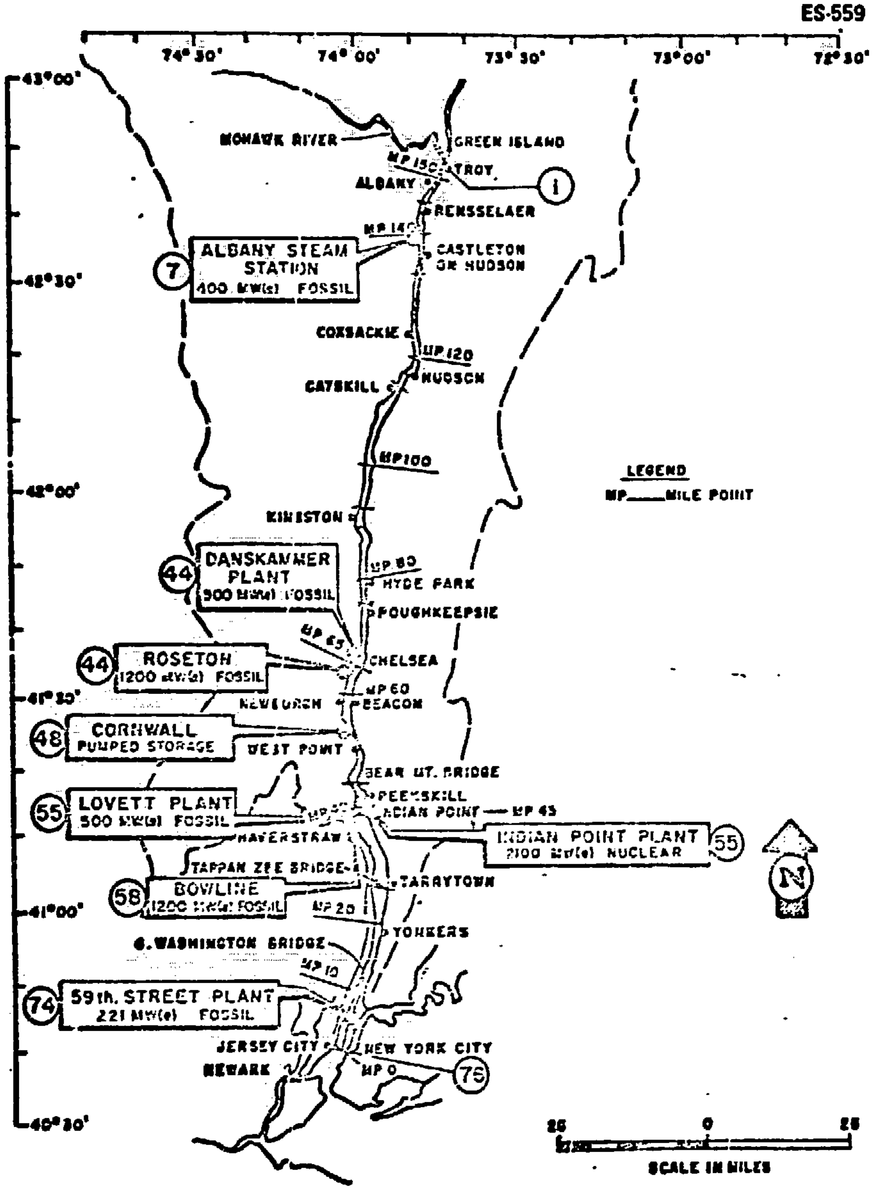
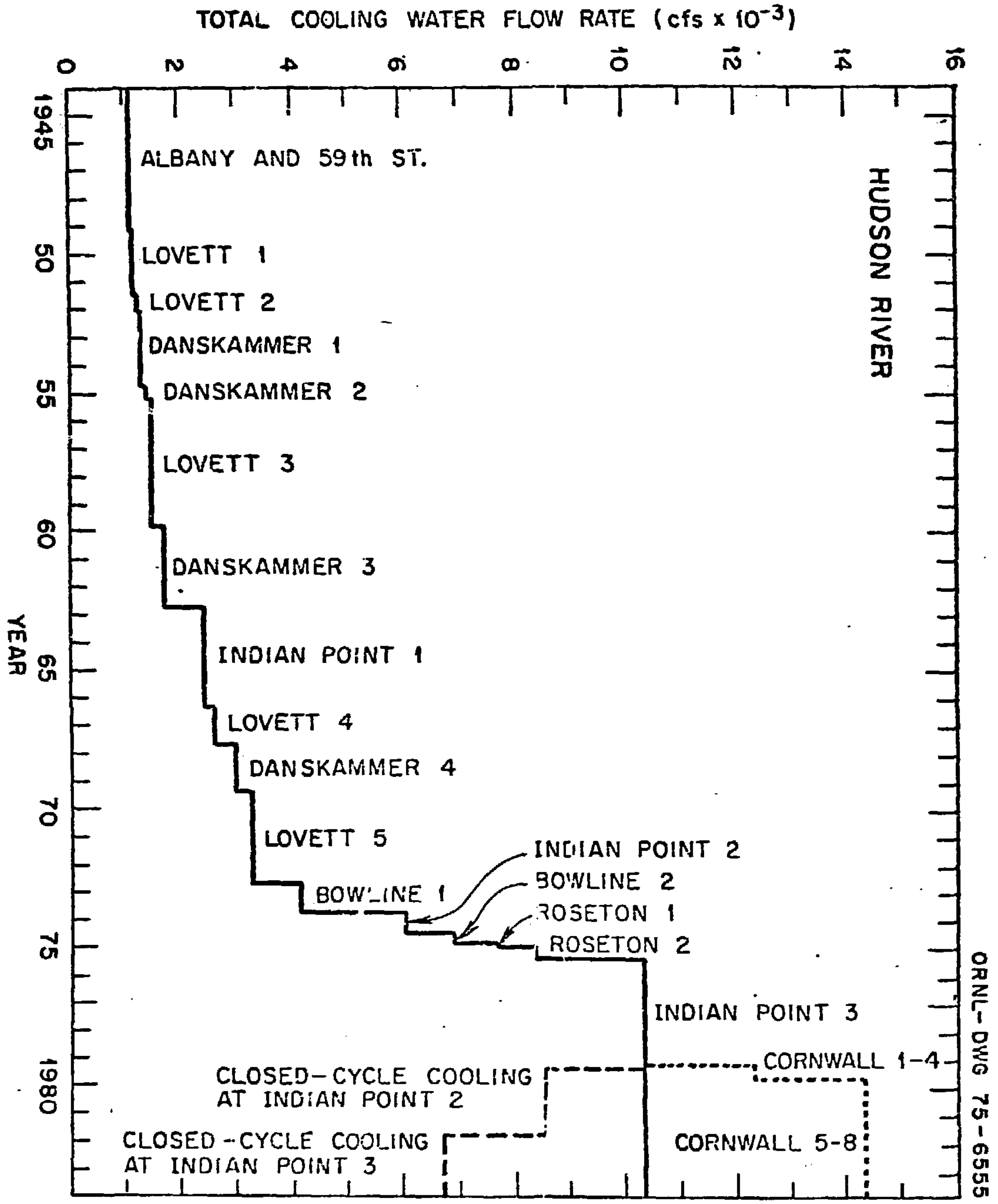


