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THE EFFECTS OF IMPINGEMENT AND ENTRAINMENT
BY THE J. R. WHITING PLANT ON YELLOW PERCH, PERCA FLAVESCENS,
COMMERCIAL AND SPORT FISHERIES IN LAKE ERIE

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THE EFFECTS OF IMPINGEMENT AND ENTRAINMENT BY THE J. R. WHITING PLANT ON YELLOW PERCH, *PERCA FLAVESCENS*, COMMERCIAL AND SPORT FISHERIES IN *LAKE ERIE*

By

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ABSTRACT

THE EFFECTS OF IMPINGEMENT AND ENTRAINMENT
BY THE J. R. WHITING PLANT ON YELLOW PERCH, PERCA FLAVESCENS,
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This study assesses the bioeconomic effects of the J. R. Whiting power plant on the yellow perch, Perca flavescens, commercial and sport fisheries in the Michigan waters of Lake Erie. The impact of impingement (fish killed on plant intake screens) and entrainment (egg and larval mortality inside the plant during cooling) is estimated to be a 1.7 percent annual reduction in the yellow perch population size. The value of this loss is estimated to be $10,710/year. The annual economic value of angling at the plant site is derived from a demand schedule and estimated to be $7,720.

During 1978-79 a roving creel survey was conducted in Monroe County to improve the angling catch and effort data utilized in the surplus production model to estimate the size of the yellow perch population. Anglers caught 509,001 yellow perch with 29,411 angler days effort. Mail surveys by the Michigan Department of Natural Resources (MDNR) apparently have been overestimating these numbers by a factor of about 4. Therefore, past MDNR estimates of catch and effort are adjusted for use in the surplus production model of the perch population.

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The surplus production model is applied to both the yellow perch commercial and sport catch and effort data from the Lake Erie waters of Michigan. The yellow perch population size in the Monroe area, estimated from the surplus production model, is approximately 1.074×10^{10} fish. The Leslie matrix, a density-independent mathematical model, then simulates the effects of the J. R. Whiting power plant impingement and entrainment on this population over the plant's 50-year life expectancy (1952-2002). The combined effect of impingement and entrainment over the 50 years of plant operation represents an annual 1.7 percent reduction in the yellow perch population size.

A 1.7 percent reduction per year in the yellow perch sport fisheries catch from impingement and entrainment results in a simple total economic loss of $535,500 over 50 years of plant operation, assuming a value of $1.50 per pound for perch. In contrast, the total potential market value of angling at the plant site during the same time period was estimated to be $386,000. Yet, anglers were willing to pay a maximum of $1,545,000 (total social value) to keep the plant site in existence for angling. In the long run (life expectancy of the plant) the economic losses of the plant to the fisheries seem to outweigh the economic fisheries benefits in the marketplace, but not in overall social values.

Dedicated to my wife,

Linda Oliphant Stanford

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I. INTRODUCTION

Concern in the United States regarding cooling systems of power plants originally centered on the potential impact of their thermal effluent. Recently, however, a major topic of study has been the impact on fish populations resulting from mortality of fish eggs and larvae carried by the cooling waters through the plant (entrainment) and from mortality of juvenile and adult fish trapped on intake screens (impingement) (Van Winkle, 1977).

Increasingly, scientists and engineers are realizing the importance of improving their ability to assess the effects of impingement and entrainment on fish populations. Recently, in relation to power plant sites, they have proposed that mathematical or simulation models be employed to evaluate these effects.

In this study, the surplus production and Leslie matrix models were applied to estimate the effects of impingement and entrainment by the J. R. Whiting plant on the yellow perch population in the Michigan waters of Lake Erie. The surplus production model estimates the harvestable biomass and harvestable numbers in the population from catch and effort data of the commercial and sport fisheries. The Leslie matrix model projects the future number of fish and the age distribution of the population.

Parameters of the surplus production model are estimated from catch and effort data. Traditionally catch and effort information has been supplied by governmental agencies, varying from state to state, responsible for natural resources. In Michigan, the Department of Natural Resources (MDNR) surveys licensed anglers by mail to estimate total catch and effort by species in established statistical (geographical) districts. These surveys have overestimated catch by as much as a factor of 5 (Rybicki and Keller, 1978). Therefore, a roving creel survey was conducted in Monroe County. The catch and effort estimates of this survey are compared with those of the MDNR.

Commercial catch and effort data in Michigan deserve the same scrutiny as the sport estimates, but there are no known studies questioning their accuracy. The type of investigation that is needed can be seen in the work of Schaaf and Huntsman (1972). In a marine fishery, they studied the Atlantic menhaden commercial fishing fleet, observed its improved fishing efficiency, and by necessity, redefined a unit of effort. Subsequently, they applied a stock-recruitment model to this fishery and they determined that the menhaden resource was overexploited.

Another factor contributing to the suspected inadequacy of Great Lake commercial catch and effort statistics may be MDNR fishing rules such as Michigan R299.884(1970), which prohibits commercial fishing of yellow perch with gill nets in the Michigan portion of Lake Erie. The MDNR initiated a zone management plan which eliminated gill netting in Lake Erie. Consequently carp has become the dominant species caught by Michigan commercial fishermen in Lake Erie.

Power plants not only have direct positive effects such as providing electric power, but they may also incidentally provide access points and angling sites for fishermen. To assess the value of angling at a plant site a demand schedule for angling at the site must be estimated. This will measure in dollars the willingness of anglers to exchange their resources for various amounts of angling. The demand for angling at the J. R. Whiting plant site was estimated using a method developed by Clawson and Knetsch (1966). A demand curve is estimated from the cost per visit, the travel distance to the angling site, and the visit rates (angler days/1000 capita) for each travel distance zone.

This dissertation is part of an overall Consumers Power report. The main objective of the overall report is to estimate the economic value lost to anglers (beyond the scope of this dissertation) resulting from impingement and entrainment. In order to estimate this economic loss the results of my research are necessary. The primary objectives of my dissertation are to:

1. Estimate the total yellow perch population size (numbers) in the Michigan waters of Lake Erie utilizing two surplus production models (sport and commercial).
2. Estimate the percent reduction in numbers of juvenile and adult yellow perch from impingement and entrainment after the total population size in numbers has been determined.
3. Estimate the economic value of angling provided by the plant site based on a demand schedule.

In this dissertation, Chapter II is a brief historical and theoretical review concerning 1) catch and effort estimations from roving creel surveys, 2) the development of population models, 3) the approaches employed by resource economists for estimating demand, 4) the life history of the yellow perch, <u>Perca flavescens</u>, and 5) the description and operation of the J. R. Whiting plant. Chapters III, IV, and V are the methods, results and discussion, and concluding observations, respectively.

II. LITERATURE REVIEW: HISTORY AND THEORY

1. Roving Creel Surveys

A paucity of information exists regarding roving creel surveys. Most investigators collect catch and effort data at access points in the fishery and obtain information from anglers regarding completed fishing trips. In many inland areas access points may not be readily available. For example, it is difficult to encounter all anglers, particularly those located along a path of stream flow only accessible via private property. This difficulty of locating anglers led to the development of the roving creel survey.

Robson (1960) outlined a detailed creel census procedure for estimating catch per unit effort (CPE), total effort, and thus total harvest, using stratified random sampling. This method, however, was found to be inefficient in the field. Sampling areas had to be small to allow a complete census of anglers during any sampling period, thus precluding its use on bodies of water where many access points are present. Field personnel were inefficiently used since they were stationery and dependent on anglers coming to them.

Hayne (1966, 1972) utilized the stratified random sampling approach. However, he also introduced a roving investigator into the sampling scheme so field personnel could actively contact anglers. This procedure is adaptable and versatile in many field situations and is applicable in both access point and roving creel surveys. The basic features of this approach are:

1. The entire period for which the fishery is to be surveyed is divided into time blocks. The amount of fishing expected to take place within these blocks should be similar.
2. Each time block is divided into non-overlapping sampling units.
3. Probabilities of expected fishing pressure are assigned to the sampling units. The sum of the probabilities assigned to the sampling units within any given block equals 1.0.
4. Sampling units are randomly chosen within each block based on the above sampling probabilities. The probability that sampling will actually be done during any given sampling unit is proportional to the amount of fishing expected to occur during that unit.
5. Sampling on the water body is comprised of counts and interviews. Counts of fishermen are done as quickly as possible, preferably being made for the entire body of water from some vantage point. It may be necessary to divide large lakes into sections. The sections, like the sampling units, are randomly chosen with probability proportional to the amount of fishing expected to occur in the sections. After counts are made fishermen are interviewed. Information gathered from them must include time spent fishing and weight of fish caught so total harvest can be estimated.
6. The probability assigned a sampling unit or lake section, x, equals the number of units of expected fishing effort in

sampling unit or lake section, x, divided by the total number of expected units of fishing effort of all sampling units or lake sections (probability proportional to size).

Malvestuto, Davies, and Shelton (1978) conducted a roving creel survey with nonuniform probability sampling employing the techniques of Hayne (1966, 1972). They estimated catch and effort at a Georgian reservoir and indicated that there was no significant difference between the mean catch/effort for completed trips measured through access points and the mean catch/effort of incompleted trips measured with the roving survey.

Talhelm (1972) developed a roving creel survey technique for interviewing anglers on inland streams. His method, which also may be applied to lake shore anglers, was used in this study. Talhelm's survey method incorporates a few of the same concepts as Hayne (1966, 1972), but instead of counting all the anglers and then interviewing them, the anglers were interviewed as soon as they were contacted. Information concerning angling hours, angler days, catch in numbers and pounds, species composition, and other pertinent information was gathered. In this tehcnique, it is assumed that all anglers on a lake or stream segment could be interviewed at any selected point in time on a sample day. Each stream or lake segment is sampled at several points in time on its sample day. At each selected point in time, the interviewer travels the length of the lake or stream interviewing all anglers encountered. If there were a large number of anglers, making it impossible to interview all of them, then every second or third angler would be interviewed. The probability of finding each angler is proportional to 1) his length of stay in that area, 2) the number and distribution of the point samples throughout the day, and 3) the length of day. It is assumed that anglers know how long they will remain in the area on the sample day.

It is not possible for one or two interviewers to administer a ten-minute questionnaire to all anglers at one point in time on a lake or stream. Therefore, the interviewer starts at one end of each lake or stream segment and systematically samples the entire segment, interviewing each angler encountered along the way. Talhelm (1972) defines this sample as a traverse. One traverse is statistically treated as a sample of the entire stream or lake segment at one point in time. In fact, each point on the stream or lake segment is sampled at a particular point in time. Assuming the composition of the angling population does not change significantly over the period of the traverse, the result is essentially the same as a sample at one point in time. The interviewer does not interview anglers who leave as he approaches a point or anglers who arrive at a point just after he passes that point. Anglers encountered more than once within an area sampled on a particular sample day are not re-interviewed.

Since more anglers may be distributed throughout an area at a particular time of day, as opposed to other times of the day, the effectiveness of each traverse is maximized by spacing the traverses at equal time intervals from one another throughout the sample day. Each traverse is viewed as the midpoint of a segment of an equally divided sampling day, and the interviewers attempt to traverse the area at least three times a day. For example, assuming a 12-hour day, the three segments of the day would be approximately 4 hours long: 6:00-10:00, 10:00-2:00, and 2:00-6:00. The number of hours of each segment depends on the angling day length. In this example, the area would be traversed at equal time intervals as close as possible to 8:00, 12:00, and 4:00.

On a particular sample day an interviewer traverses a given area along a well-defined route. The interviewer follows this path identically for each traverse during the sample day. The route within each area is in a north-south direction. When a particular area is sampled on another sample day, the interviewer should start his first traverse at a different geographic point (selected randomly) from the one sampled in that area on a previously sampled day. Three starting points were chosen within each area: the most northerly and southerly points and a point midway between both of these. This is done so that most areas are sometimes traversed early and sometimes late for the duration of the entire creel survey.

If it is assumed that anglers are distributed throughout the day in a random pattern, the likelihood of encountering them can be determined. Figure 1 (Talhelm, 1972) is a graph which enables a researcher to ascertain the percent of 3-hour anglers on a stream (or lake) who have been interviewed in relation to the time of interview during a 9-hour angling day (0 to 9). Specifically, the isosceles triangle ABC indicates the instantaneous percentage of 3-hour anglers who will be or have been interviewed at any specific point in time. For example, if one traverse is performed during an entire 9-hour angling day and it is initiated at T=3, then 100 percent of the 3-hour anglers who arrive on the stream or lake between 0 and 3 would be interviewed.

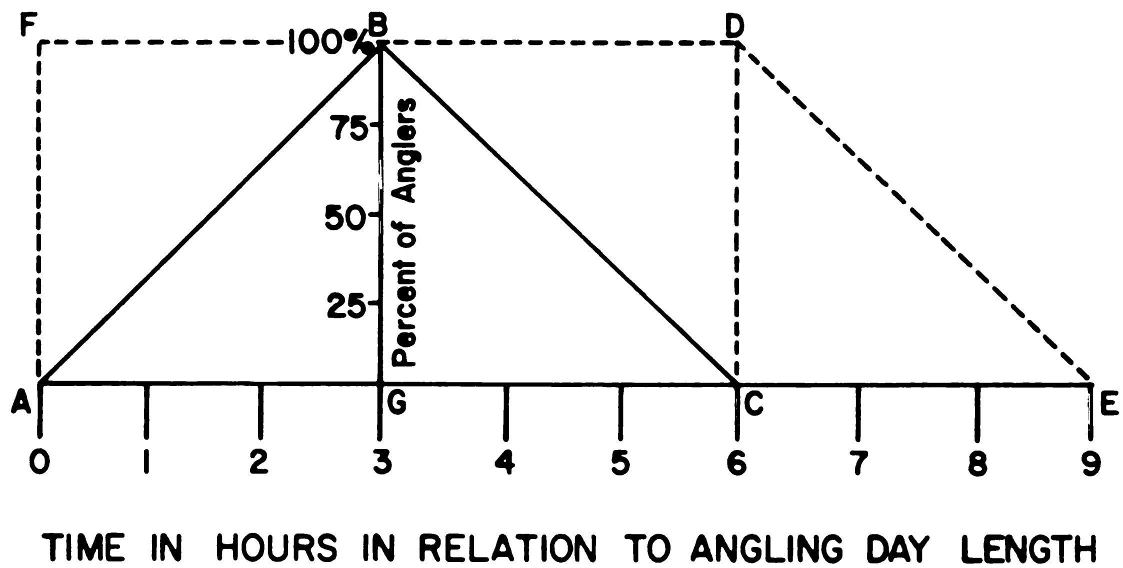

Figure 1. Percent of anglers on a stream or lake who have been or will be interviewed in relation to the time of interview; all anglers stay three hours each and arrive randomly.

Half of the 3-hour anglers (ABC is half the area AFDC) who are on the stream or lake from 0 to 6 are interviewed and none from 6 to 9.

A second traverse at T=6, along with the traverse at T=3, would result in 50 percent of the anglers being interviewed from 0 to 3 (half retangular area AFBG), 100 percent from 3 to 6 (entire area GBDC), and 50 percent being interviewed from 6 to 9 (CDE is half the area since an area equivalent to AFB is placed atop CDE). The percentage of 3-hour anglers interviewed or the probability of encountering these anglers during the entire 9-hour day given two traverses (at T=3 and T=6) would be $66^{2/3}$ percent (4 of 6 possible areas of Figure 1). Both of the above examples assume random arrival and departure of anglers during the 9-hour day, and before 0 and after 9 (open-ended).

If the angling day is assumed to begin exactly at 0 and end exactly at 9 (close-ended), then all 3-hour anglers prior to time 3 would be interviewed. This shifts AB to AFB during the first 3-hour period, and an area equivalent to AFB is placed atop CDE. This indicates that 100 percent of all anglers would be interviewed (traverses at T=3 and T=6) during the 9-hour angling day.

The geometrical representation for estimating the percentage of 3-hour anglers interviewed or the probability of encountering 3-hour anglers during the 9-hour angling day with traverses at T=3 and T=6 (Figure 1) can also be expressed mathematically (Talhelm, 1972). The probability of encountering 3-hour anglers is:

$$\frac{m_i \cdot h_{ij}}{x_i} = \frac{2 \cdot 3}{9} = \frac{2}{3} \quad \text{(equivalent to the geometric solution)}$$

where

m_i = number of traverses on sampling day i,

h_{ij} = total fishing hours on sampling day i by interviewed angler j,

x_i = length in hours of the angling day on sampling day i.

The total number of angling hours (q_i) on a stream or lake during angling day i is given by equation (1) which is separated into forms (A) and (B):

$$a_i = \sum_{j=1}^{v_i} \frac{x_i}{m_i \cdot h_{ij}} \cdot h_{ij} = v_i \left(\frac{x_i}{m_i} \right) \tag{A}$$

Form (A) is used under the condition that the probability of encountering these interviewed anglers is less than 1.

where

a_i = angling hours on day i,

v_i = number of different interviews on day i where the probability of encountering these interviewed anglers is less than 1.

$$b_i = \sum_{j=1}^{n_i} h_{ij} \tag{B}$$

Form (B) is employed under the condition that the probability of encountering anglers equals 1.

where

b_i = angling hours on day i,

n_i = number of different interviews on day i where the probability of encountering these interviewed anglers equals 1.

The summation of equations (A) and (B) gives:

$$q_i = v_i \left(\frac{x_i}{m_i}\right) + \sum_{j=1}^{n_i} h_{ij} \tag{1}$$

Form (A) is used to calculate the number of angling hours of interviewed angler j if $m_i \cdot h_{ij} < x_i$ (probability of encounter is less than 1). Form (B) is employed if $m_i \cdot h_{ij} \geq x_i$ (probability of encounter = 1). For example, if angler j reports angling hours (h_{ij}) = 1, and x_i = 12 and m_i = 3, then the probability of encountering 1-hour anglers would be:

$$\text{probability (encounter)} = \frac{m_i \cdot h_{ij}}{x_i} = \frac{3 \cdot 1}{12} = \frac{1}{4}$$

The number of angling hours represented by interviewed angler j would be 4 (form (A)) ($\frac{12}{3 \cdot 1} \cdot 1 = \frac{12}{3} = 4$). If angler j reports $h_{ij} \geq 4$ the probability of encounter would equal 1. Therefore, form (B) would be used, and the number of angling hours would equal h_{ij}.

The total number of angler days or visits/day (AD_i) on angling day i is estimated by equation (2) which is separated into forms (C) and (D):

$$c_i = \sum_{j=1}^{v_i} \frac{x_i}{m_i \cdot h_{ij}}, \text{ if for a particular interviewed angler } j,\ m_i \cdot h_{ij} < x_i. \tag{C}$$

where

c_i = angler days on day i.

$$d_i = \sum_{j=1}^{n_i} \frac{x_i}{m_i \cdot h_{ij}} = n_i, \text{ if for a particular interviewed angler } j,\ m_i \cdot h_{ij} \geq x_i. \tag{D}$$

where

d_i = angler days on day i.