Fig. 4. The Hudson River showing major existing and planned power generating plants (U.S. Nuclear Regulatory Commission, February 1975).

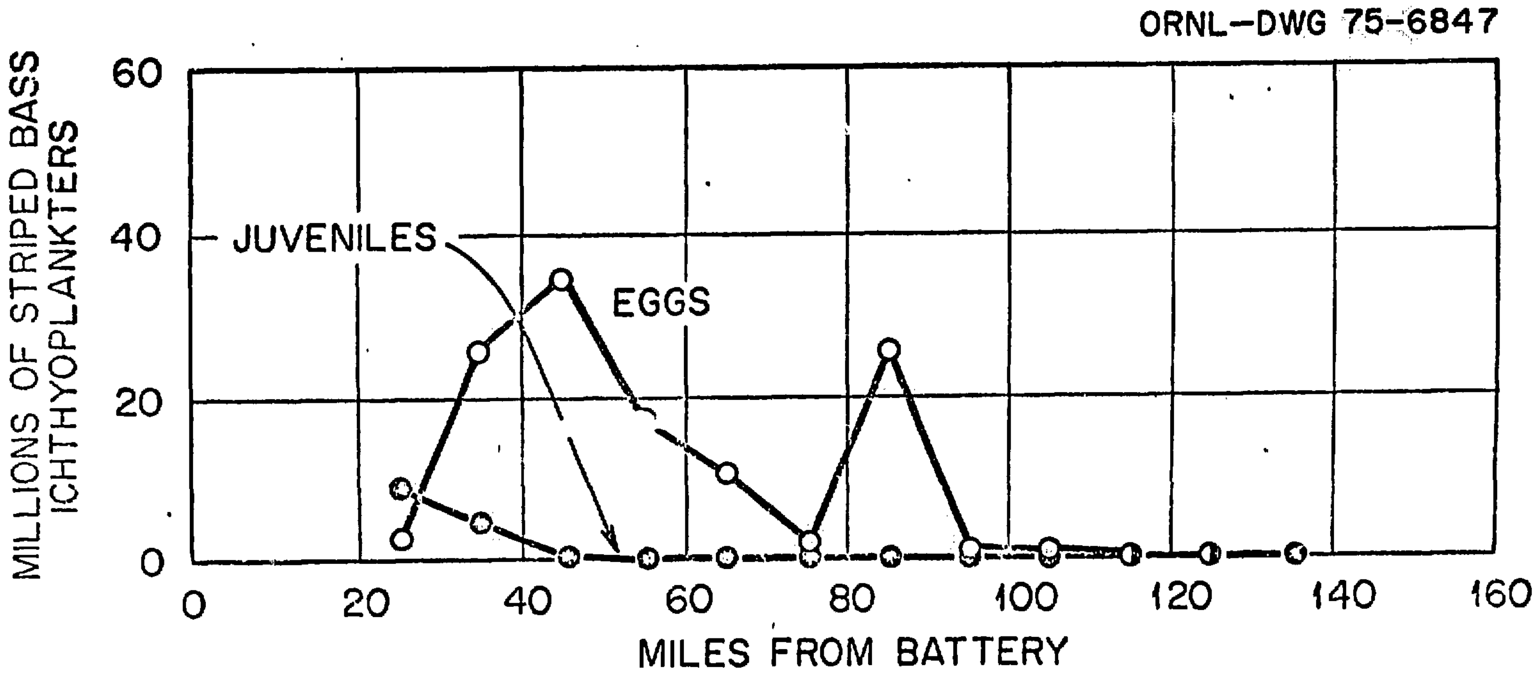
Fig. 9. Maximum cumulative intake flow withdrawn by the power plants on the Hudson River over the period 1944 through 1984. For the period 1979 through 1984 the solid line (————) is for Indian Point Units 2 and 3 with once-through cooling and without Cornwall, the dashed line (----------) is for Indian Point Units 2 and 3 with closed-cycle cooling and without Cornwall, and the dotted line (• • • • •) is for Indian Point Units 2 and 3 with once-through cooling and with Cornwall.