The summation of equations (C) and (D) gives:

$$AD_i = \sum_{j=i}^{v_i} \frac{x_i}{m_i \cdot h_{ij}} + n_i \tag{2}$$

Usually all shore anglers encountered could be interviewed. See Appendix H for an explanation of how the occasionally skipped angler is entered into equations (1) and (2).

Equations (1) and (2) assume an open-ended fishery. These equations may underestimate total angling hours or angler days because the sport fishery acts like a close- ended fishery instead of an open-ended fishery, but since angling occurs at night underestimates may result. Therefore, to compensate for this underestimation, a correction factor must be subjectively introduced by multiplying the correction (C.F.) times equations (1) and (2) (Talhelm, 1972). For example:

$$q_i = v_{i\left(\frac{x_i}{m_i}\right)} (C.F.) + \sum_{j=1}^{n_i} h_{ij} \; (C.F.) \tag{3}$$

C.F. = 1 + a fractional adjustment which allows for the probability that total angling hours or angler days are underestimated.

The C.F. is equivalent to shifting AB to some position approaching AFB in Figure 1.

Angling hours, angler days, and catch were computed for each sampling day in each area, then seasonal estimates were calculated by proportionally expanding the sample results to the population of days involved during the survey.

2. Population Models

Frequently fishery biologists must decide whether or not restrictions or regulations must be imposed on fishing effort within a particular fishery. Often these regulations are initiated to prevent overexploitation of a fish stock. In the future, with increasing demand for fish as a food source or for recreation, it is likely that increased regulation will be needed. Biologists and other concerned professionals (economists, lawyers, etc.) must ensure that the most suitable measures be introduced. Management of fisheries depends on accurate biological and socioeconomic information about a fish stock to ensure that the consequences of management action satisfy those directly involved in the fishery.

In predicting the consequences of a management action, fishery biologists must model the fish population. Models consist of mathematical expressions which represent the events that occur in the fish stock. The results of models assist managers in predicting the effect of management actions, such as controls on the amount of fishing or the sizes of fish caught. If the model is useful management actions can be analyzed and the results predicted by the model will correspond reasonably well to what would actually occur in practice.

Two models commonly used by fishery biologists are: 1) the logistic surplus production model which treats the population as a whole, considering the changes in biomass without reference to its structure (age composition, growth, etc.) (Graham, 1935; Schaefer, 1957) and 2) the dynamic pool model which considers the population as the sum of its individuals and deals with the growth and mortality rates of these individuals (Baranov, 1918; Beverton and Holt, 1957; Ricker, 1958).

The logistic surplus production model treats the population as a single variable, biomass. The simplest types of data (catch and effort) are used in its application. Only relative abundance, measured in terms of catch per unit of effort, is needed to determine the harvestable biomass of a fish stock. The logistic model is based on a generalized logistic population growth equation. In the logistic growth equation the biomass of a population will tend to increase until the population has reached the limit of the carrying capacity of the environment. The rate of increase will be determined solely by the current biomass of the population, expressed mathematically as:

$$\frac{dB}{dt} = f(B). \tag{4}$$

Limits to f(B) are set by the fact that it will be zero when the population is zero and at equilibrium. At equilibrium the population will tend to stabilize in the absence of exploitation. As the population increases from an initial size close to zero the rate of increase will rise to a maximum at some intermediate value and then decrease. A plot of the population growth rate against population abundance forms a parabolic curve if it is assumed that the exponent of the generalized logistic growth equation equals 2.

If fishermen remove an amount of biomass from a fish stock during year, t, equal to its natural increase, then the biomass available for year, t+1, will be identical to that during year, t. This biomass removal could be repeated each year indefinitely; this removal is termed surplus production or sustainable yield. In the equations for the surplus production model, the change in yield is a function of fishing effort and stock size or biomass (Equation 5) and change in biomass is equal to growth minus harvest or yield (Equation 6).

$$\frac{dY}{dt} = qEB \qquad (5)$$

$$\frac{dB}{dt} = kB - \frac{kB^2}{K} - qEB \qquad (6)$$

where

Y = yield (or catch) in pounds or numbers

t = time in years

q = catchability coefficient

E = fishing effort (fishing gear used per time period)

B = harvestable biomass or numbers of the population (biomass is in pounds)

k = population growth constant

K = environmental carrying capacity

The assumptions of the surplus production model are:

1. Model is deterministic (no random variables), it describes the average situation.
2. Age structure is stable.
3. Time lags are ignored.
4. Catchability is constant over years and population sizes.
5. Population over the area of interest is a single stock.
6. Surplus production is a parabolic function of biomass.

The parameters q, K, and k of the logistic model are estimated from the catch and effort data of commercial and sport fisheries. Several methods of fitting the surplus production curve have been developed including a method for linearizing equation (6) (Schaefer, 1957).

A multiple linear regression analysis can be utilized with this method if more than three years of data are available. This study employs the Schaefer method since the assumption that fisheries must be in equilibrium is not required (See Chapter III). The parameter estimates (estimated by ordinary least squares) from this method were then varied and substituted into a computerized systematic search routine to find parameter values which minimize the residual sum of squares (Jensen, 1976). Further details are in Appendix B. Jensen (1976) discussed other methods some of which require the fishery to be in equilibrium. Schaefer (1954) proposed an equilibrium approximation method that was further discussed by Gulland (1969) and Fox (1975). Several equilibrium equations were derived by Gulland and Fox for the surplus production model such as:

$$Y_e = qKE - \frac{Kq^2}{k} E^2 \qquad (7)$$

These equilibrium relations are linearized easily. However, these methods may not work well for fisheries which are never in equilibrium. Finally, for the non-equilibrium fishery Pella and Tomlinson (1969) developed a method of numerically integrating equation (5) instead of approximating it as Schaefer (1957) did. Substituting Pella and Tomlinson's solution of the integration of equation (6) into equation (5) gives an equation for yield as a function of time which can be integrated numerically for given values of the parameters K, q, and k. A computer search routine is then applied to find values of the parameters which minimize the residual sum of squares. This method works well with data points on both sides of the maximum sustained yield point of the surplus production curve. Since the data points in this study were scattered to one side of the maximum sustained yield point of the surplus production curve, Pella and Tomlinson's method was not employed.

Dynamic pool models consider the population of fish as the sum of its individual members, rather than a single unit. Growth and death rates of these individuals are analyzed. Logistic models assume that the rate of growth, death rates from causes other than fishing, and the number of young fish recruited to a fishery each year are constant and independent of the abundance of the stock, or the amount of fishing. Logistic models also assume that individual fish of the same age do not differ among themselves regarding their rate of growth or susceptibility to capture by fishermen using various types of fishing gear. These assumptions can be relaxed and replaced by more realistic, yet more complex, dynamic pool models.

The ideal analytical approach of dynamic pool models for estimating total yield of a stock would be to consider one cohort of fish throughout its life. However, in a steady state (constant fishing and mortality rates), the average yield in a year from all year classes present would be equal to the yield from any one cohort during its life. The assumptions of the dynamic pool model involving the simple algebraic expression of yield are:

1. The instantaneous fishing and natural mortality coefficients are constant.
2. Recruitment is constant.
3. Fish grow isomorphically (fish have the same shape throughout life). Otherwise the cubic exponent in equation (10) may not be totally valid.

The actual calculations require a mathematical expression for the growth of the individual fish. The algebra is easier if the expression of growth can be combined easily with an expression for the number of fish. The latter can be obtained from mortality rates. In mathematical terms the change in numbers is given by:

$$\frac{dN}{dt} = -ZN \tag{8}$$

where

N = cohort or year class numbers of fish,

$Z = F + M$ = instantaneous total mortality coefficient,

F = instantaneous fishing mortality coefficient,

M = instantaneous natural mortality coefficient.

If Z is constant, the differential equation can be solved to give:

$$N_t = Re^{-M(t_c - t_r) - (F + M)(t - t_c)} \tag{9}$$

where

N_t = number of fish alive at time, t,

R = number of recruits annually,

t_c = age fish become vulnerable to the fishing gear,

t_r = age of recruitment into the fishery.

A convenient mathematical expression of growth which fits a wide range of ages is the von Bertalanffy growth curve, used by Beverton and Holt (1957). This expresses the weight in the form:

$$W_t = W_\infty(1 - e^{-k'(t - t_o)})^3 \tag{10}$$

where

W_t = average weight of a fish at age, t,

W_∞ = average asymptotic weight of a fish,

k' = growth coefficient,

t_o = time when the length of a fish is theoretically zero.

This expression for weight combined with the expression for numbers, provides the formula for yield

$$Y = F \int_{t_c}^{t_1} RW_\infty e^{-(F + M)(t - t_c)} \sum_{n=0}^{3} U'_n e^{-nk(t - t_o)} dt \qquad (11)$$

where

t_1 = maximum age attained,

$U'_0 = 1$,

$U'_1 = -3$,

$U'_2 = 3$,

$U'_3 = -1$.

Cubing the parenthetical expression in equation (10) gives these U'_n constants in equation (11). Other more complicated algebraic expressions of yield are possible but will not be discussed. The essential point is that the yield may be limited by management agencies either by controlling the amount of fishing (F), or the age of first capture (t_c).

To make a calculation of yield it is necessary to have estimates of several parameters in the yield equation. The parameters relating to growth of the individual fish (W_∞, k, t_o) are easily calculated if the age of the individual fish can be determined from scales or otoliths. The pattern of growth plus some knowledge of the general biology and behavior of the fish can provide an estimate of t_r. The natural mortality coefficient, M, is difficult to estimate directly. Usually only the total mortality, Z, is easily measured. Various techniques are used to separate Z into fishing and natural mortality. The effect of management measures can depend quite critically on the natural mortality. Recruitment is frequently not explicity estimated, but rather the yield is expressed as the yield per recruit, Y/R. Recruitment is difficult to estimate directly. For many fisheries, the best recruitment estimates are obtained by multiplying Z times Y and dividing both by F. Recruitment is often determined by dividing Y/R into the observed value of the yield. The reason Y/R is calculated is that in a number of fisheries annual recruitment fluctuations vary very widely. The fluctuations appear almost random and quite independent of fishing. The most important reason for expressing the results as Y/R is that in the simple yield model it is assumed that recruitment is unaffected by the amount of fishing, or the abundance of the parent stock. The relationship between stock and recruitment can take many forms (asymptotic, dome-shaped, or parabolic curves) which in turn may have very different effects on the shape of the curve of total yield against the amount of fishing. It may also be difficult to determine the true form of the stock-recruitment curve for a particular stock of fish.

The surplus production model was selected for use in this dissertation because the data available (catch and effort) could be readily applied. The simplicity of application of the logistic surplus production model enabled this investigator to conduct two other analyses simultaneously, a creel survey and an economic evaluation of the plant site. The major disadvantages of utilizing the logistic model include: 1) several assumptions in the model are unverifiable (e.g. whether the plot of yield versus effort is in fact a parabolic curve), 2) accurate parameter estimates are difficult, and 3) the basic equations are not easily modified to make the model more realistic. Given the harvestable biomass (or numbers) estimated from this model, life history information, and the percent of the total catch by weight of each age class with trapnets (percentage often ranges between 50 and 65 percent depending on effort), the population size was estimated (See Chapter III). After estimating the yellow perch population size (number) using the surplus production model, the Leslie matrix model was employed to simulate power plant effects (impingement and entrainment) on this population through time.

The Leslie matrix model was introduced by Leslie (1945). It has been extensively used in demography but overlooked by ecologists until recently. Saila and Lorda (1977) discussed the advantages and disadvantages of this model. The advantages of this discrete time model include its computational straightforwardness and consideration of age structure without assuming a stable age distribution.

The major disadvantage of the Leslie matrix model is that it implies a linear (density-independent) stock-recruitment relationship, since compensatory mechanisms (density dependent) are ignored; it also requires estimation of a large number of parameters. In this case, compensation refers to changes in birth rates and death rates in response to changes in population density.

The mathematical structure of the Leslie matrix model is:

$N_{t+1} = \underline{A} \times N_t$, or

$$\begin{bmatrix} n_o \\ n_1 \\ n_2 \\ \cdot \\ \cdot \\ n_x \end{bmatrix}_{t+1} = \begin{bmatrix} f_o & f_1 & \cdot & \cdot & \cdot & f_{x-1} & f_x \\ s_o & o & \cdot & \cdot & \cdot & o & o \\ o & s_1 & \cdot & \cdot & \cdot & o & o \\ \cdot & \cdot & & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & & \cdot & \cdot \\ o & o & & & & s_{x-1} & o \end{bmatrix} x \begin{bmatrix} n_o \\ n_1 \\ n_2 \\ \cdot \\ \cdot \\ n_x \end{bmatrix}_t \qquad (12)$$

The column vector N_t is the population number by age class at time t; the n_x elements correspond to the number of individuals at each of X + 1 ages. The X + 1 by X + 1 population projection matrix $\underline{A}$ has elements in the first row corresponding to the reproductive potential or eggs produced per adult (fecundity). The elements of the subdiagonal correspond to the age specific survival (number of males and females alive at the end of a one-year period relative to the number alive at the beginning of a one-year period). If sufficient information for a species exists to estimate the age-specific fecundity and survivorship parameters in the population $\underline{A}$ matrix, then the population growth rate, λ, can be determined by eigenvalue analysis. The intrinsic rate of increase or so-called finite population growth rate, λ, is defined as the rate of increase per individual per unit of time. The population growth rate (λ) is the positive real eigenvalue (λ) of the matrix. If $\lambda = 1.0$, then the population is most likely stable or in equilibrium. The model also permits a detailed analysis of short term predictions (period of 50 years or less) of the population dynamics under the assumption of constant fecundity and survivorship rates.

A sample calculation for one iteration of the Leslie matrix model would be:

$$n_o(t+1) = f_o n_o(t) + f_1 n_1(t) + \cdots + f_x n_x(t).$$

$$n_1(t+1) = S_o n_o.$$

$$n_2(t+1) = S_1 n_1.$$

$$\vdots$$

$$n_x(t+1) = S_{x-1} n_{x-1}.$$

where

n_x = number of age x fish

f_x = fecundity of age x fish

s_x = survivorship of age x fish

Given the initial population (equivalent to N_t above) calculated from the surplus production model, survivorship, fecundity, and impingement and entrainment mortality rates, the following will be determined in this study utilizing the Leslie matrix model:

1. Effects on all age classes, especially adults, affected by power plant operation.
2. The effects of impingement and entrainment on yellow perch stocks during the expected life of the plant (50 years).
3. Changes in the population growth rate resulting from differential survival rates of the different age classes as a consequence of power plant operation.

A sensitivity analysis will also be conducted to test the effect of changes in the elements of the $\underline{A}$ matrix (survival rates) on the population growth rate.

3. Population Life History of Yellow Perch

The scientific literature and commercial fisheries statistics were reviewed to determine the population life history and structure (age composition, growth, etc.) of the yellow perch, Perca flavescens. This information formed the basis for parameterizing the population models.

The yellow perch is a North American freshwater fish (Family Percidae). It occurs naturally from Nova Scotia south to the Florida panhandle, north to western Pennsylvania, west to eastern Kansas, northwest to Montana, north to Great Slave Lake (Northwest Territories) and southeast to James Bay, Quebec, and New Brunswick. The yellow perch has also been introduced successfully in most states to the south and west (Scott and Crossman, 1973).

The yellow perch spawns in the spring, usually during April and May, but spawning may be extended into July. The adults migrate shoreward into the shallow areas of lakes. Spawning occurs at night and early morning, usually near rooted vegetation, submerged brush, or fallen trees, and occasionally over sand or gravel. The food of yellow perch changes with their increase in size from immature insects to small fish (Keast and Webb, 1966).

The reported sex ratio of yellow perch varies. El-Zarka (1959) reported that on the average female yellow perch constituted 38 percent of the spawning runs in Saginaw Bay, while Lake Huron had from 83 percent in age 2 to 23 percent in age 6 from 1943 to 1955. Table 1 contains sex ratios reported from Lake Huron.

Commercial fisheries data on Lake Erie indicate that age 6 is the oldest age class (Jobes, 1952). Both El-Zarka (1959) and Jobes (1952)

Table 1. Life Table of Yellow Perch of Western Lake Erie and Lake Huron.

Age (year)	Weight[1] (gm)	Standard Length[2] (mm)	Fecundity[3] (eggs/female)	Proportion[4] of Population Females	Survival[5] (males and females)
0	No Data	No Data	0	N/A	.01175
1	9	78	0	N/A	.08572
2	59	146	0	N/A	.08572
3	117	183	17,258	.50	.17499
4	172	208	28,642	.41	.25872
5	226	228	47,098	.30	.33132
6	269	240	69,984	.23	0

[1,2] Jobes (1952)

[3] Sheri and Power (1969)

[4] El-Zarka (1959)

[5] Survival = 1-mortality (Ricker, 1975); Stone and Webster (1978)

state that the majority of females are not sexually mature until age 3 in Lakes Huron and Erie. Yellow perch become highly vulnerable to sport fishing at age 2. Age was determined by scale samples taken during the creel survey in Monroe County.

Survivorship of each age class of yellow perch in the western basin of Lake Erie can be estimated using age frequency distribution provided by Jobes (1952). Stone and Webster, Inc. (1978) estimated survival by a least squares regression of the natural log of the number commercially collected for ages 2 to 6 against the log of the age; survival of age 1 was assumed equal to age 2. For age 0 fish the indirect method of Vaughan and Saila (1976) was used to estimate the survival rate from egg to age 1; these were the only survival rates available for Lake Erie yellow perch (Table 1).

Fecundity and average weight as well as length (L) information were estimated by Sheri and Power (1969) and Jobes (1952) respectively (Table 1). Formulae for fecundity (F) and weight (W) are:

$$\log_{10} F = 3.769 + 0.004\ W$$

$$W = 1.776 \times 10^{-5} L^{3.015}$$

The percent of the total commercial trapnet catch by weight of each age class of western Lake Erie yellow perch was estimated by Muth (1978). The percentage of females in each age class and the fecundity estimates reported by El-Zarka and Sheri and Power respectively are lower than those of other investigators. For this reason the El-Zarka and Sheri and Power data were used in this study. These lower estimates result in a smaller population size for year, t, when the Leslie matrix is iterated.

This in turn maximizes the adverse power plant induced mortality effects of impingement and entrainment on the yellow perch population.