TOTAL COOLING WATER FLOW RATE (cfs x 10^-3)
0
2
4
6
8
10
12
14
16
YEAR
1945
50
55
60
65
70
75
1980
HUDSON RIVER
ALBANY AND 59th ST.
LOVETT 1
LOVETT 2
DANSKAMMER 1
DANSKAMMER 2
LOVETT 3
DANSKAMMER 3
INDIAN POINT 1
LOVETT 4
DANSKAMMER 4
LOVETT 5
BOWLINE 1
INDIAN POINT 2
BOWLINE 2
ROSETON 1
ROSETON 2
INDIAN POINT 3
CORNWALL 1-4
CLOSED-CYCLE COOLING AT INDIAN POINT 2
CLOSED-CYCLE COOLING AT INDIAN POINT 3
CORNWALL 5-8
ORNL-DWG 75-6555

[Fig. 9]

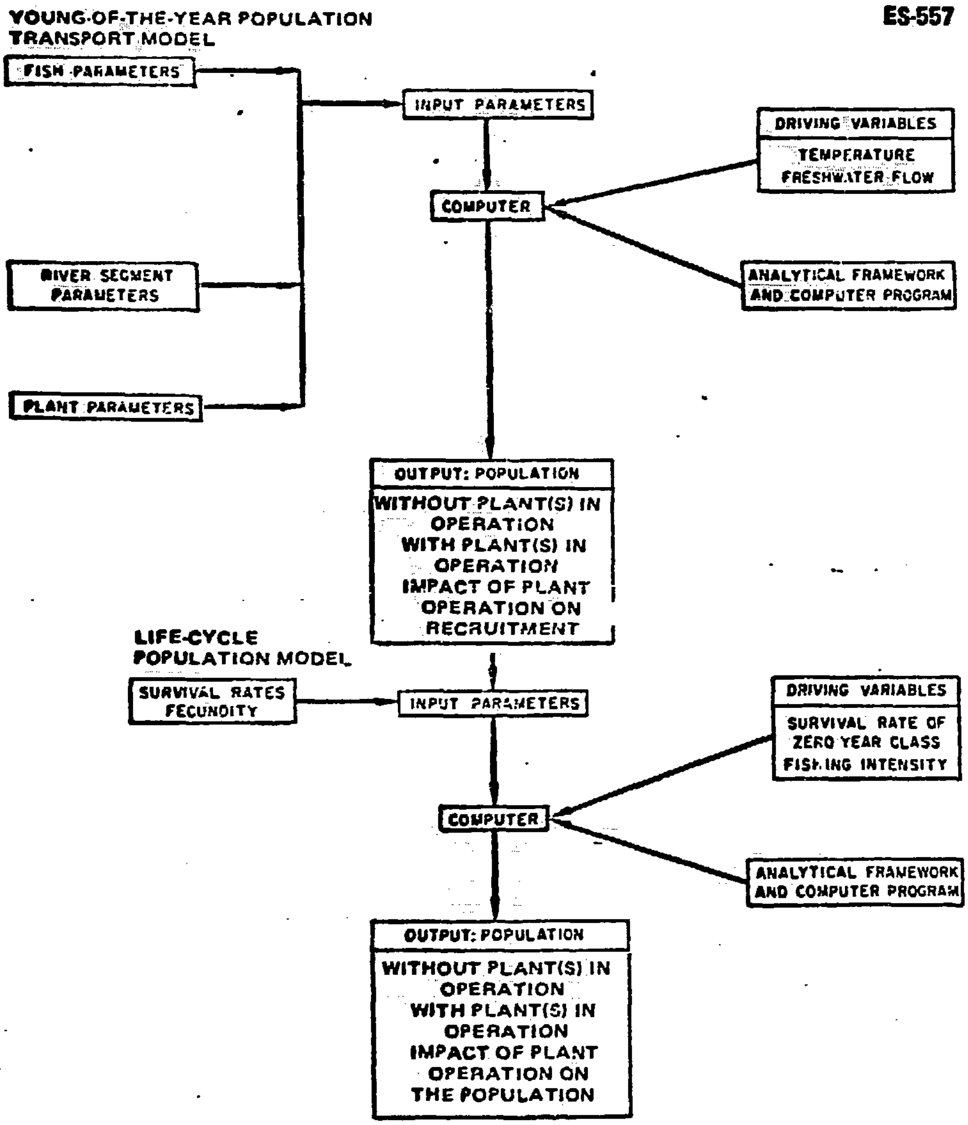
Fig. 10. Longitudinal distribution along the Hudson River of striped bass eggs during the week beginning May 14, 1973 and of striped bass juveniles during the week beginning August 6, 1973 (based on data provided in letter dated August 30, 1974, from Carl L. Newman, Consolidated Edison Company of New York, Inc., to George W. Knighton, U.S. Atomic Energy Commission, transmitting Quirk, Lawler, and Matusky's reduction of the 1973 data from the Texas Instruments' longitudinal river trawl survey and seining survey).


ORNL–DWG 75–6847
MILLIONS OF STRIPED BASS ICHTHYOPLANKTERS
60
40
20
0
JUVENILES
EGGS
0
20
40
60
80
100
120
140
160
MILES FROM BATTERY

[Fig. 10]

Fig. 11. Overview of the striped bass young-of-the-year population transport model and life-cycle population model (Van Winkle et al. 1974).

[Fig. 11]



~~Fig. 7.~~ Overview of the striped bass young-of-the-year population transport model and life-cycle population model (Van Winkle et al., December 1974).

Fig. 12. Schematic representation of the computer simulation model for the striped bass young-of-the-year population in the Hudson River [Eraslan et al. (in press)].

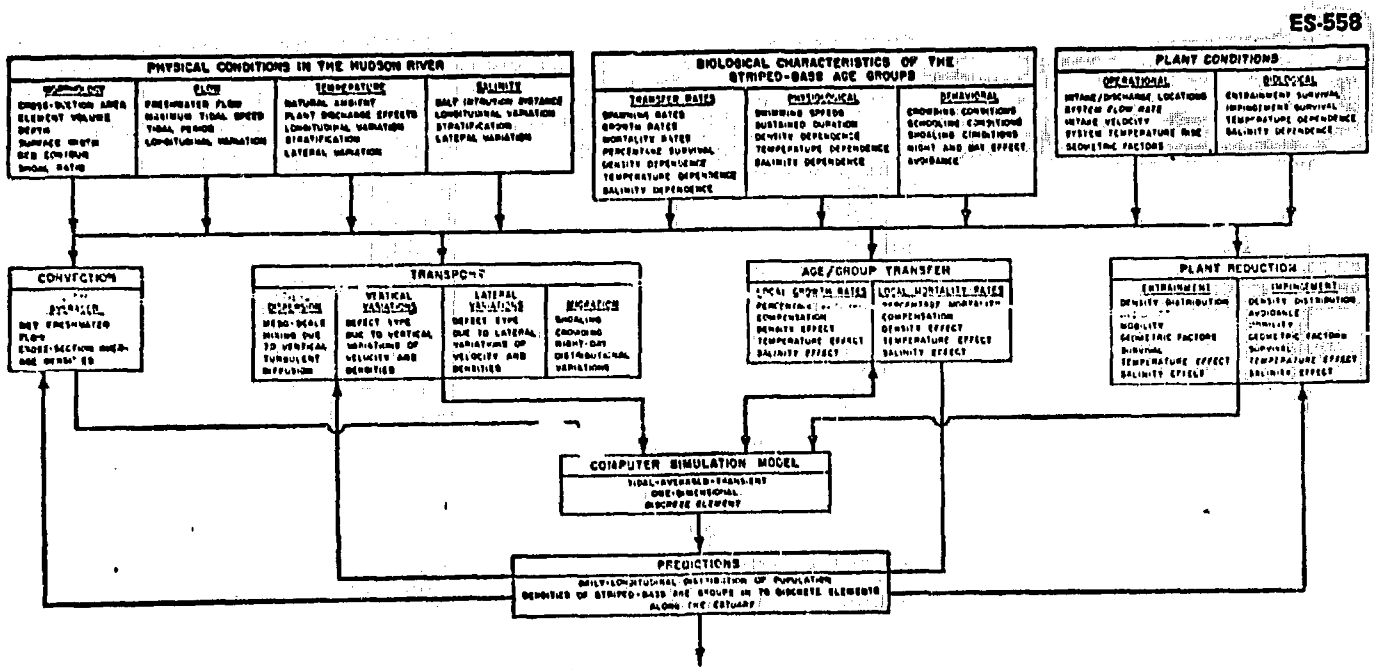


Fig. 8 Schematic representation of the computer simulation model for the striped bass young-of-the-year population in the Hudson River (Eraslan et al., in press).

[Fig. 12]

Fig. 13. Schematic representation of a discrete element as considered in the computer simulation model for the striped bass young-of-the-year population in the Hudson River (USNRC 1975, Appendix B, p. B-58).