The yellow perch has economic importance to man both commercially and recreationally. The yellow perch is sold almost everywhere. It inhabits a vast territory and aggregates near shore especially in the spring; it usually stays in shallow water of less than 30 feet, although it may be found in deeper water. These facts make it readily accessible to fishermen. Leach and Nepszy (1976) state that the population of yellow perch in the western basin of Lake Erie is currently unstable, since the exploitation of yellow perch stocks has intensified since the decline of the blue pike and walleye in the 1950's. Variability in year class strength has been characteristic of perch populations in western Lake Erie since the 1950's. Strong year classes were recruited in 1959, 1962, 1965, and 1970. Since 1970 the year classes of yellow perch in western Lake Erie have not been strong, resulting in a depressed commercial resource (Leach and Nepszy, 1976).

4. Demand and Supply for Outdoor Recreation

Introduction

Most demand studies of outdoor recreation have focused on travel costs as a primary variable influencing visitation (Korson, 1979). Hotelling (1949), Trice and Wood (1958), and Clawson (1959) defined broad geographic zones around the recreation site, and assumed that money and travel costs determined the quantity of use at visited sites. The amounts of participation associated with each level of travel costs are employed to derive a demand curve for a single unique recreation site (Clawson, 1959).

Defining Demand and Supply

Consumers respond to decreases and increases in the relative price of a product by increasing or decreasing their consumption of that product respectively. A demand curve summarizes this behavior. Demand is defined as a schedule of the maximum quantities purchased (per unit of time) at every possible price over a particular period of time, holding other influences on demand constant.

The demand for angling is similar to the above price-quantity schedule, but prices here are not determined by typical market forces. Rather the "price" of angling represents the cost of angling in terms of the money and time resources required of the angler for participation in angling activities. Angling demand relates costs (prices) of participation to the amounts (quantities) of participation. For instance, if the price of angling increases, the aggregate quantity of use (days) enjoyed by anglers will decrease, *ceteris paribus*. An angler day is defined as any part of a day an angler fished. "Demand for a particular type of angling is the willingness of anglers to exchange their resources for that type of angling" (Talhelm, 1973b).

Other factors influence demand. These factors change the shapes and positions of demand curves, and consequently participation rates of angling. Dwyer, et al. (1977) states "that influences such as availability and quality of alternative forms of angling, and the nonhomogeneous tastes and income in the population should be considered."

The quantity of a good offered for sale by producers depends on the expected price in the marketplace. Curve A in Figure 2 represents a typical supply curve; it is a price-quantity relationship which shows

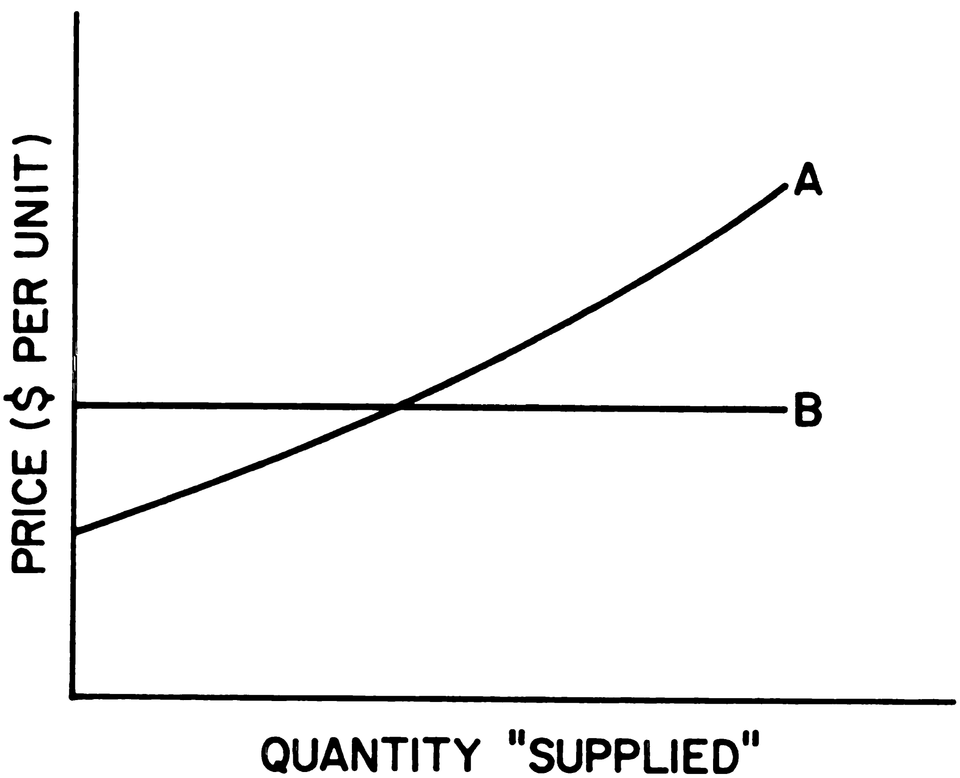

Figure 2. A normal supply curve (A) and a supply curve for angling with a given travel time requirement (B).

the given quantities of goods which will be produced (per unit of time) at various prices during a specified time period, *ceteris paribus* (Talhelm, 1973b).

The supply of angling recreation is different since consumers are also the producers of angling activity. Anglers exchange their personal time and monetary resources for angling activity. The price of procuring a unit of angling is determined by the monetary and time costs of transportation to the site and by other costs. Therefore, angling supply is defined as the minimum price at which each quantity of a particular kind of angling use is available at an angling site during a specified time period (Talhelm, 1973b).

Angling "price equations" express angling costs as a direct function of travel time or distance (Talhelm, 1978). The leading sources of angler costs incurred to produce angling are: 1) travel time value necessary to participate in angling, 2) transportation, 3) monetary cost of food and lodging, 4) direct expenditures for fees, licenses, and equipment, and 5) value of time spent angling.

Visitation rates to a particular recreation site are not influenced solely by monetary costs, but also by the time restraints of reaching the site. Greater travel distance increases the time and monetary cost of travel and reduces the recreational time available in a given time period (Talhelm, 1972). Under conditions of perfectly flexible substitution of work and non-work activities, the opportunity cost (e.g. expense of opportunities foregone) of time should equal the lowest current wage rate after taxes (Talhelm, 1972, 1978). It may also equal the potential wage rate one could have earned by reallocating time and effort to other endeavors. Variation in trip costs for a particular angler depends on the distance an angler travels; consequently, a horizontal angling supply curve is defined for every possible angling distance (Figure 2). For a particular travel distance, numerous angling trips may be taken at a relatively constant cost per angler day (Talhelm, 1972, 1973b, 1976).

The above interpretation of supply provides the foundation for statistically estimating demand equations for a variety of angling experiences. A point on a per-capita-demand curve is formed by each of the respective price and quantity/1000 capita observations. Therefore, given supply prices and observed use of angling for anglers residing at hypothetical locations (A and B), a demand function can be formed by points a and b (Figure 3).

Given a demand schedule the social value (all-or-none value or consumer surplus) of fishing at the plant site was estimated. The "all-or-none value" is the maximum willingness of anglers to pay or accept monetary compensation to have the use of an angling site, as opposed to not having it at all.

5. Description and Operation of the J. R. Whiting Plant

The J. R. Whiting plant (Figure 4), owned and operated by Consumers Power Company, is a fossil fueled facility located on the western shore of Lake Erie, in Erie Township, Monroe County. The plant has three coal-fired units; Units 1 and 2 each have a gross capacity of 105 megawatts (MWe) of electricity, and Unit 3 has a gross capacity of 133 MWe. The plant started electrical production in 1952, and it has a life

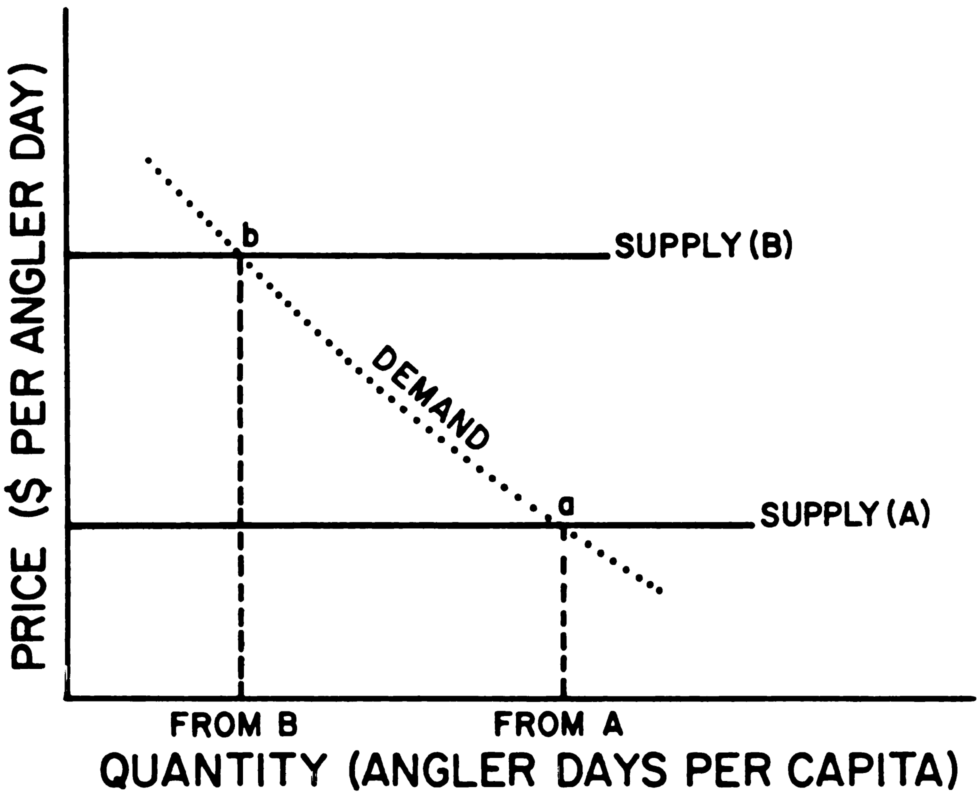

Figure 3. An angling demand curve traced out by supply curves (prices) and quantities of angling for anglers residing at hypothetical locations A and B.

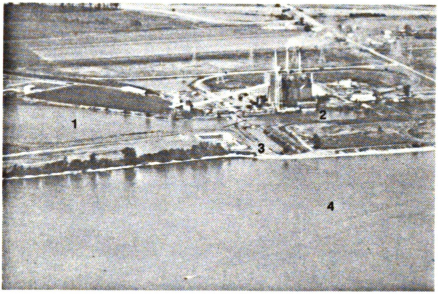

Figure 4. J. R. Whiting plant site. 1=North Maumee Bay, 2=intake, 3=discharge channel, 4=Lake Erie.

expectancy of 50 years. Condenser cooling water for the plant is drawn from the north end of North Maumee Bay. Three vertical traveling screens (3/8-inch wire mesh) prevent fish and smaller debris from entering the plant. Each generating unit has two circulating water pumps. Pumps for Units 1 and 2 each discharge water at a maximum rate of 30,000 gpm, and for Unit 3 at 47,000 gpm. The discharge from the plant flows east via a 900 ft. long discharge duct into Lake Erie. Angling activity occurred in the discharge duct and in the power plant plume of Lake Erie.

III. METHODS

1. Roving Creel Survey

Stratified random sampling employing a roving creel survey was conducted along the Monroe County shoreline to sample catch and effort. The shoreline was stratified into the following segments:

A. Five areas (Figure 5)

1. Area 1 (between 1 and 2)
2. Area 2 (between 2 and 3)
3. Area 3 (between 3 and 4)
4. Area 4 (between 4 and 5)
5. Whiting plant site.

B. Three seasonal periods

1. Winter-Spring (Period I, January through May: January 1979, February 1978 through May 1978)

   this period was further segmented:

   a. ice fishing

   b. non-ice fishing

2. Summer (Period II, June 1978 through August 1978)
3. Fall (Period III, September 1978 through December 1978).

C. Sample dates

1. Weekdays
2. Weekends/Holidays

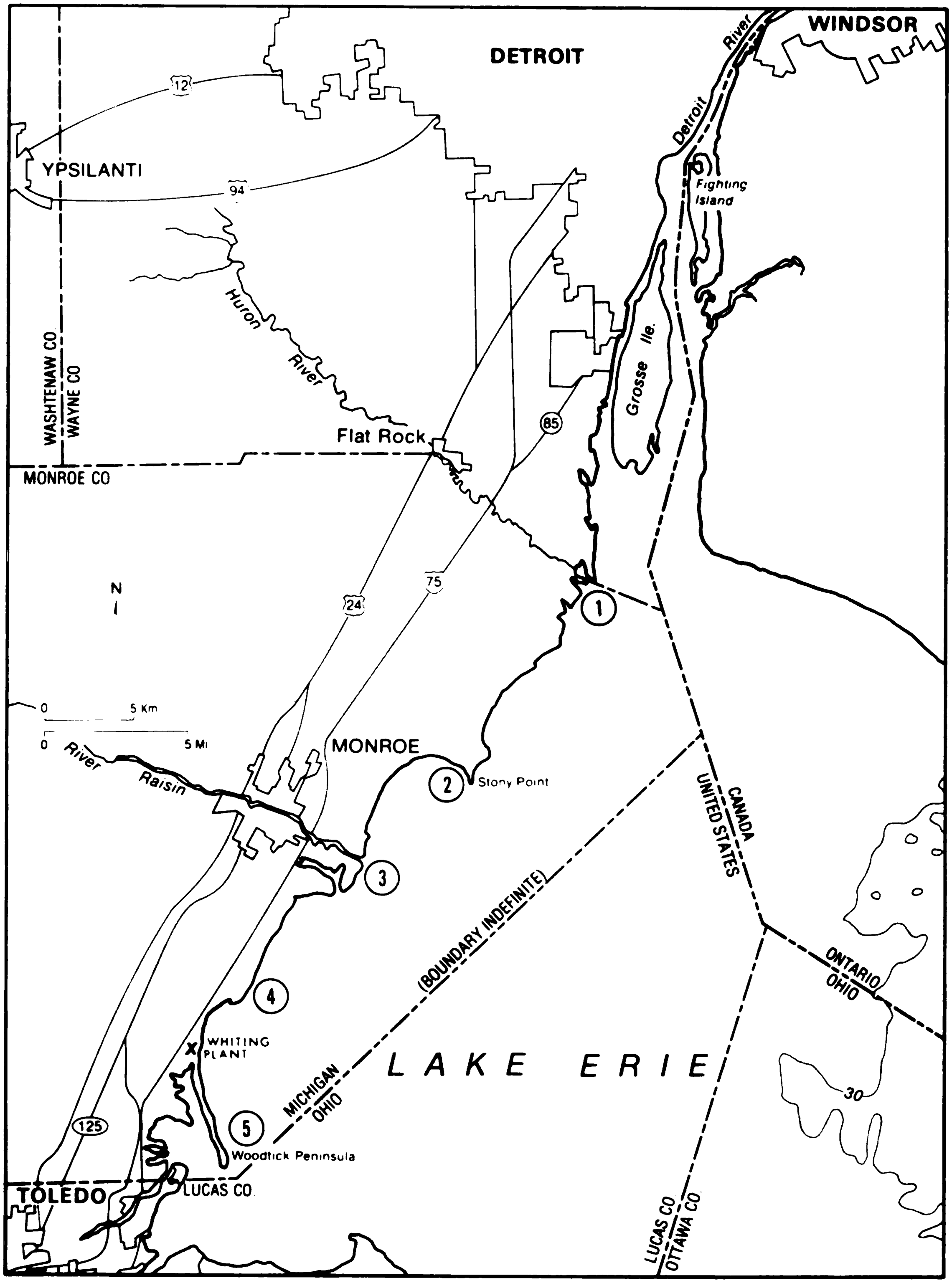

Figure 5. Map of western Lake Erie.

D. Type of fishermen

1. Boat

2. Shore

The sizes of the four geographic areas, and consequently the sampling effort of the interviewers within these strata, was determined by the angling pressure and coastal mileage within each area so that each area could be sampled intensively in one sampling day. Each area was sampled between 36 and 55 days during the year. Since fishing pressure was expected to vary seasonally and different angler behavioral patterns were expected on weekends versus weekdays, it was decided that the seasons and days of the week should be segmented. The weekends and weekdays were divided into two groups and sampled independently. Three weekdays and every weekend day were sampled per week. Holidays were considered weekend days. Every holiday was sampled except Christmas day. The areas and days of the week were selected randomly. Interviewers had two consecutive days off per week, and three holiday substitute days vacation. It was deemed important to stratify the data into boat and shore fishermen, since both groups are not equally accessible for interview, and each may catch different fish species. Although the survey sampling methods utilized for shore and boat fishermen differed, interviewers sampled both types of fishermen during a sampling day. The sampling of boat fishermen is discussed later in this chapter.

One full-time and one part-time interviewer were employed simultaneously during Period I 1978 only (part-time interviewer hired only for the ice fishing season). During Period II there were two full-time interviewers. The rest of the time only one full-time interviewer was necessary. In each period during any given sampling day one interviewer was solely responsible for the intensive sampling of a particular area. Each interviewer recorded on a questionnaire (Appendix A) the number of hours fished, species caught, and other pertinent information concerning the anglers encountered.

Talhelm (1972) provided calculations for estimating catch (numbers and pounds) of shore anglers:

$$(TFC)_{ik} = \sum_{j=1}^{v_{ik}} \frac{(ch)_{ijk}}{(hr)_{ijk}} \cdot \frac{x_i}{m_i} \ (C.F.) + \sum_{j=1}^{n_{ik}} \frac{(ch)_{ijk}}{(hr)_{ijk}} \cdot h_{ijk}(C.F) \quad (13)$$

where

$(TFC)_{ik}$ = total fish caught (number or pounds) on day i for species k,

$(ch)_{ijk}$ = catch so far on day i by angler j for species k,

$(hr)_{ijk}$ = hours fished so far on day i by angler j for species k,

x_i and m_i defined in equation (1),

v_{ik}, n_{ik}, and h_{ijk} are equivalent to v_i, n_i, and h_{ij} in equation (1) except for subscript k indicating species,

C.F. = correction factor.

Talhelm (1972) indicated that equations (1) and (2) (open-ended) could possibly underestimate angling hours and angler days when anglers fish beyond the "normal" angling day length. Therefore, I estimated a correction factor (equation 3) for each period by randomly selecting two weekend and two weekdays per month for interviewing anglers. On these days, I initiated interviewing much earlier (two and one-half hours before sunrise) and much later (two and one-half hours after sunset) than the other interviewers. I traversed an area once every hour, counted the total number of anglers, and then interviewed all of them compiling the total number of hours they fished during the day. Anglers were not re-interviewed if encountered more than once in the area. Since most anglers stayed at least one hour in an area, I assumed the angling population did not change from one traverse to the next. Then I summed the total number of angler days and angling hours for each randomly selected weekday and weekend sampling day (four per month). I compared total angler day and angling hour estimates of my randomly selected weekdays and weekends with the total angler days and total angling hours which I estimated from the other interviewers' data for identical sample days. The estimates of angler days and angling hours from the interviewers' data appeared to be slightly low. To rectify this apparent error a correction factor for each period was estimated from the calculations above and subjectively introduced into equations (1) and (2). The correction factors were:

Period	Correction Factor
I (ice fishery)	1.08
I (non-ice fishery)	1.02
II	1.05
III	1.03

Fishing beyond the "normal" angling day length was minimal throughout the year for shore fishermen except during ice fishing when vast numbers of yellow perch can be caught. The remaining fishing effort throughout the year was concentrated on walleye, white bass, catfish, and other species. I suggest that future creel survey forms incorporate more detailed questions regarding angling beyond what the investigator considers to be the "normal" angling day length.

The procedure for estimating catch and effort for boating anglers was somewhat different. Usually interviewers traversed an area three times on a sampling day; consequently with the aid of binoculars each interviewer recorded on a special form (Appendix C) three instantaneous counts (one per traverse) of the number of boat fishermen in the appropriate sector of the lake. Each count was taken at the beginning of the traverse. From June through the middle of November a sixteen-foot aluminum boat with a six-horsepower engine was rented one weekday and one weekend day per week. This enabled the interviewer to sight shore and boat fishermen easily. By dividing the three instantaneous counts by three the average instantaneous number of boat fishermen, $\bar{X}$, could be estimated. The total angling hours (t_{ik}) of all boat fishermen in the particular area sampled was estimated by multiplying $\bar{X}$ times the length of the angling day.

Based on actual interviews of returning boat fishermen at lake boat access points, the total catch, effort, and catch rate for each species on a sample day in a particular area were calculated. Total angler days (visits/per day or number of fishermen) for the entire sampling day were estimated by first determining the average hours fished per fisherman:

$$\bar{h}_{ijk} = \sum_{j=1}^{v_{ik}} h_{ijk}/v_{ik} \qquad (14)$$

where

$\bar{h}_{ijk}$ = average hours/fisherman on day i for species k,

h_{ijk} = total fishing hours on day i by angler j for species k,

v_{ik} = number of different interviews on day i for species k.

Angler days were then calculated for a particular sample day:

$$a_{ik} = t_{ik}/\bar{h}_{ijk} \tag{15}$$

where

a_{ik} = total angler days on day i for species k,

t_{ik} = total angling hours on day i for species k.

Total catch rate (r_{ik}) equals

$$r_{ik} = \sum_{j=1}^{v_{ik}} c_{ijk} / \sum_{j=1}^{v_{ik}} e_{ijk} \tag{16}$$

where

r_{ik} = total catch rate on day i for species k,

c_{ijk} = catch (actual number or pounds) on day i by angler j for species k,

e_{ijk} = effort (actual hours fished) on day i by angler j for species k.

Total catch $(tc)_{ik}$ was estimated by multiplying r_{ik} by t_{ik}. During Periods I and III virtually all the angling effort (t_{ik}) by boat fishermen was directed toward yellow perch. From June to the middle of August (most of Period II) 60 to 80 percent of their angling effort was expended on walleye with the remaining effort going to yellow perch.

Simple statistical analyses were performed to test the validity of the boat fishermen estimates (Appendix D).

Once the angling hours, angler days, and catch were computed for both shore and boat fishermen for each sampling day and area, then seasonal estimates (for Periods I, II and III) of the different variables were calculated. Cochran (1977) provided formulae for determining seasonal population totals and variances, standard errors, and degrees of freedom. The creel survey was initiated during the fourth week of February 1978 and terminated the last week in January 1979. The sample information gathered from the fourth week of February 1978 was extrapolated back to the third week of February 1978, and the samples taken in the last two weeks of January 1979 were extrapolated forward to the second week of February 1979. These extrapolations were necessary in order to attain population estimates for the month of February. The results of the survey are in Table 2, Chapter II.

2. Surplus Production and Leslie Matrix Models

The general block diagram (Figure 6) illustrates the interrelationships of the different mathematical equations and life history data utilized by the surplus production and Leslie matrix models.

The commercial catch and effort data from the National Marine Fisheries Services, Ann Arbor, Michigan, and the sport catch and effort data from the Michigan Department of Natural Resources, Lansing, Michigan, provided the necessary input data for estimating the parameters of the surplus production model. Catch in commercial fisheries was reported in pounds. The harvestable biomass (in pounds) of the

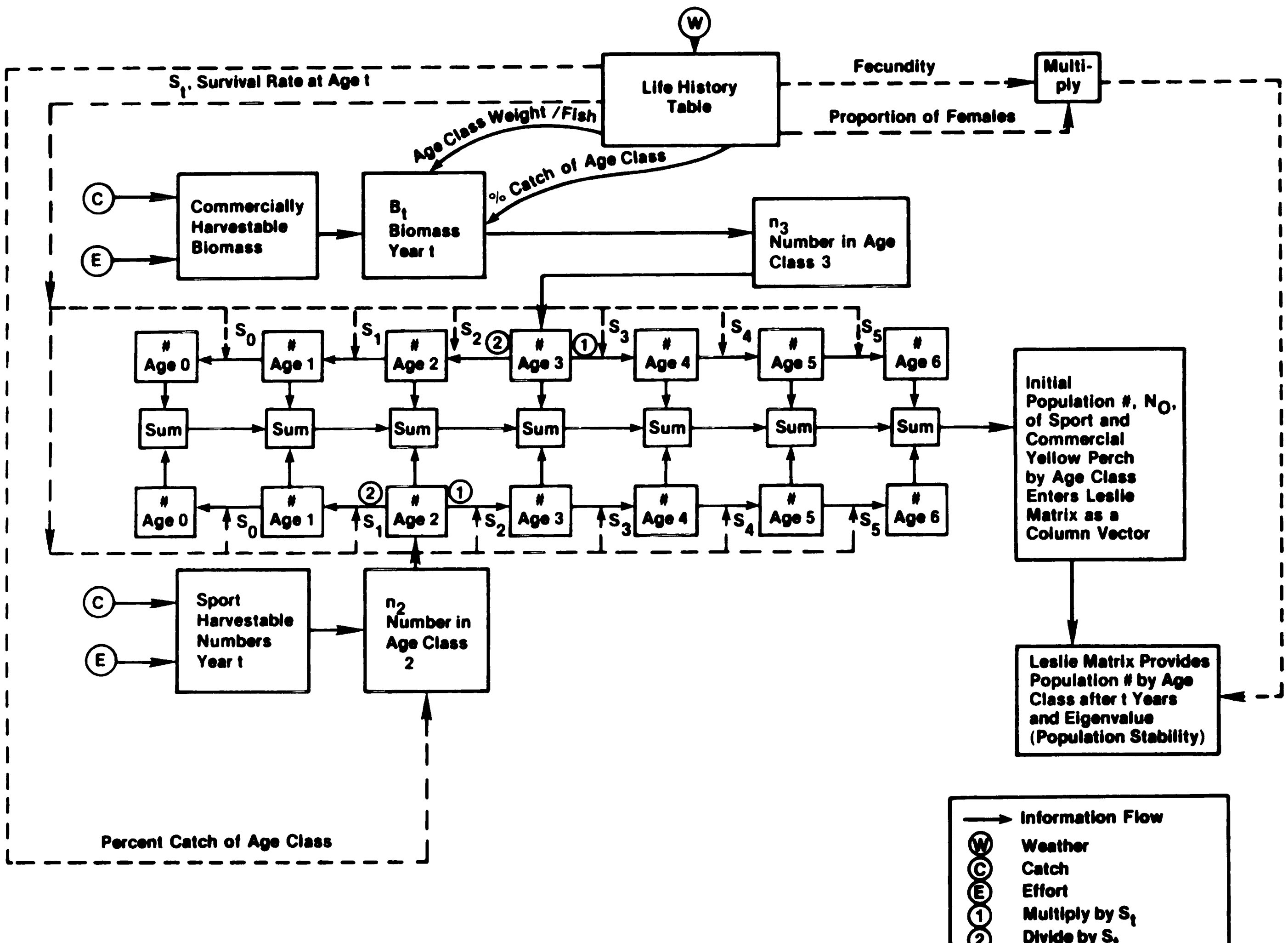

Figure 6. General system block diagram.

commercial fishery for a particular year can be converted to numbers of fish by knowing:

1. The harvestable biomass in pounds during a particular year.
2. The percent of catch by weight of age classes.
3. The age specific average weight of different age class fish.

Only the number of age class 3 yellow perch (n_3 in Figure 6) was estimated since age class 3 includes the youngest yellow perch that are highly vulnerable to the commercial fishing gear. By either dividing or multiplying by the survival rate, the numbers of fish in the other age classes may be calculated (Figure 6).

Sport fishing catch data were reported in numbers of fish. Yellow perch in the sport fishery become highly vulnerable to the gear at age 2. Given the number of age 2 fish the remaining calculations for estimating the number of sport fish in other age classes are similar to those of the commercial fishery (n_2 in Figure 6).

The initial population, N_0, represented in the Leslie matrix model as a column vector (Figure 6), was estimated by adding together the number estimates of fish of identical age classes from both the sport and commercial models. The Leslie matrix model can simulate the effects of power plant mortality on the various age classes and total population through time. The model includes estimates of the initial population, N_0, fecundity, and survivorship values (from the life table and specified in the $\underline{A}$ matrix). Since the survivorship figures include males and females together, the fecundity figures were multipled by the proportion of females within each age class (Table 1, Chapter II). This represents fecundity per adult in equation (12).

To apply the surplus production model, the yellow perch commercial catch and effort data for the years 1960 to 1969 were converted to a standard gear. Only current commercial catch and effort data were used. Commercial fishermen used several gear types, but the gear most utilized was the shallow trapnet. The total yield per unit of effort (YPE) as described by Jensen (1976) is calculated as:

$$\text{YPE} = \text{total yield/total effort} \tag{17}$$

where

$$\text{Total Effort} = x \cdot y/z \tag{18}$$

where

x = effort with standard gear

y = total yield

z = yield with standard gear

Angling effort is reported only in angler days, so angling effort was not standardized. To apply the surplus production model sport fishery data for the years 1970 to 1977 were used. Yellow perch sport catch and effort have been available only since 1970.

Schaefer (1957) developed a method for linearizing equation (6). Jensen (1976) described the equations developed by Schaefer as follows:

$$B_t = (1/q)\ (Y_t/E_t) = (1/q)\ (U_t) \tag{19}$$

where

B_t = average biomass during year t,

Y_t = yield for year t,

U_t = yield per unit of effort for year t,

E_t = effort for year t.

The derivative of equation (6) can be approximated with the two point formula (Hamming, 1962):

$$\left(\frac{dB}{dt}\right)_t = \frac{B_{t+1} - B_{t-1}}{2} = (1/q)\ (\Delta U_t) \tag{20}$$

where

$$\Delta U_t = \frac{(U_{t+1} - U_{t-1})}{2}$$

Substituting equations (19) and (20) into equation (6) gives the linear equation:

$$Z_t = a_1X_1 + a_2X_2 + a_3X_3 \tag{21}$$

where

$Z_t = \Delta U_t$,

$X_1 = U_t$,

$X_2 = U_t^2$,

$X_3 = Y_t$,

$a_1 = k$,

$a_2 = -k/Kq$,

$a_3 = -q$.

The constants a_1 a_2 and a_3 were estimated by least squares regression.

The parameters were estimated separately for the commercial and sport fisheries surplus production models employing Schaefer's method. These parameter values were then varied separately (for commercial and sport fisheries) and substituted into a computer systematic search routine to find parameter values which minimize the residual sum of squares (Jensen, 1976). Further details are in Appendix B. Once the parameters were estimated an equilibrium stock production curve was plotted for each fishery utilizing equation (7).

The most recent estimates of harvestable biomass (B_{69}) and numbers (N_{77}) of the commercial and sport fisheries respectively were employed to estimate the initial population, N_0, in the Leslie matrix model.

Sport fishermen harvested yellow perch throughout the period of commercial fishing, but no catch and effort data are available. The harvestable biomass (in pounds) of the commercial fishery in 1969 was converted to numbers of fish by the formula:

$$n_3 = \frac{b_{69}\ (p_3)\ (454)}{\bar{w}_3} \tag{22}$$

where

n_3 = number of harvestable yellow perch at age 3 (age of high vulnerability to commercial fishing gear),

b_{69} = harvestable biomass in pounds in 1969,

p_3 = percent of catch by weight of an age 3 fish (Muth, 1978),

1 pound = 454 gm,

$\bar{w}_3$ = age specific average weight of an age 3 fish in grams.

The effect on the yellow perch stock of entrainment and impingement was simulated over the 50-year life expectancy of the plant with the Leslie matrix. The analysis was carried out in four ways assuming:

1. No plant mortality

2. Entrainment only

3. Impingement only

4. Both entrainment and impingement.

It was assumed that entrained larvae had survived from some greater number of spawned eggs. In order to assess the estimates of entrained eggs it was necessary to backcalculate to the number of potentially spawned eggs (age 0) required to produce the entrained larvae (Stone and Webster, 1978). It was shown that yellow perch larvae reach the juvenile stage 52 days after spawning (Mansueti, 1964), so the assumption was made that larvae older than 52 days could not fit through the 3/8 inch mesh screen of the power plant. All juveniles entrained throughout the year are assumed to be 52 days old (t in equation (23)). Stone and Webster (1979) provided a negative exponential function with a daily loss rate, d, equal to .02 to estimate the potential number of spawned eggs (N_0):

$$N_0 = N_t e^{dt} \tag{23}$$

where

N_t = total annual number of larvae (age 52 days) that managers of the power plant reported entrained,

N_0 = total annual number of eggs (age 0) from which the entrained larvae came,

d = daily entrainment loss rate,

t = time in days.

The entrainment and impingement mortality figures were supplied by Consumers Power of Michigan (Wapora, Inc., 1979).

Lastly, the effects of changes in the growth rate, λ, were estimated by a sensitivity analysis, given the following assumed changes in survivorship values of the Leslie model A matrix:

1. Age 0 survival was increased ten times its normal value, while the survivorship of age classes 1 to 6 remained at their original values.
2. The survival rates of age classes 1 to 6 were increased to 100 percent survival separately while age class 0 remained at its original survivorship value.

This analysis indicates which age classes are most sensitive to changes in survivorship. All changes in survivorship were arbitrarily chosen to test the system's response.

3. Price and Demand Equations for the J. R. Whiting Plant Site

Data Collection

Interviewers sampled angling at the J. R. Whiting plant site in conjunction with sampling in area 4. They collected and recorded data on a special questionnaire (Appendix E) concerning origin-destination patterns, angling catch and effort, and travel and other costs to anglers who visited the plant site. A more detailed discussion of how the data is employed can be found in Appendix H.

Price and Demand Equations

The price and demand equations used in this study are similar in functional form to those estimated for an inland lake study of boating and angling in Michigan (Talhelm, 1976), and similar to those developed from a general theory of supply and demand for outdoor recreation (Talhelm, 1978).

Price equations were developed to express angler travel costs as a function of travel time and distance (mileage) to the site.[1] Costs attributable to fishing include: 1) the estimated value of time and, 2) expenditures on travel, equipment, fees and lodging. The functional form for the price equation is:

$$P = c+b_1T+b_2\ln(T+1) \tag{24}$$

where

P = price in dollars per angler day

$c_1b_1b_2$ = constants

T = one-way travel time

ln = natural logarithm

Separate price equations were derived for Periods I, II, and III respectively.

The Whiting Plant site was considered a separate area, so catch and effort (angler days) were estimated separately from areas 1, 2, 3, and 4. Angler days and catch were calculated using the same statistical procedure described previously (Cochran, 1977).

The information required for estimating demand functions is: 1) the number of angler days use at the plant site from each origin and, 2) the corresponding minimum (supply) prices of angling at the plant site from every origin. The demand analysis in this study consisted of a single-site model for estimating the all-or-none value of this particular plant site. I assume that only one "product" or kind of angling was

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[1]All of the individuals who were interviewed had traveled to the Whiting Plant site solely for the purpose of fishing.

available at the plant site: moderate catch rate of non-salmonid fish (some of the species include white bass, catfish, and carp) at the plant discharge channel and plume. Given the information from every origin concerning the prices and quantities of use of the plant site product, demand equations were estimated. Each demand function can be described by the following general functional form:

$$Q = b_0 + b_1 P + b_2/P \tag{25}$$

where

Q = number of visits per 1000 capita at the plant site for non-salmonid fishing,

P = minimum available price of non-salmonid fishing,

b_0, b_1, b_2 = constants.

The demand equation was estimated using ordinary least squares regression. Separate demand equations were derived for Periods I, II, and III respectively.

IV. RESULTS AND DISCUSSION

1. Roving Creel Survey

It was imperative that reliable catch and effort estimates be derived from this creel survey. These estimates, the Michigan Department of Natural Resources (MDNR) catch and effort estimates, and the commercial catch and effort data were utilized to estimate the parameters of two surplus production models (commercial and sport).[2] The commercial and sport surplus production models were used to estimate the yellow perch population size (numbers) in the Michigan waters of Lake Erie.

Based on a mail survey of anglers, the 1976 "Michigan Great Lake Yellow Perch Survey," the MDNR estimated yellow perch sport catch and effort for the Michigan waters of Lake Erie.[3] Slightly less than 95 percent of the Lake Erie yellow perch catch and 85 percent of the effort was in Monroe County (the remaining was in Wayne County). Comparing the results of the MDNR's Monroe County catch and effort estimates with those of this roving creel survey it appears that either the MDNR is overestimating both catch and effort by a factor of about 4, or my creel survey is underestimating catch and effort by the same amount.

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[2]See Appendix F for catch and effort of other species caught in Monroe County.

[3]Michigan Department of Natural Resources, Office of Surveys and Statistics, "Michigan Great Lake Yellow Perch Survey," 1976. (unpublished).

The estimated yellow perch annual sport catch (numbers) and effort (angler days) from my survey were 509,001 and 29,411 respectively (Table 2).[4] The estimated annual yellow perch catch and effort from the 1976 MDNR survey were 1,865,990 and 129,960 respectively. I compared the catch and effort estimates of my survey to the 1976 MDNR survey because the MDNR 1976 survey estimates of yellow perch sport catch and effort are the only estimates pertaining solely to Lake Erie yellow perch. The regular MDNR "Michigan Sport Fishing Survey" estimates of Lake Erie yellow perch sport catch and effort (Table 3) also include the effort of salmonid, non-salmonid, and stream anglers. The number of salmonid and stream anglers is minimal. The catch and effort data in Table 3 also include Wayne and Monroe counties together. However, I will assume that all catch and effort in this table are from Monroe County, since the MDNR 1976 survey indicated approximately 95 percent of the catch was in this county. Jamsen (1979) indicated that the MDNR 1976 survey can be effectively compared with my creel survey catch and effort data.[5]

The MDNR catch and effort totals for Monroe County (Table 3) were applied in this study to estimate sport harvestable yellow perch numbers (N_{77}) for the year 1977 (Equation 19).[6] Rybicki and Keller (1978)

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[4]Yellow perch comprised over 95 percent of the total catch in Monroe County. This percentage excludes fish caught at power plant sites.