[Fig. 13]

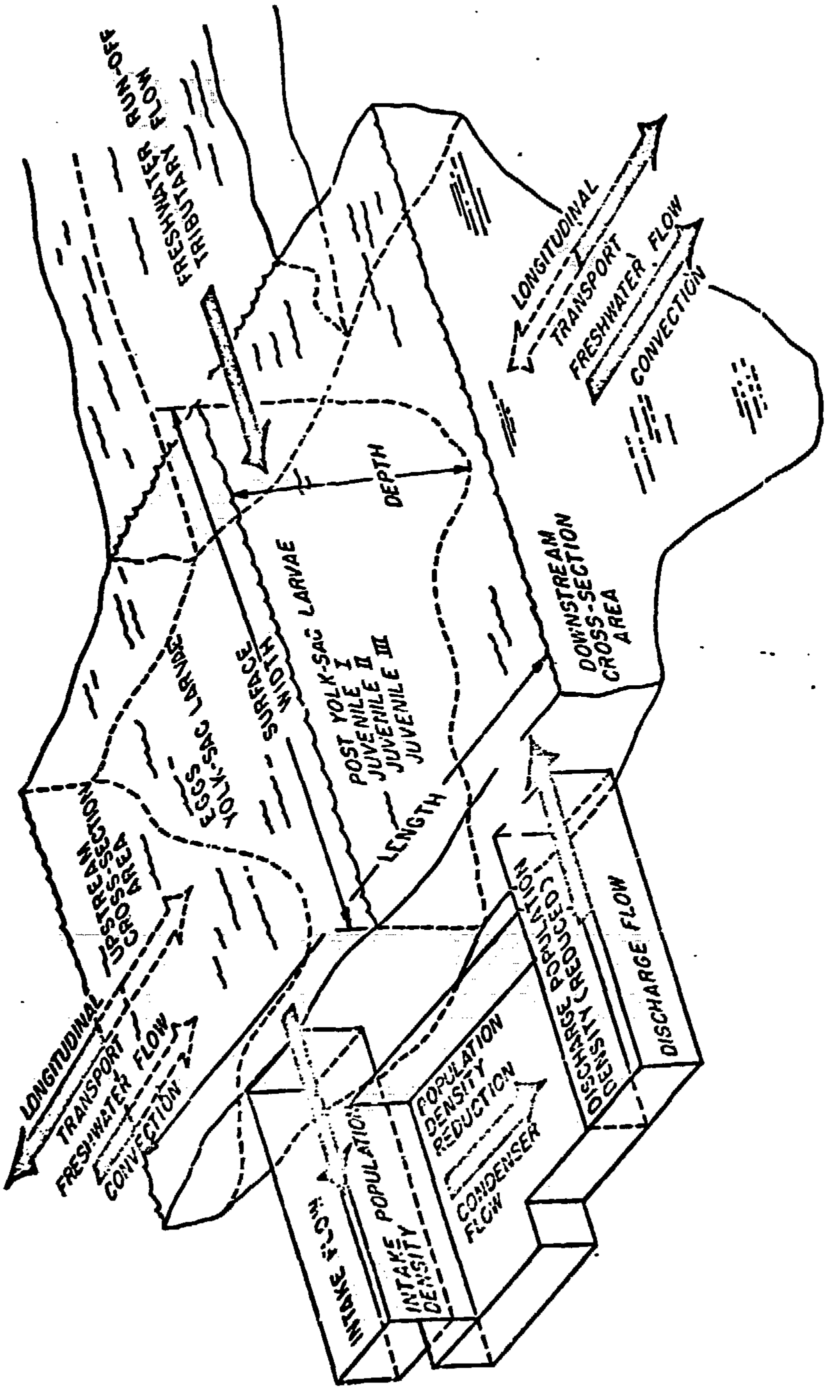
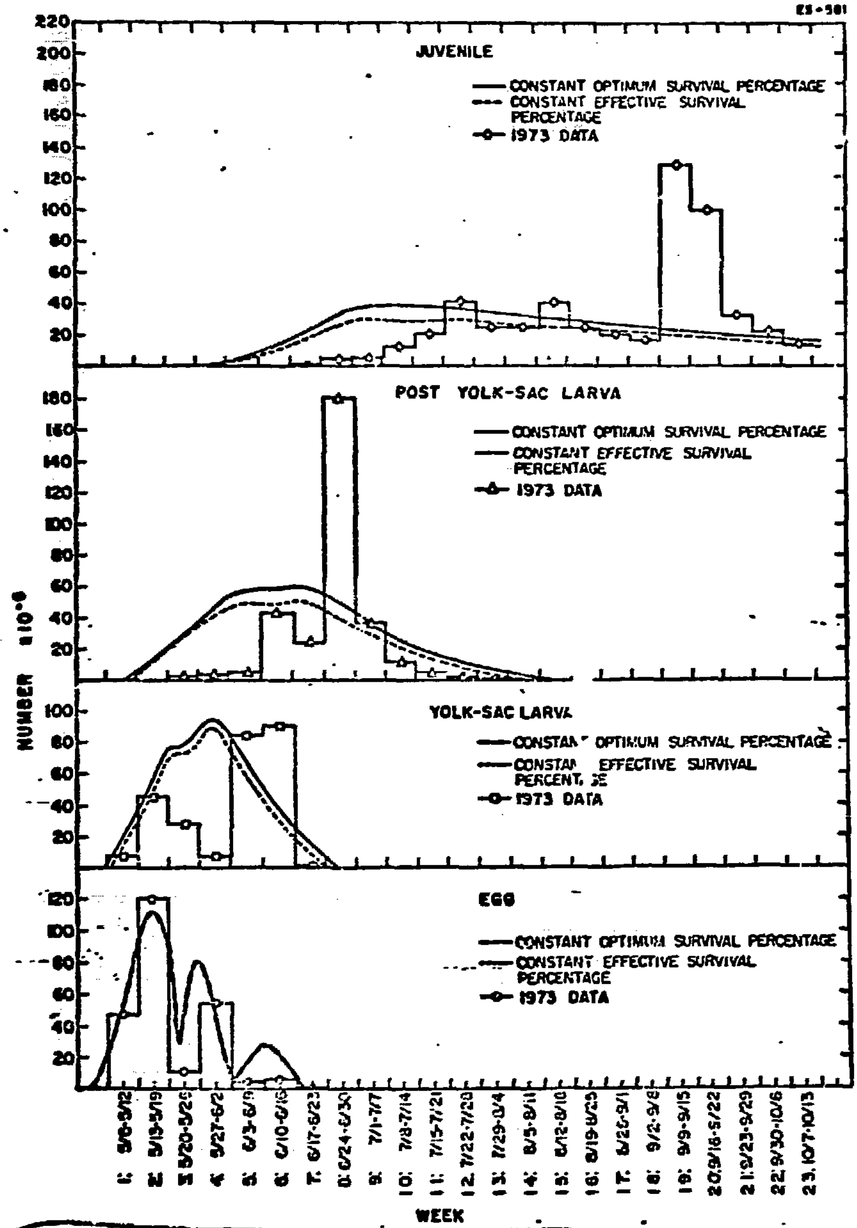