[5]Jamsen (1979) recently reported that 1978 yellow perch catch and effort data are slightly higher than previous years. However, he stated there has been little variation in catch and effort since 1970.

[6]B_t and N_t may be substituted for one another.

Table 2. Yellow Perch Sport Catch and Effort Estimates from the Roving Creel Survey in Monroe County from February 1978 to January 1979.

Period	Catch or Effort	$Y \pm t_{.975,df}SE$[1]
I:	Angling Hours	57,358 ± 14,568
	Angling Days	14,906 ± 4,192
	Pounds	27,253 ± 13,197
	Numbers	154,027 ± 81,824
II:	Angling Hours	21,807 ± 3,524
	Angling Days	5,273 ± 862
	Pounds	8,800 ± 2,387
	Numbers	39,302 ± 11,748
III:	Angling Hours	41,064 ± 9,452
	Angling Days	9,232 ± 2,060
	Pounds	63,009 ± 19,995
	Numbers	315,672 ± 102,349

[1]The degrees of freedom (df) for Periods I, II, and III were 3, 56, and 27 respectively. In Period I, the majority of the yellow perch were caught during the short ice fishing season; consequently, the degrees of freedom are low.

Table 3. Yellow Perch Sport Fisheries Data Reported for Michigan Waters of Western Lake Erie.[1]

Year	Estimates: Total Catch (numbers)	Estimates: Effective Effort (angler days)
1970	2,013,520	136,650
1971	2,542,060	295,140
1972	1,563,150	214,540
1973	1,780,560	203,220
1974	2,719,980	401,940
1975	2,243,490	416,840
1976	1,874,240	372,800
1977	2,342,067	443,555

[1]Catch and effort for 1974 are projected figures (G. Jamsen, MDNR personal communication). Remaining catch and effort reported by the Department of Natural Resources, Lansing, Michigan.

showed that the MDNR overestimated lake trout catch by a factor of 5, so my creel survey results apparently indicated that the MDNR is overestimating the catch and effort of yellow perch in Monroe County by a factor of 4. Consequently, I compensated for the apparent overestimation when I calculated the harvestable population numbers, N_{77}. After calculating N_{77} (Equation 19) using the catch and effort in Table 3, I multiplied N_{77} times .273 giving n_{77}, since the roving creel survey catch estimate was .273 of the MDNR 1976 survey figure. Only one year of data from the roving creel survey is available for comparison with the MDNR catch and effort data. Consequently, an adjusted harvestable population number was assumed to lie halfway between the upper and lower limits of N_{77} and n_{77} respectively. The adjusted harvestable population number was calculated as:

$$\bar{N}_{77} = \frac{N_{77} + n_{77}}{2} \tag{26}$$

where

$\bar{N}_{77}$ = adjusted sport yellow perch harvestable population number. This number is reported in the next section.

The adjusted sport yellow perch harvestable population number will be used to estimate the sport yellow perch population size by age class (next section). The effects of impingement and entrainment on the population would be less if N_{77} were substituted since a larger population size estimate would result. Substituting n_{77} would decrease the population size estimate somewhat but the effects from impingement and entrainment on this population would still be minimal.

2. Surplus Production and Leslie Matrix Models and Sensitivity Analysis

Surplus Production

To calculate the estimates of yellow perch commercially harvestable biomass, commercial catch and effort data for the years 1960 to 1969 were utilized (Table 4). Sport catch and effort estimates for the years 1970 to 1977 provided the necessary input for estimating recreationally harvestable numbers (Table 3).

Table 5 contains a list of parameter estimates of equation (7) for the yellow perch commercial and sport fisheries. The most recent harvestable commercial biomass estimate (B_{69}) and harvestable sport numbers estimate ($\bar{N}_{77}$) are 354,968 pounds (Equation 19) and 1,680,430 fish (Equations 19 and 26) respectively.

By substituting into equation (22) the commercially harvestable biomass of 354,968 pounds, 61.3 percent of the catch by weight of age class 3 fish (Muth, 1978), and the age specific average weight of 117 gm (life table), the numbers of age class 3 fish were estimated to be approximately 844,345 (equivalent to n_3 in Figure 6). This is the first age class to become highly susceptible to commercial fishing.

Yellow perch become highly vulnerable to sport fishing at age class 2. Age class 2 yellow perch constitute about 50 percent of the sport catch. Multiplying the harvestable sport numbers estimate ($\bar{N}_{77}$) by .5 gives an estimate of age class 2 fish of 840,215 (n_2 in Figure 6).

As mentioned in Chapter III, page 50, once n_2 of the sport model and n_3 of the commercial model are calculated, these estimates are then multiplied or divided by the survivorship values of the respective models.

Table 4. Yellow Perch Commercial Fisheries Data Reported for Michigan Waters of Western Lake Erie.[1]

Year	Total Catch (pounds)	Trapnet Effort[2]
1960	117,858	3,274
1961	103,600	4,000
1962	96,875	2,735
1963	89,701	2,516
1964	36,751	2,248
1965	68,997	2,271
1966	136,748	2,664
1967	112,177	2,020
1968	172,929	2,012
1969	111,815	1,750

[1] Catch and effort data provided by the National Marine Fisheries Service, Ann Arbor, Michigan.

[2] One lift of a trapnet is 1 unit of effort.

Table 5. Estimates of the Parameters k, K, and q for the Commercial and Sport Surplus Production Models.

Fishery	k	K	q
Commercial	.55	1,400,000(pounds)	$.18 \times 10^{-3}$
Sport	2.10	4,406,625(numbers)	$.20 \times 10^{-5}$

The initial population, N_0 (Table 6), was determined by adding together the number of fish of identical age classes from both the sport and commercial models.

The stock production equations for the commercial and sport fisheries are:

Commercial fishery: $$Y = 252.0E - .082E^2 \quad (27)$$

Sport fishery: $$Y = 8.81E - .00000839E^2 \quad (28)$$

The commercial and sport stock production curves in Figures 7 and 8 respectively have yield plotted as a function of effort. The mean short run yield curve of the commercial fishery intersects the equilibrium curve (parabola) to the right of the maximum sustained yield level (apex of the parabola) which indicates the stock is overexploited. The sport fishery seems slightly underexploited since the mean short run yield curve interests the equilibrium curve to the left of MSY. The parameter values of the commercial and sport surplus production models (Table 5) were used to calculate predicted yields. See Appendix B for a graph showing a plot of observed yields and predicted yields.

Leslie Matrix

The effects of impingement and entrainment on the yellow perch population were simulated for a 50-year period with the Leslie matrix. This was accomplished by assuming respectively:

1. no impingement and entrainment mortality from the plant (Table 7),
2. only entrainment (Tables 8 and 9),
3. only impingement (Tables 8 and 9),

Table 6. Yellow Perch Population Estimate in the Michigan Waters of the Western Basin of Lake Erie by Age.

Age	Survival	Population[1]
0	.01175	10,600,000,000
1	.08572	125,000,000
2	.08572	11,000,000
3	.17499	916,000
4	.25872	160,000
5	.33132	41,000
6	0	14,000

[1]Numbers quoted were rounded to three significant figures.

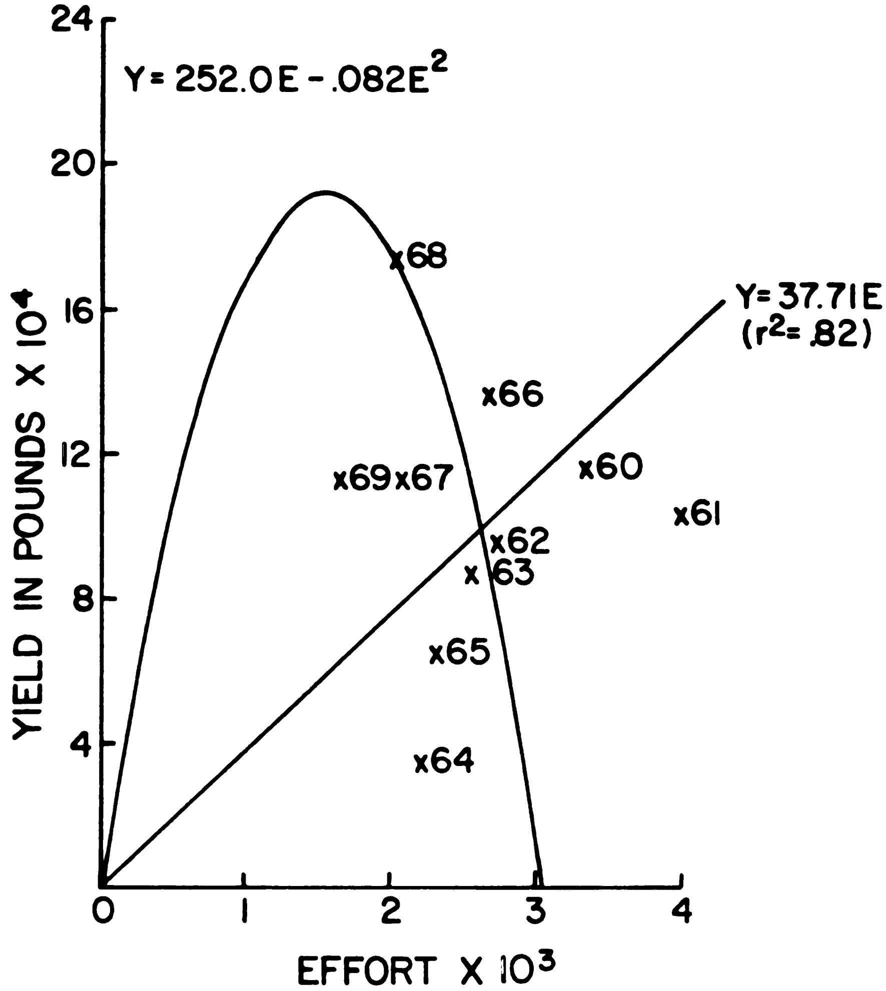

Figure 7. Estimated equilibrium yield and effort relation (parabola), and regression of yield on effort (solid line). The points are observed yield and effort values from 1960 to 1969 for the commercial fishery.

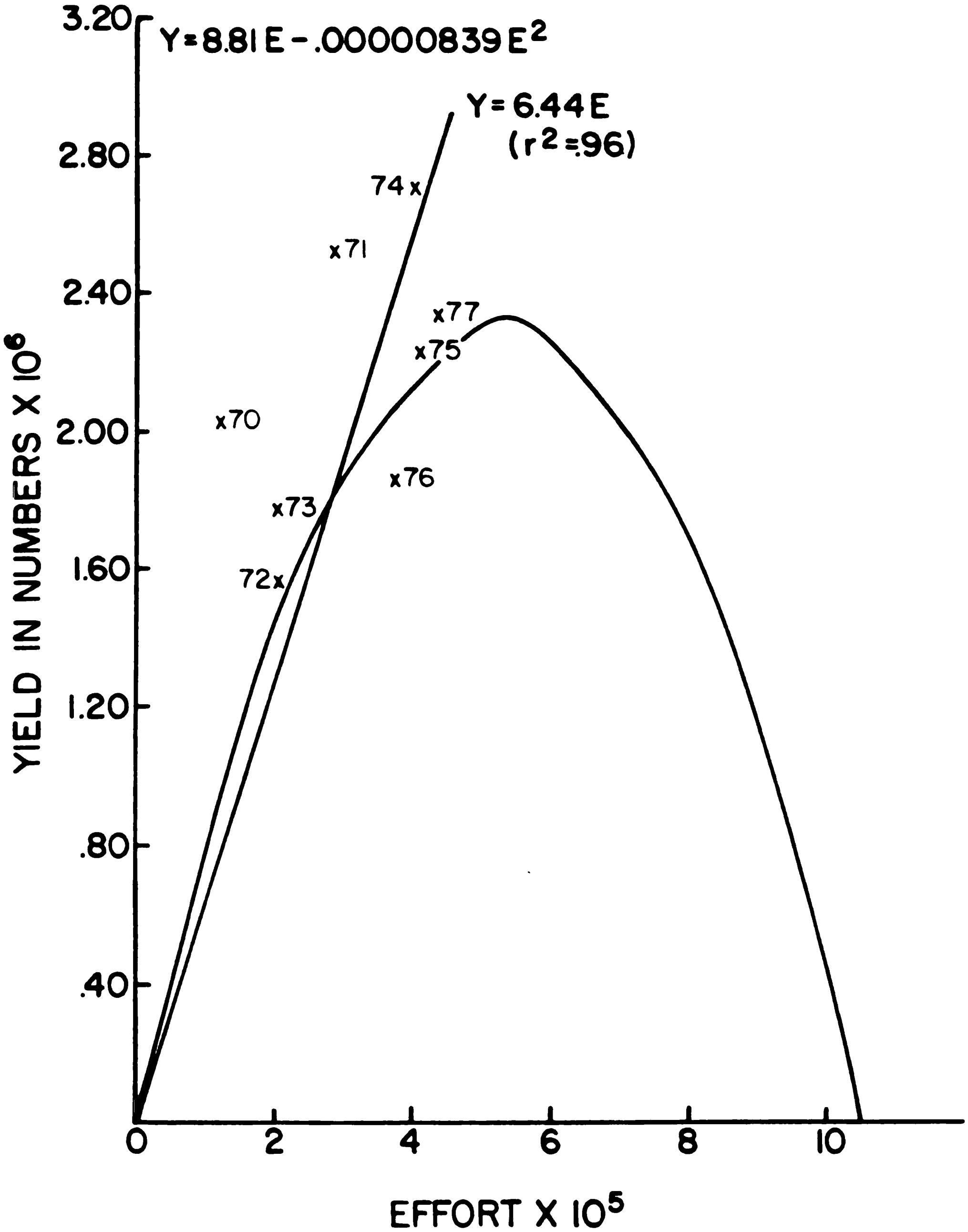

Figure 8. Estimated equilibrium yield and effort relation (parabola), and regression of yield on effort (solid line). The points are the observed yield and effort values from 1970 to 1977 for the sport fishery.

Table 7. The $\underline{A}$ Matrix with Survivorship and Fecundity Estimates of the Existing Natural Population and Initial Population by Age Class.

$$\underline{A} = \begin{bmatrix} 0 & 0 & 0 & 8629 & 11743 & 14129 & 16096 \\ .01175 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & .08572 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & .08572 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & .17499 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & .25872 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & .33132 & 0 \end{bmatrix}$$

Initial population as a column vector N_o

$$N_o = \begin{bmatrix} 10,600,000,000 \\ 125,000,000 \\ 11,000,000 \\ 916,000 \\ 160,000 \\ 41,000 \\ 14,000 \end{bmatrix}$$

Table 8. Number of Yellow Perch Impinged and Entrained by Age at the J. R. Whiting Plant from March, 1978 to February, 1979.

Type of Mortality	Age	Total[1]	Annual Mortality[2]
Entrainment	0	4,840,000	.00046
Impingement	1	52,489	.00042
Impingement	2	59,189	.00538

[1]Wapora, Inc., 1979.

[2]Annual mortality is calculated by dividing the number of fish entrained or impinged in a particular age class by the estimated number of fish in that age class (Table 6). For example, the calculation of entrained fish at age 0 is:

$$\text{Annual mortality} = \frac{4{,}840{,}000}{10{,}600{,}000{,}000} = .00046$$

Table 9. Fifty-Year Simulated Loss to the Yellow Perch Population in the Michigan Waters of Lake Erie.

Type of Mortality	Estimates of Percentage Loss per Year
Impingement	1.6
Entrainment	.4
Impingement and Entrainment	1.7

4. both entrainment and impingement (Table 9).

Impingement and entrainment reduce the yellow perch population by a small percentage annually. This can be represented by what is known as a "harvest matrix" (Appendix J). Age classes 0, 1, and 2 are harvested (from impingement and entrainment) each year, t. The number of fish in each age class at the start of the next year, t + 1, will therefore be reduced accordingly. If p_j represents the percentage of the j^{th} age class that is harvested during year, t, where $0 \leq p_j \leq 1$, then $(1-p_j)$ will be the percentage of the j^{th} age class that is left. The effect of impingement and entrainment was simulated by multiplying the harvest matrix by the Leslie $\underline{A}$ projection matrix where p_j = the annual impingement and entrainment mortality rates for age class j (Table 8). The population was at equilibrium (λ = 1.0) before harvesting began. After harvesting, the combined effects of impingement and entrainment reduced the whole yellow perch population (all age classes combined) by 1.7 percent per year (Table 9; Appendix J). The assumption was made that the population was in a steady state before harvesting was initiated. Therefore each age class separately was assumed to be reduced by 1.7 percent per year. Stone and Webster (1978, 1979) stated that the fisheries yield will be reduced by the same proportion (1.7 percent per year) as the whole population, assuming a steady state population and no change in fishing strategy.

The economic loss from the J. R. Whiting plant was computed under these assumptions:

1. The maximum mortality loss from impingement and entrainment will probably result in an annual 1.7 percent reduction

in the yellow perch catch during the 50 years of plant operation.

2. The dockside value of yellow perch (in the round) is $1.50/pound although selling it without a license is illegal (N. Fogle, 1979, and the Bay Port Fish Company, personal communication). Since 1970 yellow perch commercial fishing has been prohibited in Lake Erie; therefore, only the economic loss to the yellow perch sport catch from impingement and entrainment is estimated. It appears that the sport fishery will continue to predominate in Lake Erie in the future. A more detailed economic analysis, outside the scope of this dissertation, will estimate a more accurate change in economic value of the yellow perch sport fishery resulting from impingement and entrainment. Therefore, $1.50/pound, a gross value, should be considered a provisional figure at this time.

The average sport catch of yellow perch from 1970 to 1977 was approximately 2.1 million fish/year. The average weight/fish of yellow perch caught by anglers was .2 pounds (creel survey estimate) resulting in an average weight of yellow perch caught/year of 420,000 pounds. The impingement and entrainment mortality loss from the plant was 1.7 percent/year. A 1.7 percent loss/year in catch would be 7,140 pounds/year and an economic loss of $10,710/year or $535,500 at the end of 50 years of plant operation assuming $1.50/pound for yellow perch.

The Leslie matrix, a population simulation model, is density-independent and suitable for this study because insufficient information was available to incorporate density-dependent or compensatory mechanisms. Compensatory mechanisms could increase egg and larval survival. If compensatory mechanisms are operating in this population then these population reduction estimates should be considered an upper limit of power plant impact (Stone and Webster, Inc., 1978).