RUN-OFF
FRESHWATER TRIBUTARY FLOW
LONGITUDINAL
TRANSPORT
FRESHWATER FLOW
CONVECTION
DEPTH
DOWNSTREAM CROSS-SECTION AREA
SURFACE
WIDTH
YOLK-SAC LARVAE
POST YOLK-SAC LARVAE
POST YOLK I
JUVENILE II
JUVENILE III
EGGS
YOLK-SAC LARVAE
UPSTREAM CROSS-SECTION AREA
LENGTH
LONGITUDINAL
TRANSPORT
FRESHWATER FLOW
CONVECTION
DISCHARGE POPULATION DENSITY (REDUCED)
DISCHARGE FLOW
POPULATION DENSITY REDUCTION
CONDENSER FLOW
INTAKE FLOW
INTAKE POPULATION DENSITY

Fig. 14. Validation procedure for the striped bass young-of-the-year population transport model, comparing simulated and observed weekly standing crop values for each of the life stages [Eraslan et al. (in press)].

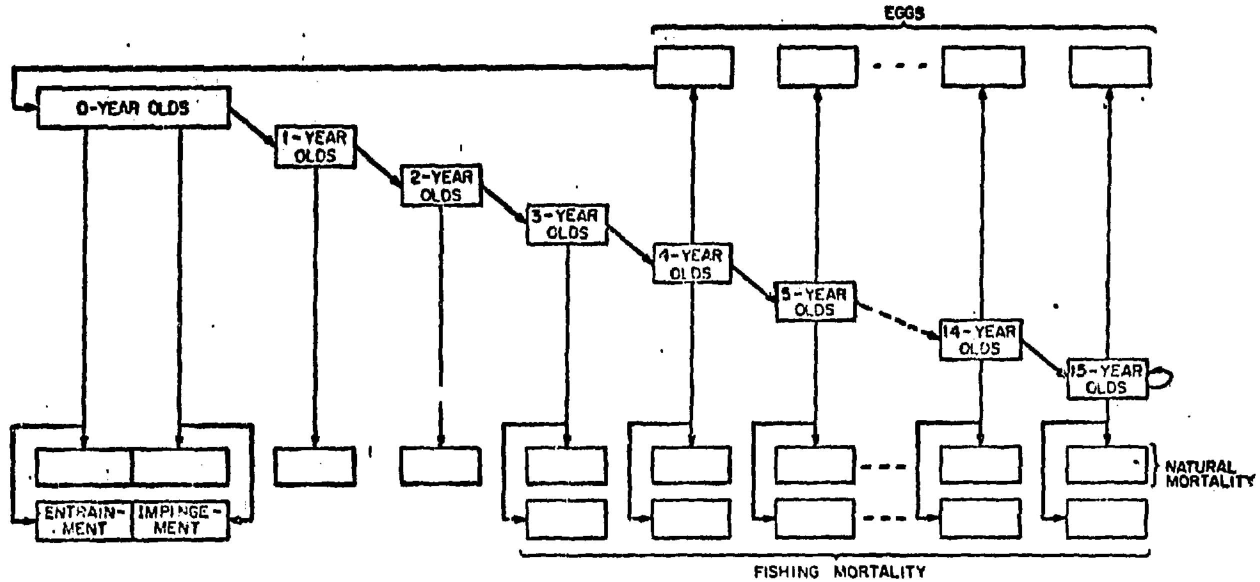
[Fig. 14]



~~Fig. 10.~~ Validation procedure for the striped bass young-of-the-year population transport model of comparing simulated and observed weekly standing crop values for each of the life stages (Efaslan et al., in press).