Sensitivity Analysis

A sensitivity analysis utilizing the Leslie matrix model tested the effect of changes in the elements of the $\underline{A}$ matrix (survival rates) upon the population growth rate. Table 7 lists the survivorship values of the original yellow perch population along the subdiagonal of the $\underline{A}$ matrix by age class. During the sensitivity analysis each age specific survivorship value was increased by a certain value while the remaining age class survivorship values remained at their original values. As a particular age class had its survivorship value incremented by a certain amount (others remained at their original values) the eigenvalue (λ) was estimated and then plotted on the graph (Figure 9). The eigenvalue (λ) for each of the six age classes was estimated and plotted in this manner. Age 0 survivorship was multipled by 10 times its original value, while the remaining age classes were increased to 100 percent survival. These incremental values were arbitrarily chosen to test the response of the system. The original population, without any incremental changes, had an eigenvalue (λ) or growth rate of 1.0. When S_0 was increased 10 times its original value and the other age classes

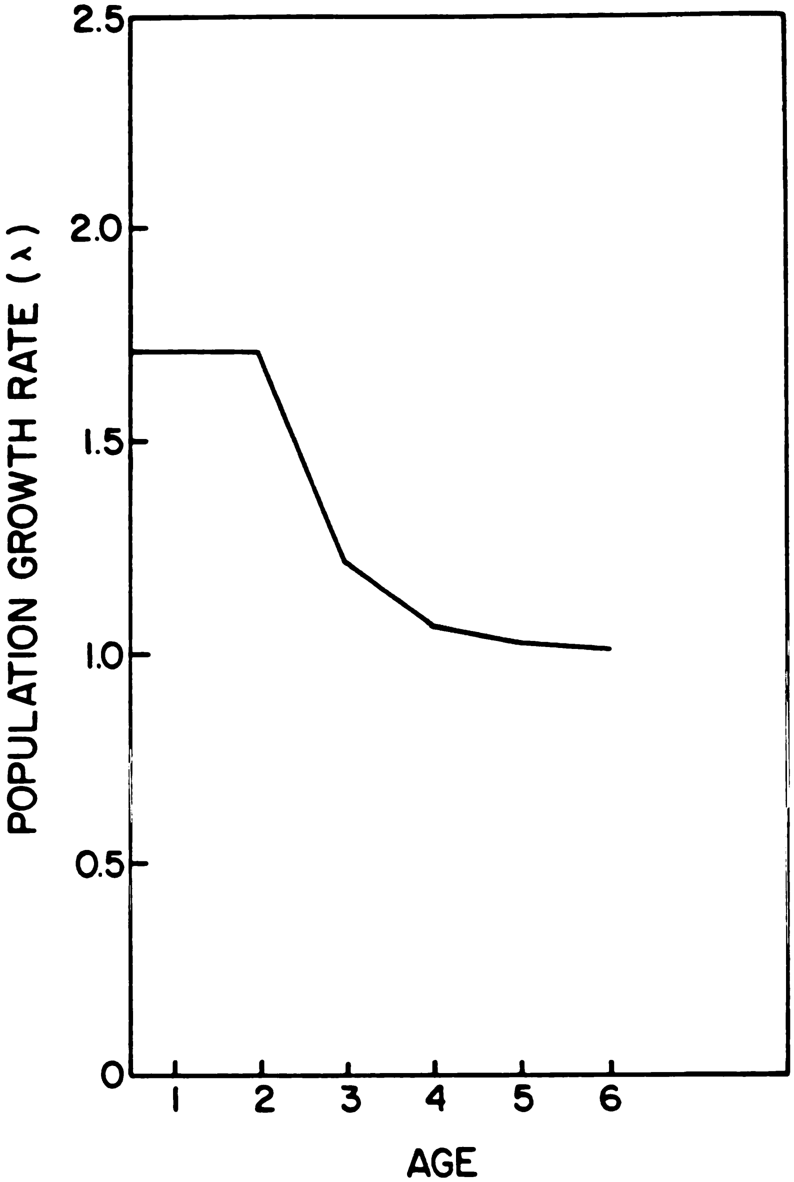

Figure 9. New growth rate of Lake Erie yellow perch for each respective change in survivorship within each age class.

remained constant the eigenvalue (λ) jumped to 1.7. This represents an increase of 70 percent. S_0, S_1, and S_2 (pre-reproductive years) showed the greatest sensitivity to changes in growth rate in response to survivorship changes (70 percent increase from 1.0 to 1.7). Fishery biologists consider the critical period for success of a year class to be early in the fishes' life; it appears that the sensitivity analysis agrees with this assumption.

3. Price Equations, Demand Analysis, and Consumer Surplus

Price Equations

A price equation for angling at the plant was derived for each period.[7] These equations are graphically represented in Figures 10, 11, and 12. The specific price equation coefficients (Table 10) were derived from the ordinary least squares regression analyses of equation (24). The price of angling from every population origin will be incorporated into equation (25) to estimate the demand equation for the plant product for each period (see next section).

Demand Analysis

The demand for angling at the J. R. Whiting plant site for each period is shown in Figure 13. The demand equations are:

$$\text{Period I:}\quad Q = \underset{(4.88)}{-11.59} + \underset{(.05)}{.11P} + \underset{(104.99)}{304.53/P}$$

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[7] All species caught at the plant site were considered non-salmonid fish. See Appendix G.

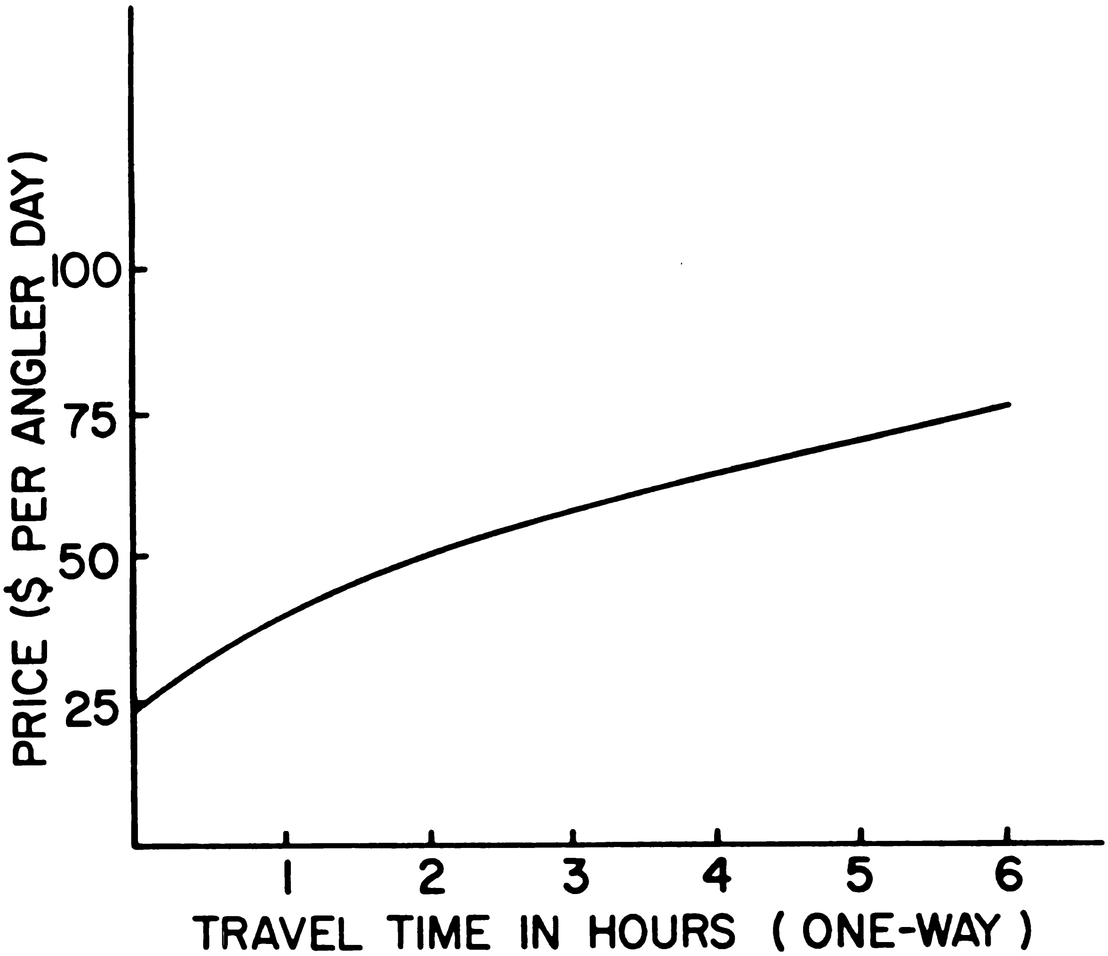

Figure 10. Price curve, Period I, showing the user cost of angling as related to travel time to the J. R. Whiting plant site.

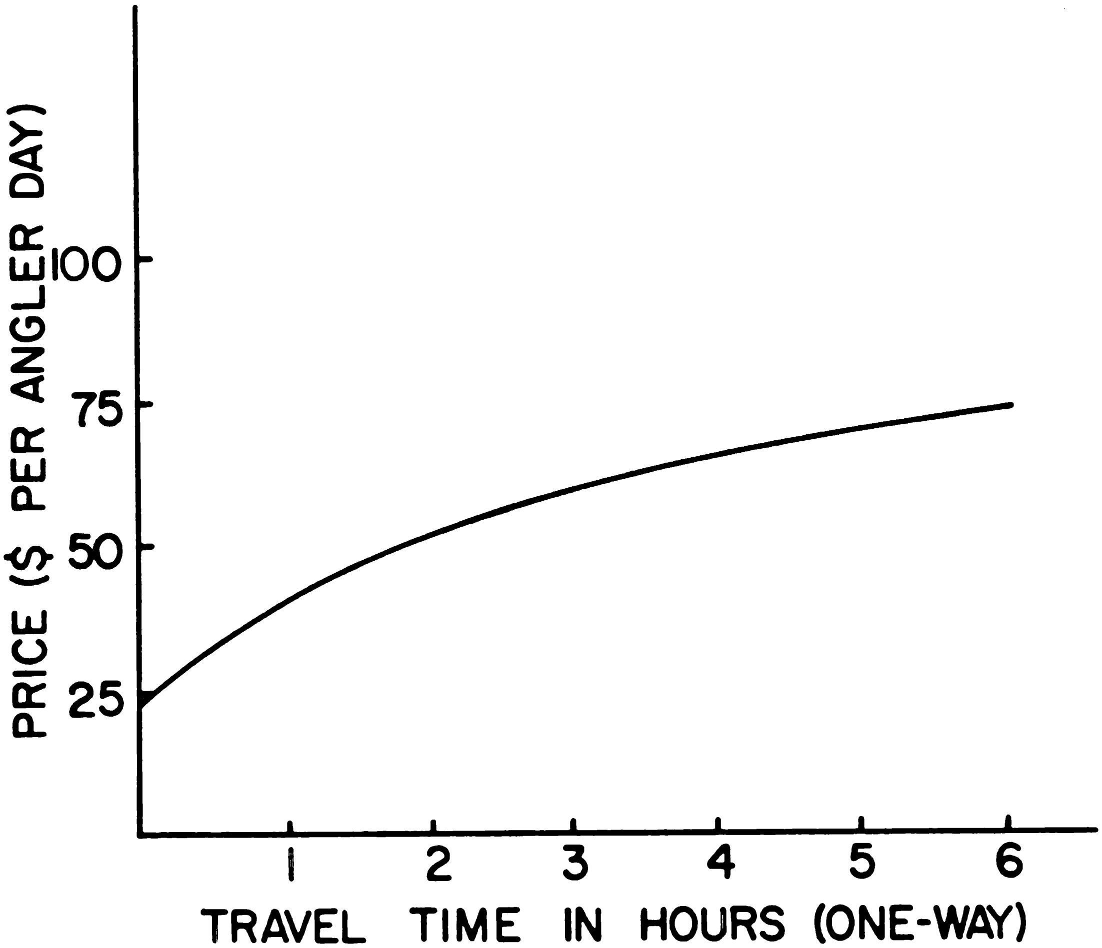

Figure 11. Price curve, Period II, showing the user cost of angling as related to travel time to the J. R. Whiting plant site.

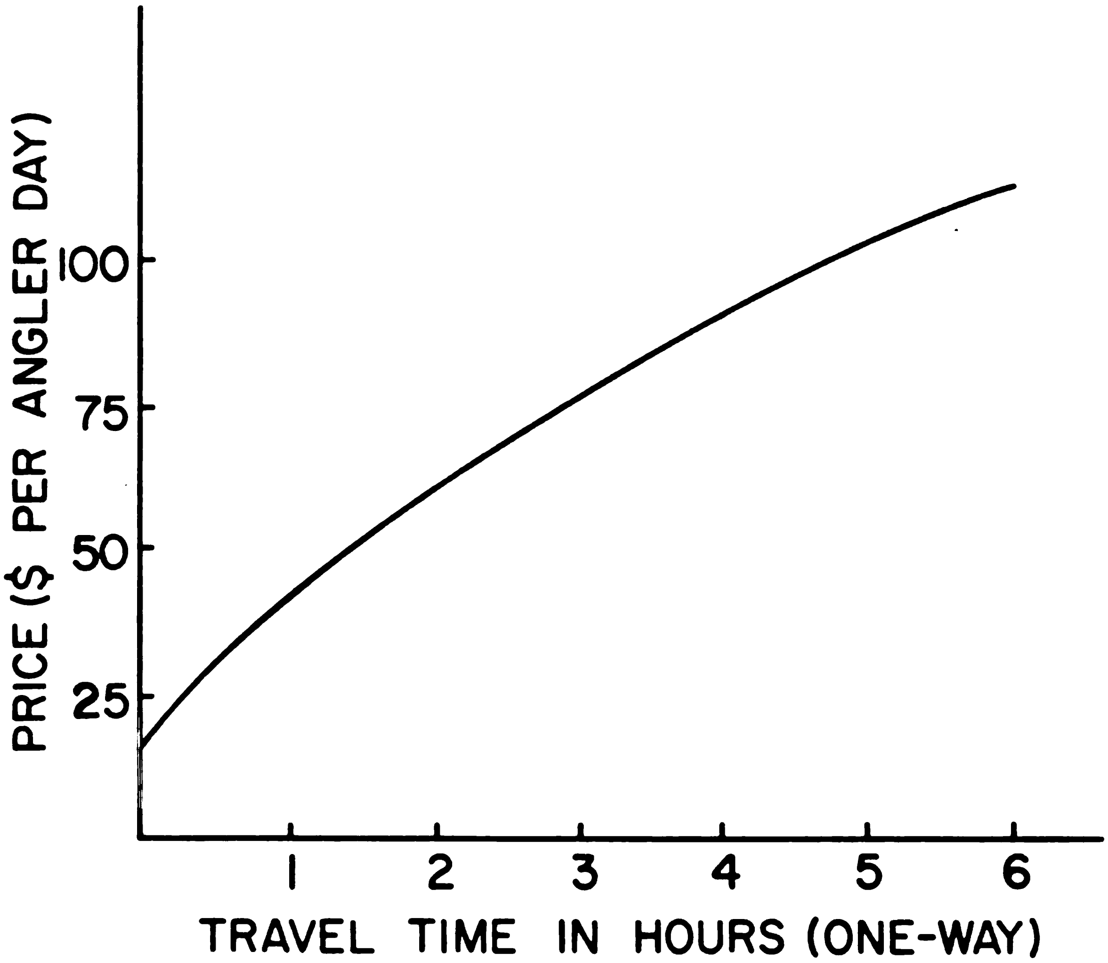

Figure 12. Price curve, Period III, showing the user cost of angling as related to travel time to the J. R. Whiting plant site.

Table 10. Price Equation Coefficients for Fishing at the J. R. Whiting Plant Site from February, 1978 to January, 1979.

				Statistics[1,2]	
Period	C	T	ln(T+1)	R^2	DW
I	24.79	1.80	19.39	.18	1.7
II	24.12	-.57	26.66	.04	1.9
III	18.67	6.85	26.52	.26	2.0

[1]The t and F tests for the price equation coefficients were significant at the 95 percent confidence level, except that the t-test for the T coefficients was not significant. C is a constant and T is one-way travel time.

[2]Maddala (1977) describes the Durbin-Watson statistic.

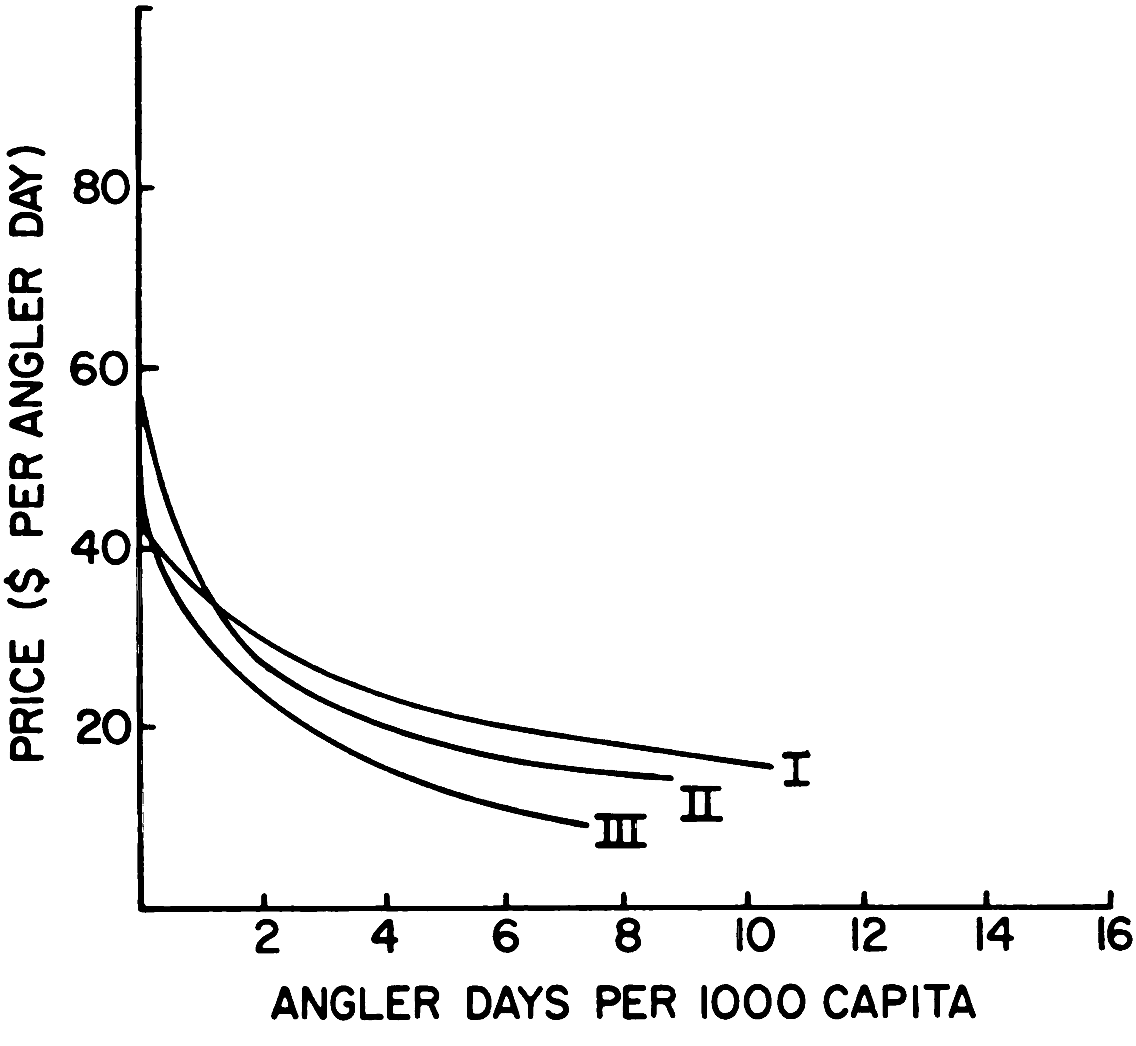

Figure 13. Demand curves for non-salmonid fishing at the J. R. Whiting plant site during Periods I, II, and III.

$$DW = 2.8$$

$$R^2 = .71$$

Period II: $$Q = -4.84 + .04P + 156.08/P$$
$$\quad (2.70) \quad (.03) \quad (56.21)$$

$$DW = 3.3$$

$$R^2 = .77$$

Period III: $$Q = -3.10 + .02P + 103.24/P$$
$$\quad (1.66) \quad (.01) \quad (36.99)$$

$$DW = 2.7$$

$$R^2 = .76$$

The t-test was significant at the 90% confidence level for all demand equation coefficients except for Period II; the second coefficient was significant at the 70% confidence level. The F-test for all demand equations was significant at the 95% confidence level. Secondly, in Periods I, II, and III the Durbin-Watson statistic was slightly high, indicating autocorrelation. It is possible that several variables could have been included or omitted in the demand analysis. In the future a slightly different structural form of demand equation (25) may be needed for demand analyses at power plant sites.

Consumer Surplus

Given the demand schedule for each period the consumer surplus (all-or-none value or total social value) of the non-salmonid fishery at the plant site was calculated. Consumer surplus is the maximum amount of money all the anglers together would pay to keep the plant site in existence for angling, rather than give it up entirely. Geometrically the consumer surplus is equivalent to the entire area under the demand curve and above the price at which the supply curve intersects the demand curve. Each population origin has a different supply curve. Total consumer surplus can be derived by summing all the individual areas left from the intersection of the supply curves from each origin. The total value of the plant site was estimated to be approximately $30,900 per year or $1,545,000 after 50 years of plant operation. This value, however, is never found in a real market situation since only a monopolist could acquire this amount by collecting every increment of payment as prices increased to their maximum. In the final analysis the most revenue a real owner of this non-salmonid fishery could recover from anglers is probably one-quarter of the consumer surplus; this value minus administrative costs would be the market value of this fishery (Talhelm, 1973b). It appears that the economic loss to the yellow perch fishery could possibly range from $357,000 to $1,428,000 (one to four dollars per pound) as compared to the non-salmonid marketable value of $386,000 (one-quarter total social value) after 50 years of plant operation. Given the present dockside value of $1.50/pound the economic loss is assessed to be $535,500. However, the all-or-none-value or total social value of $1,545,000 indicates that all the anglers together would be willing to pay this maximum amount of money rather than not have the plant site as a sport fishery resource. The public's interest (anglers) apparently would be best served by the existence of the plant since the total social value of $1,545,000 is more than the economic loss of $535,500 from impingement and entrainment. However, in the marketplace, and as far as Consumers Power is concerned, the economic loss of the fishery from the plant outweighs its economic benefits.

V. CONCLUDING OBSERVATIONS

This study attempted to analyze the positive and negative effects of impingement and entrainment at the J. R. Whiting power plant on the commercial and sport fisheries in the Monroe County, Michigan area of Lake Erie. During the projected 50-year life of the plant, the economic losses (negative effect of impingement and entrainment) would seem to outweigh the positive economic benefits of the plant site for angling in the marketplace, but not in total social value.

The most significant findings were that impingement of adult yellow perch had a greater effect on future adult populations than did entrainment of eggs or larvae, and that anglers were willing to pay a maximum of $1.5 million (during the life expectancy of the plant) to keep the plant site in existence for angling. The major obstacle was that no compensatory mechanisms were simulated. These mechanisms may involve increases in egg and larval production which could in turn increase the yellow perch population size. Therefore, the power plant population mortality estimates should be considered an upper limit of power plant impact.

Most fish populations exhibit some variation in their natural survivorship rates. In order to strengthen the results of the Leslie matrix model, I recommend that future impingement and entrainment studies incorporate stochastic variation of age-specific survivorship rates into the $\underline{A}$ projection matrix. Age 0, 1, and 2 yellow perch are most affected by impingement and entrainment in the Michigan waters of Lake Erie. The mean yellow perch survivorship of age classes 1 and 2 can be estimated from at least 2 or 3 years of mark-and-recapture field data in the Monroe County area. Age 0 fish can be subdivided into several different life stages beginning with eggs and then proceeding through the various juvenile stages. Larval density in a column of water is monitored in the field by high-speed samplers. Subsequently, the mean survivorship is estimated for each juvenile life stage covering at least a 2- or 3-year period. The variance in age-specific mean survivorship for age 0, 1, and 2 yellow perch is estimated and introduced into the Leslie matrix model utilizing a table of random numbers which contains boundary conditions for the variance. Numerous simulations of the stochastic version of the Leslie matrix provide a range of population sizes, and consequently a range in the annual percentage reduction of the yellow perch population size from impingement and entrainment.

Harvestable biomass or numbers was estimated in this study utilizing the surplus production model. A single yellow perch stock was assumed to inhabit the Michigan waters of Lake Erie. A more complete assessment of harvestable biomass or numbers would test the validity of this assumption. If a number of different stocks are prevalent the surplus production model could be applied separately to these stocks, and a more realistic estimate of harvestable biomass or numbers might result. Tagging studies could provide insight into the migratory patterns of the yellow perch, and therefore the number of stocks in an area. In conjunction with tagging studies electrophoretic techniques could be employed to analyze the blood groups of the different stocks and to help verify the existence of different stocks. Populations within a species often differ from one another in the gene concentration of these blood groups. Differentiation of populations by the frequencies of individual genes enable investigators to analyze the species structure and to detect intraspecific groups. Hopefully, a more concise estimate of the harvestable biomass of all the yellow perch stocks would become available.

In previous studies Talhelm (1973b, 1976) found considerable variation about price equation (24) which was employed in my economic analysis. Sources of variation include differences in wage rates, supplies and equipment, lodging choices, length of stay, and errors in measuring travel distance or time. Talhelm found that only about 20 percent of the variation was attributable to travel time. Similar results were obtained in my study. The greatest cost item in producing recreation trips is the opportunity cost of time for travel and participation.

Although the J. R. Whiting plant in isolation from other plants seems to provide some economic benefit to the Monroe County area, a few perplexing questions remain unanswered:

1. Are there any additive mortality effects from impingement and entrainment induced by other power plants in the area on the yellow perch stock studied in this report?
2. What effect does impingement and entrainment have on the prey and predators of yellow perch?
3. Are impingement and entrainment the only adverse effects of the plant on yellow perch?

It is hoped that future researchers will answer these vital questions.

APPENDICES

APPENDIX A

GENERAL CREEL SURVEY QUESTIONNAIRE

APPENDIX A

GENERAL SURVEY

Interviewer:____________________ Area Number _______ Date ___ ___/___

1 2 3 4

1 = Yellow Perch	6 = Largemouth bass	11 = Pike	16 = Suckers
2 - White bass	7 = Smallmouth bass	12 = Trout	17 = Panfish
3 = Freshwater Drum (Sheepshead)	8 = Chinook salmon	13 = Bullheads	18 = Other
4 = Walleye	9 = Coho salmon	14 = Catfish	0 = non-boat - type of
5 = Rock bass	10 = Salmon	15 = Carp	1 = boat - fishermen

PERSON		#1	#2	#3	#4	#5	#6
TIME		6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9
Traverse Number		10	10	10	10	10	10
Type of Fishermen		11	11	11	11	11	11
No. Licensed Fishermen		12 13	12 13	12 13	12 13	12 13	12 13
No. Unlicensed Fishermen		14 15	14 15	14 15	14 15	14 15	14 15
No. Fishermen Skipped		16 17	16 17	16 17	16 17	16 17	16 17
Tot. No. Hrs. Fishing so far on this site		18 19	18 19	18 19	18 19	18 19	18 19
Tot. No. Hrs. you plan to fish on this site		20 21	20 21	20 21	20 21	20 21	20 21
Tot. No. and Tot. wt. of each species caught on this site	SP	22 23	22 23	22 23	22 23	22 23	22 23
	WT	24 25 26	24 25 26	24 25 26	24 25 26	24 25 26	24 25 26
	NO	27 28 29	27 28 29	27 28 29	27 28 29	27 28 29	27 28 29
Tot. No. and Tot. Wt. of each species caught on this site	SP	30 31	30 31	30 31	30 31	30 31	30 31
	WT	32 33 34	32 33 34	32 33 34	32 33 34	32 33 34	32 33 34
	NO	35 36 37	35 36 37	35 36 37	35 36 37	35 36 37	35 36 37
Tot. No. and Tot. Wt. of each species caught on this site	SP	38 39	38 39	38 39	38 39	38 39	38 39
	WT	40 41 42	40 41 42	40 41 42	40 41 42	40 41 42	40 41 42
	NO	43 44 45	43 44 45	43 44 45	43 44 45	43 44 45	43 44 45

APPENDIX B

PARAMETER ESTIMATION OF THE SURPLUS PRODUCTION MODEL, AND A PLOT OF OBSERVED YIELDS VERSUS PREDICTED YIELDS

APPENDIX B

Jensen (1976) estimated the parameters of the surplus production model by nonlinear least squares using the approximation:

$$\hat{Y}(t+1) = qE \int_{t}^{t+1} B\,dt = qE\,\frac{(B(t+1) + B(t))}{2} \tag{29}$$

where

$$B(t) = \left[\frac{k}{B_\infty(k-qE)} + \left[\frac{1}{B_0} - \frac{k}{B_\infty(k-qE)}\right] e^{-(k-qE)t}\right]^{-1} \tag{30}$$

All variables were defined in equations (5) and (6) except B_∞ which equals K, and B_0 which is the initial biomass.

In my analysis initial guesses of the parameters k, B_∞, and q were derived from the Schaefer (1957) method discussed in Chapter III. These initial guesses were substituted into equation (30) to calculate B(t) for all values of t from 1960 to 1969 for the commercial fishery and 1970 to 1977 for the sport fishery. B(t) is calculated and then substituted into equation (29) to estimate yield. The residual sum of squares (RSS) is then calculated: $\Sigma(Y-\hat{Y})^2$. Y is observed yield and $\hat{Y}$ is predicted yield. The RSS is calculated several times with different parameter values of B_∞, q, and k until an approximate minimum RSS is found.

A simple linear regression involving observed yield and predicted yield was then run:

$$Y = a + b\hat{Y} \tag{31}$$

Ideally it is hoped that the observed and predicted yields are identical (R^2=1). In my study the commercial and sport R-squared values equaled .31 and .74 respectively. A plot of observed yields versus predicted yields over time for the commercial and sport fisheries is shown in Figures B1 and B2 respectively.

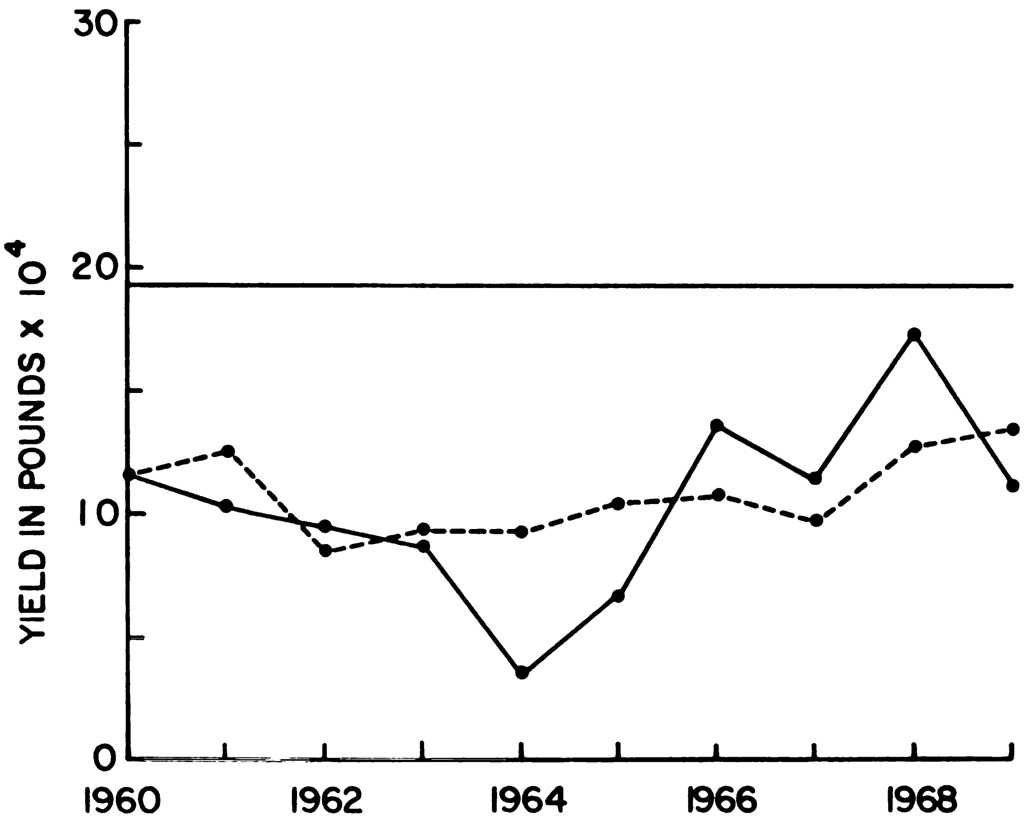

Figure B1. Observed yields (solid line) and yields predicted by the surplus production model (dashed line) for the commercial fishery. The solid horizontal line is MSY.

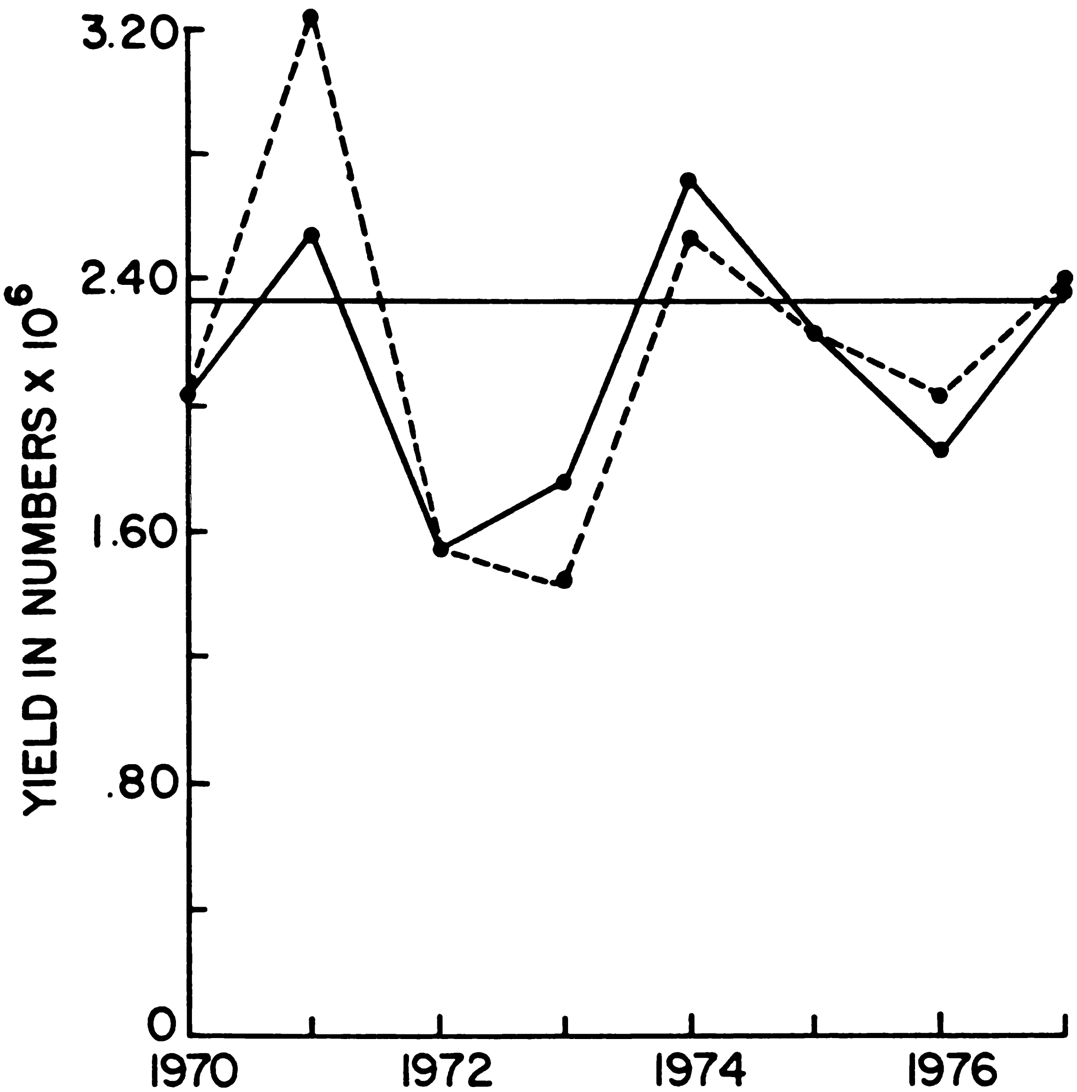

Figure B2. Observed yields (solid line) and yields predicted by the surplus production model (dashed line) for the sport fishery. The solid horizontal line is MSY.