Fig. 15. Box-and-arrow diagram for the striped bass life-cycle population model illustrating aging transfers, production of eggs by sexually mature females, and losses due to natural mortality, fishing mortality, and entrainment and impingement at power plants (Van Winkle et al. 1974).

ES-684

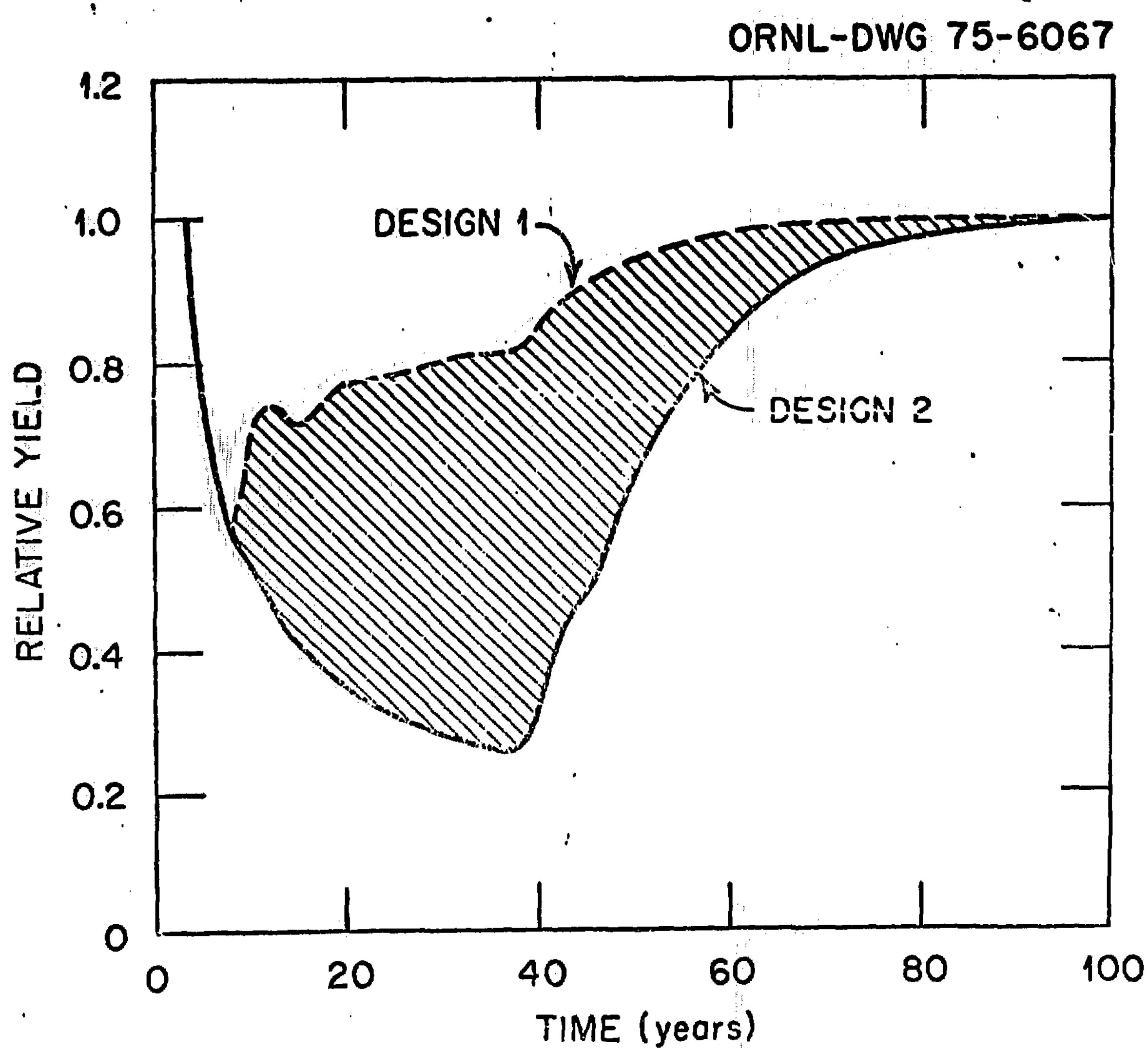


Population Model.

Fig. 11 Box and arrow diagram for the striped bass life-cycle population model illustrating aging transfers, production of eggs by sexually mature females, and losses due to natural mortality, fishing mortality, and entrainment and impingement at power plants (Van Winkle et al., December 1974).

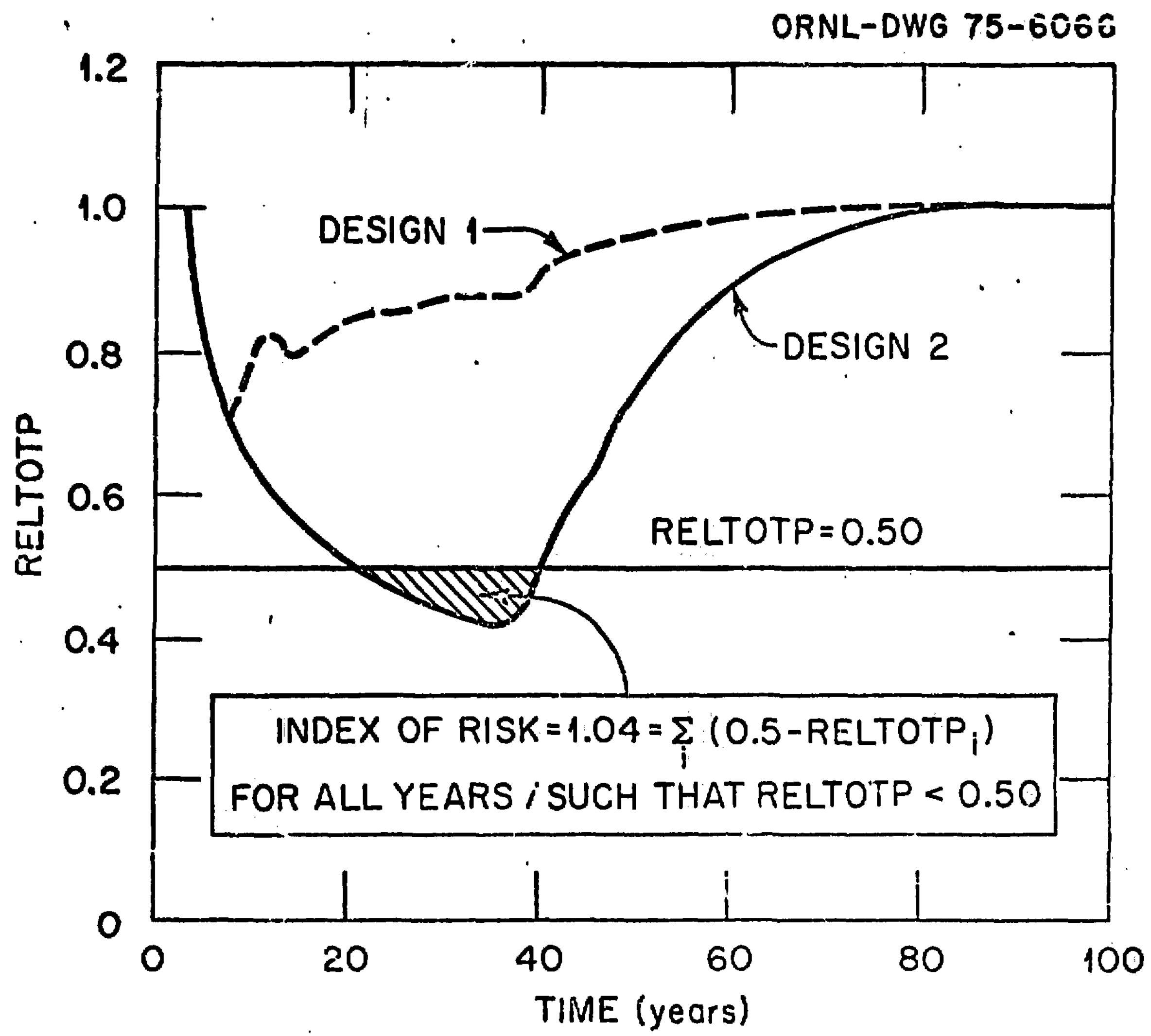
Fig. 15

Fig. 16. Two hypothetical curves of relative yield to the fishery versus years to illustrate the type of biological information needed in addressing the two questions: Is the socioeconomic benefit of the project greater than the socioeconomic cost of the impact of the project on the biological system? Is the present design (including mode of operation) of the project optimally cost-effective with respect to minimizing the damage to (or enhancing the value of) the biological system? [See decision points (4) and (7), Fig. 3].


ORNL-DWG 75-6067
RELATIVE YIELD
1.2
1.0
0.8
0.6
0.4
0.2
0
DESIGN 1
DESIGN 2
0
20
40
60
80
100
TIME (years)

[Fig. 16]

Fig. 17. Two hypothetical curves of relative size of the fishable population (RELTOTP) versus years to illustrate one approach towards addressing the question: Is the impact of the project on the biological system reversible? [See decision point (2), Fig. 3].



ORNL-DWG 75-6066
DESIGN 1
DESIGN 2
RELTOTP=0.50
INDEX OF RISK=1.04=Σ_i (0.5-RELTOTP_i)
FOR ALL YEARS i SUCH THAT RELTOTP < 0.50
RELTOTP
TIME (years)

[Fig. 17]