APPENDIX C

DATA SHEET FOR RECORDING BOAT

COUNT INFORMATION

APPENDIX C

BOAT COUNT DATA AND NOTES

Interviewer ____________________ Area Number ____________
1

Date _ _ / _ _
2 3 4 5

Count Number

	#1	#2	#3	#4	#5	#6
Time	_ _ _ _ 6 7 8 9	_ _ _ _ 6 7 8 9	_ _ _ _ 6 7 8 9	_ _ _ _ 6 7 8 9	_ _ _ _ 6 7 8 9	_ _ _ _ 6 7 8 9
Tot. no. Boat Fishmn. at site	_ _ _ _ 10 11 12 13	_ _ _ _ 10 11 12 13	_ _ _ _ 10 11 12 13	_ _ _ _ 10 11 12 13	_ _ _ _ 10 11 12 13	_ _ _ _ 10 11 12 13

	Start	End	Tot. # miles
Mileage	____	____	________

Transects:	Approximate Time Begin	End
1	___	___
2	___	___
3	___	___
4	___	___
5	___	___

Notes:

APPENDIX D

STATISTICAL ANALYSIS OF BOAT FISHERMEN

TOTAL ANGLER DAYS

APPENDIX D

To test the validity of the procedure used for estimating the number of boat fishermen angler days, samples were drawn from a hypothetical boat fishermen population. Actual field data (frequency of angling hours fished, etc.) were employed to assist in the establishment of this hypothetical population of angling activity. Two tests were performed to show that consistent estimates of the average angling hours/fisherman can be obtained by subsampling this hypothetical population. The average angling hours/fisherman was used for estimating the total angler days during a sample day. For both tests assumptions were made that 1) anglers arrive and depart randomly and 2) anglers are concluding their angling day when they return to their access entry points (typical of Monroe anglers).

In test one each fisherman in the hypothetical population was numbered. From a table of random numbers a twenty-five percent sample of the numbered boat fishermen was taken from the hypothetical population, and their angling hours recorded. A t-test was performed to determine whether there was a significant difference between the population and sample mean angling hours of the fishermen. The result showed no significant difference between the population and sample means ($p < .05$). Numerous populations were employed in this procedure. In conclusion, accurate estimates of the average angling hours/fisherman can be obtained from field data.

Test two was based upon the probability of encountering each individual fisherman within the hypothetical population. For example, there is a 2/5 probability of encountering fishermen who stay for 2 hours throughout the day with an angling day length of 15 hours and 3 traverses ($\frac{3 \cdot 2}{15} = \frac{6}{15} = \frac{2}{5}$). Based upon the frequency distribution of angling hours fished by fishermen in Monroe County (from actual data) each member of the population was assigned a particular number of angling hours and consequently a probability of encounter. Based upon these probabilities a table of random numbers was used to determine which fishermen were included in the sample taken from the population. A t-test was again performed to determine if there was a difference between the population and sample means ($p < .05$). Numerous populations were employed in the procedure. The results showed no significant difference between the population and sample means. Therefore, accurate estimates of the mean angling hours/fisherman are attainable in the field.

The sample means of these tests represent $\overline{h}_{ijk}$ in equation (14). Although there was no significant difference between the population and sample means, the sample mean values that were calculated did vary. Consequently, after substituting these different sample means into equation (15) a range of values resulted for the total angler day estimates. This range was up to fifteen percent above or below the actual population number of angler days.

During most of the year at Monroe County the angling day length for boat fishermen was assumed to be one-half hour before sunrise and one-half hour after sunset (same as shore fishermen). There usually was no correction factor involved since very little boat fishing occurred before or after these hours. However, during the major holidays of Memorial, Independence, and Labor Day weekends some fishing occurred beyond the normal angling day length. This augmentation of angling activity during these holidays and several other days of the year was accommodated by increasing the assumed day length used in the calculations.

APPENDIX E

WHITING PLANT SITE QUESTIONNAIRE

APPENDIX E

WHITING PLANT SITE

INTERVIEWER ______________________ Area Number ____ Date ___ ___/ ___ ___

1 2 3 4 5

1 = Yellow perch	6 = Largemouth bass	12 = Trout	16 = Suckers	
2 = White bass	7 = Smallmouth bass	13 = Bullheads	17 = Panfish	
3 = Freshwater Drum (sheepshead)	8 = Chinook salmon	14 = Catfish	18 = Other	
	9 = Coho salmon	15 = Carp	0 = non-boat	Type of fisherman
4 = Walleye	10 = Salmon		1 = boat	
5 = Rock bass	11 = Pike			

PERSON	#1	#2	#3	#4	#5	#6
Time	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9
Traverse No.	10	10	10	10	10	10
Type of Fishermen	11	11	11	11	11	11
No. Licensed Fishermen	12 13	12 13	12 13	12 13	12 13	12 13
No. Unlicensed Fishermen	14 15	14 15	14 15	14 15	14 15	14 15
No. Fishermen Skipped	16 17	16 17	16 17	16 17	16 17	16 17
Tot. No. Hrs. Fishing so far on this site	18 19	18 19	18 19	18 19	18 19	18 19
Tot. No. Hrs. you plan to fish on this site	20 21	20 21	20 21	20 21	20 21	20 21
Tot. No. hrs. you plan to spend on other activities on this site	22 23	22 23	22 23	22 23	22 23	22 23
What % of your trip was for fishing; what % for other purposes	F __ __% 24 25 O __ __% 26 27	__ __% 24 25 __ __% 26 27	__ __% 24 25 __ __% 26 27	__ __% 24 25 __ __% 26 27	__ __% 24 25 __ __% 26 27	__ __% 24 25 __ __% 26 27
Tot. No. & Tot. wt. of each species caught on this site	sp 28 29 no 30 31 32 wt 33 34 35	28 29 30 31 32 33 34 35	28 29 30 31 32 33 34 35	28 29 30 31 32 33 34 35	28 29 30 31 32 33 34 35	28 29 30 31 32 33 34 35

PERSON		#1	#2	#3	#4	#5	#6
Tot. No. & Tot. wt. of each species caught on this site	sp	36 37	36 37	36 37	36 37	36 37	36 37
	no.	38 39 40	38 39 40	38 39 40	38 39 40	38 39 40	38 39 40
	wt	41 42 43	41 42 43	41 42 43	41 42 43	41 42 43	41 42 43
Tot. No. & Tot. wt. of each species caught on this site	sp	44 45	44 45	44 45	44 45	44 45	44 45
	no.	46 47 48	46 47 48	46 47 48	46 47 48	46 47 48	46 47 48
	wt	49 50 51	49 50 51	49 50 51	49 50 51	49 50 51	49 50 51
Trip cost from home: A Out-of-Pocket	M	52 53 54 55	52 53 54 55	52 53 54 55	52 53 54 55	52 53 54 55	52 53 54 55
1. Transport. Pd. (to & from, miles/cash)	C	56 57 58 59	56 57 58 59	56 57 58 59	56 57 58 59	56 57 58 59	56 57 58 59
2. Food & Bevg. other than frm from home.		60 61 62	60 61 62	60 61 62	60 61 62	60 61 62	60 61 62
3. Lodging (rental basis)		63 64 65	63 64 65	63 64 65	63 64 65	63 64 65	63 64 65
4. Bait, Lures		66 67 68	66 67 68	66 67 68	66 67 68	66 67 68	66 67 68
5. Gas, oil:boat		69 70 71	69 70 71	69 70 71	69 70 71	69 70 71	69 70 71
6. Fees & other		72 73 74	72 73 74	72 73 74	72 73 74	72 73 74	72 73 74
B. Fixed Costs (Present Value) rod, reel, waders, other eqp. used today		75 76 77	75 76 77	75 76 77	75 76 77	75 76 77	75 76 77
		1/80	1/80	1/80	1/80	1/80	1/80
Area No.		1	1	1	1	1	1
DATE		2 3 4 5	2 3 4 5	2 3 4 5	2 3 4 5	2 3 4 5	2 3 4 5
TIME		6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9	6 7 8 9
Boat, motor water skis, etc. used today		10 11 12 13	10 11 12 13	10 11 12 13	10 11 12 13	10 11 12 13	10 11 12 13

PERSON	#1	#2	#3	#4	#5	#6
Type of fishing license	__ 14	__ 14	__ 14	__ 14	__ 14	__ 14
Tot. No. days you will use fishing license	__ __ 15 16	__ __ 15 16	__ __ 15 16	__ __ 15 16	__ __ 15 16	__ __ 15 16
Boat license if yes enter 1 if no enter 0	__ 17	__ 17	__ 17	__ 17	__ 17	__ 17
Tot. No. days you will use boat license	__ __ __ 18 19 20	__ __ __ 18 19 20	__ __ __ 18 19 20	__ __ __ 18 19 20	__ __ __ 18 19 20	__ __ __ 18 19 20
Employment and income	__ 21	__ 21	__ 21	__ 21	__ 21	__ 21
	__ 22	__ 22	__ 22	__ 22	__ 22	__ 22
	__ 23	__ 23	__ 23	__ 23	__ 23	__ 23

Area of residence
city or township
or
out-of-state county

24 ______
25 ______
26 ______
27 ______
28 ______
29 ______
30 ______
31 ______
32 ______
33 ______
34 ______
35 ______
36 ______
37 ______
38 ______
39 ______
40 ______
41 ______
42 ______

	#1	#2	#3	#4	#5	#6
	2/80	2/80	2/80	2/80	2/80	2/80

Fishing Licenses:
1 = Resident Sportman's license
2 = Resident Senior sportman's license
3 = Resident annual
4 = R. A. & Trout stamp
5 = Senior Resident Annual
6 = S. R. A. & Trout stamp
7 = Non-Resident annual
8 = N. R. A. & Trout stamp
9 = Daily

WHITING PLANT - EMPLOYMENT AND INCOME

Are you presently employed? 1 = yes

If not, are you: 2 = student, college 3 = student, other
4 = housewife 5 = retired 6 = unemployed (21)

Will you tell me in which of these categories is your current annual wage rate? If you have more than one occupation, please answer for the lowest paying one. (22)

	Annually	Hourly
1.	under $3,000	under $1.50
2.	$3,000-4,999	$1.50-2.50
3.	$5,000-6,999	$2.50-3.50
4.	$7,000-9,999	$3.50-5.00
5.	$10,000-14,999	$5.00-7.00
6.	$15,000-25,000	$7.00-12.00
7.	over $25,000	over $12.00

APPENDIX F

ESTIMATED CATCH AND EFFORT

BY SPORTS FISHERMEN

IN LAKE ERIE WATERS OF MONROE COUNTY

FROM FEBRUARY, 1978 TO JANUARY, 1979

WITH PERIODS I, II, AND III COMBINED

APPENDIX F

Table F1. Estimated Sport Fishing Catch and Effort for Monroe County Waters of Lake Erie from February, 1978 to January, 1979.

Species	Catch (Numbers)	Effort (Angler Days)
Yellow Perch	509,001	29,411
White Bass	2,408	636
Freshwater Drum	2,080	1,262
Walleye	14,381	7,851
Rock Bass	272	131
Pike	54	42
Trout	3	3
Bullheads	680	383
Catfish	5,265	1,878
Carp	593	288
Suckers	28	11
Panfish	574	260
Other	96	36

APPENDIX G

ESTIMATED CATCH AND EFFORT

BY ANGLERS

AT THE J. R. WHITING PLANT SITE

FROM FEBRUARY, 1978 TO JANUARY, 1979

WITH PERIODS I, II, AND III COMBINED

APPENDIX G

Table G1. Estimated Catch and Effort at the J. R. Whiting Plant Site from February, 1978 to January, 1979.[1]

Species	Catch (Numbers)	Effort (Angler Days)
White Bass	25,906	2,305
Freshwater Drum	789	300
Bullheads	534	166
Catfish	4,028	2,058
Carp	1,597	1,076
Other	1,744	259

[1]Yellow perch were not caught at the plant site. Neill and Magnuson (1974) indicated that yellow perch avoided thermal discharges at power plants.

APPENDIX H

DESCRIPTION AND APPLICATION OF THE DATA FROM THE CREEL SURVEY, BOAT COUNT, AND J. R. WHITING PLANT SITE QUESTIONNAIRES

APPENDIX H

This is a description of the questionnaires used for the roving creel survey, the boat count data and notes, and the J. R. Whiting plant site (Appendices A, C, and E respectively). It includes an explanation of how the information, derived from the questions on the forms, was employed in the procedures and calculations integral to this entire study. A few of the questions are extraneous, since these questionnaires were utilized in other studies which required more detailed information than was needed in my analysis. I will not describe what questions were omitted. If they are not mentioned in this section, then they were ignored.

All the questions in Appendix A are identically described on page one of Appendix E (numbering of questions not identical to Appendix A). Appendix A will be discussed in detail. However, the same information also applies to Appendix E. Numbers 1 through 11 (Appendix A) were qualitative questions used to segregate the information into different categories such as area or type of fishermen. It was assumed all anglers were licensed.

Usually all shore anglers encountered in an area during a sample day were interviewed. During Period I (ice fishery) occasionally shore fishermen were skipped. The number of these anglers was recorded. It was assumed that the catch and effort data of each angler skipped was identical to that of the previous angler who was actually interviewed.

Each horizontal number (labeled person), 1 through 6, represents the information from one interviewed angler. To facilitate my calculations each skipped angler was recorded as one interview.

The information pertaining to catch and effort (numbers 13 to 45) is substituted into equations (1), (2), (3), or (13) to obtain total catch and effort in an area for a particular sample day. For boat anglers the above information is substituted into equations (14), (15), or (16) for total catch and effort. Appendix C contains the instantaneous counts of boat anglers in an area during a sample day. This information is incorporated into equation (15) so total angler days can be estimated.

In addition to the questions contained in Appendix A, the J. R. Whiting plant site questionnaire (Appendix E) has questions pertaining to the supply and demand analysis of the plant site. The information collected included the: (1) purposes of the trip, (2) record of costs incurred by the respondent, and miles driven at his expense, (3) number of days he expects to use his license, (4) employment status, (5) current lowest wage rate, and (6) city in which the respondent lives. Given this information the price (supply) of fishing for an individual angler at the plant site can be estimated. Talhelm (1972, 1978) provided these equations for estimating an angler's costs:

$$P_f = \frac{T_t P_w + T_f P_w + \text{COSTS}}{AD} \tag{32}$$

where

P_f = price of angling in dollars/angling day,

T_t = travel time in hours,

AD = angler days (usually = 1),

P_w = wage rate (\$/hr),

T_f = angling time in hours,

$$COSTS = .1\ MT + .25\ FOOD + (1 + .01 \cdot EQUIP) + LIC/LDU$$

where:

MT = miles of automobile travel paid by the respondent,

FOOD = cost of food purchased as part of the trip,

EQUIP = current market value of equipment,

LIC = license cost,

LDU = number of days the license is used.

Traveling time from one geographical area to another in Michigan and surrounding states was provided by the Michigan Department of State Highways and Transportation.

APPENDIX I

COMMON AND SCIENTIFIC

NAMES OF FISH SPECIES

CAUGHT IN MONROE COUNTY

APPENDIX I

Table I1. Common and Scientific Names of Fish Species Caught in Monroe County from February, 1978 to January, 1979.

Common	Scientific
Yellow perch	*Perca flavescens*
White bass	*Roccus chrysops*
Freshwater drum (Sheepshead)	*Aplodinotus grunniens*
Walleye	*Stizostedion vitreum vitreum*
Rock bass	*Ambloplites rupestris*
Northern pike	*Esox lucius*
Lake trout	*Salvelinus namaycush*
Yellow bullhead	*Ictalurus natalis*
Channel catfish	*Ictalurus punctatus*
Carp	*Cyprinus carpio*
Suckers	*Catostomus* and *Moxostoma* spp.
Panfish	*Lepomis* spp.

APPENDIX J

ANNUAL REDUCTION IN THE YELLOW PERCH POPULATION FROM THE COMBINED EFFECTS OF IMPINGEMENT AND ENTRAINMENT

APPENDIX J

Table J1. Annual Simulated Percentage Loss in the Yellow Perch Population Prior to Stabilization from the Combined Effects of Impingement and Entrainment.[1]

Year	Percent Reduction ($r_{i,t}$)	Year	Percent Reduction ($r_{i,t}$)
0	.0	13	1.9
1	.0	14	1.9
2	.0	15	1.9
3	.0	16	1.9
4	.9	17	2.8
5	.9	18	2.8
6	.0	19	2.8
7	.0	20	2.8
8	.9	21	3.8
9	1.9	22	2.8
10	.9	23	2.8
11	.9	24	3.8
12	1.9	25	3.8

[1]Beyond 25 years the population reaches stabilization. Saila and Lorda (1977) state that power plant impact should be considered during the perturbation period (impact of impingement and entrainment) prior to stabilization. Stabilization is defined as the period or time it takes for the perturbed population to converge to a new stable age distribution.

The reductions in the population from impingement and entrainment are represented by the harvest matrix:

$$H = \begin{bmatrix} 1-p_0 & 0 & 0 \ldots & 0 \\ 0 & 1-p_1 & 0 \ldots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 \ldots & 1-p_n \end{bmatrix}$$

where

P_j = fractional or percentage reduction from impingement and entrainment of the j^{th} age class.

Carrying out the matrix multiplication of the harvest matrix (H) and the Leslie projection matrix ($\underline{A}$) will give:

$$H\underline{A} = \begin{bmatrix} (1-p_0)f_0 & (1-p_0)f_1 \ldots & (1-p_0)f_{n-1} & (1-p_0)f_n \\ (1-p_1)s_0 & 0 \quad \ldots & 0 & 0 \\ 0 & (1-p_2)s_1 \ldots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & (1-p_n)_{n-1} & 0 \end{bmatrix}$$

The equation for calculating the annual percentage loss from the combined effects of impingement and entrainment:

$$r_{i,t} = ((p_{w,o} - p_{i,t})/p_{w,o}) \text{ X } 100 \tag{33}$$

where

$r_{i,t}$ = percent reduction in population size from impingement and entrainment (i) during year , t,

$p_{w,o}$ = population size without plant mortality (w) during year, 0,

$p_{i,t}$ = population size from the combined effects of impingement and entrainment during year, t.

The equation for estimating the average annual percentage loss after 25 iterations or years:

$$\bar{r}_{i,25} = \sum_{t=1}^{25} r_{i,t}/25 = 1.7 \tag{34}$$

where

$\bar{r}_{i,25}$ = average percentage loss from impingement and entrainment after 25 iterations and just prior to stabilization.

It is assumed that after stabilization the plant will reduce the yellow perch population by 1.7 percent per year for 50 years (life of the plant).

Patterson (1979), utilizing a materials balance model, estimated a .8 to 4.7 percent annual entrainment loss of larval yellow perch by the Monroe power plant (Monroe, Michigan) in the Michigan waters of Lake Erie. My estimated annual entrainment loss of larval yellow perch by the J. R. Whiting plant was .4 percent (Table 9). However, the Monroe plant has nearly nine times the total generating capacity of the Whiting plant, so my lower estimate is probably somewhat comparable to Patterson's results.

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