A Feasibility Study for Estimating The Value of Commercial Fishery

by

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Dedicated to

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I. INTRODUCTION AND PROBLEM SETTING

The "best" use of natural resources--using them where they are needed the most and can provide the greatest return to society with respect to economic, political, and environmental standards--is a basic question facing our society. It is a question that has received more and more attention in recent years, as an acute awareness of ecological problems has developed in the industrialized portion of the world. The problem has also become more complex as more and more natural resources are subjected to more intensive multiple uses. Conflicts arise between the users of such resources when the actions of one user encroach upon the use of the resource by another. Usually such conflicts can only be resolved by limiting one or more uses.

In the case of renewable natural resources, such as fisheries, forests, or populations of other wild animals, assuming there is more than one user, the primary problems are, first, what is the optimum annual yield and how do we harvest only that amount, and second, how to divide the annual yield or harvest of the resource among the alternative users.

In the Great Lakes,[1] there is a general recognition by fisheries managers that there is some optimum combination of commercial and sport fishing that would best utilize the productive capacity of the resource (Talhelm, 1975). However, at present no one can precisely document the social values, the ecological constraints and the management technology needed to precisely determine optimal management of Great Lakes fisheries.

The overall purpose of the MSU Sea Grant fisheries economics research project (of which this study is one component) is:

> ". . . to assist individuals and organizations in making better use of the Great Lakes and fish culture resources by applying the social science of economics to that task. Overall project goals are as follows:
>
> 1. Provide information needed for selecting optimal utiliziation of Great Lakes fisheries by documenting the benefits, costs and other impacts of potential management strategies.
> 2. Assist private and public planning efforts by documenting economic impacts incidental to commercial and sport fishing for Great Lakes fish.
> 3. Promote better utilization of the commercial and recreation resources of the Great Lakes through

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[1] The Great Lakes form the largest body of fresh water in the world, with 95,000 square miles in area. Although the upper three lakes are cold and infertile, because of their size and location, they have a tremendous potential for both sport and commercial fishing.

> economic and business statistics, direct assistance to small firms, and studies of related aspects of recreational behavior." (Talhelm, 1975)

The first goal is of primary importance here. It is divided into three sub-goals: a) determination of sport fishing values, b) determination of commercial fishing values, and c) formulate and apply an optimum harvest model. The purpose of this study is to examine part b) in the context of a particular, renewable resource: the whitefish[2] fishery of Michigan's Great Lakes.

Until recently, Great Lakes fishing was dominated by commercial fishing.[3] Since the mid-1960's however, sport fishing increased tremendously, becoming one of the most important sport fisheries in the world (Talhelm, 1975). The Great Lakes commercial fishing industry, on the other hand, has become increasingly depressed for several reasons. Currently, management agencies are greatly restricting the species, location and methods of commercial fishing, and sharply reducing the number of commercial fishing licenses[4] with the objective of maintaining a more limited but economically viable industry.

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[2] Common and scientific names for the Great Lakes fish are given in Appendix.

[3] Some parts of this section paraphrase or quote Talhelm (1975).

[4] The number of licensed commercial fishermen in Michigan has declined from about 1100 in 1950 to around 150 at present.

Reasons for the present condition include: overfishing for certain species, ecological disruptions by sea lamprey and alewife populations, DDT and PCB contamination and other pollution. However, one of the most important reasons is recognition by the Departments of Natural Resources of the Great Lakes states that our present society finds sport fishing for fish produced in the Great Lakes, including salmon, to be more valuable than commercial fishing.

Studies show that in 1971 over 184,000 sport fishing license holders fished about two million days for Great Lakes salmon and steelhead in Michigan (Jamsen, 1973). Talhelm (1973) and Ellefson (1973) estimated the net economic value of Michigan's 1970 salmon and steelhead sport fishing including and not including non-residents of Michigan to be $30 million and $23.8 million respectively.

On the other hand, comparable economic values of commercial fishery (the social surplus) have not been documented. Apparently, however, the Michigan Department of Natural Resources (MDNR) assumes that the social value of commercial fishing is much lower than that of sport fishing.

Commercial fishing for sport species including perch, lake trout, other species of trout, bass and walleye is probhibited or nearly so in most areas. Also, gillnetting with large mesh gill nets, which has been predominant in Michigan, is now being prohibited in favor of trap netting because the gill nets reportedly kill too many lake trout.

Objectives

The main objectives of this paper are:

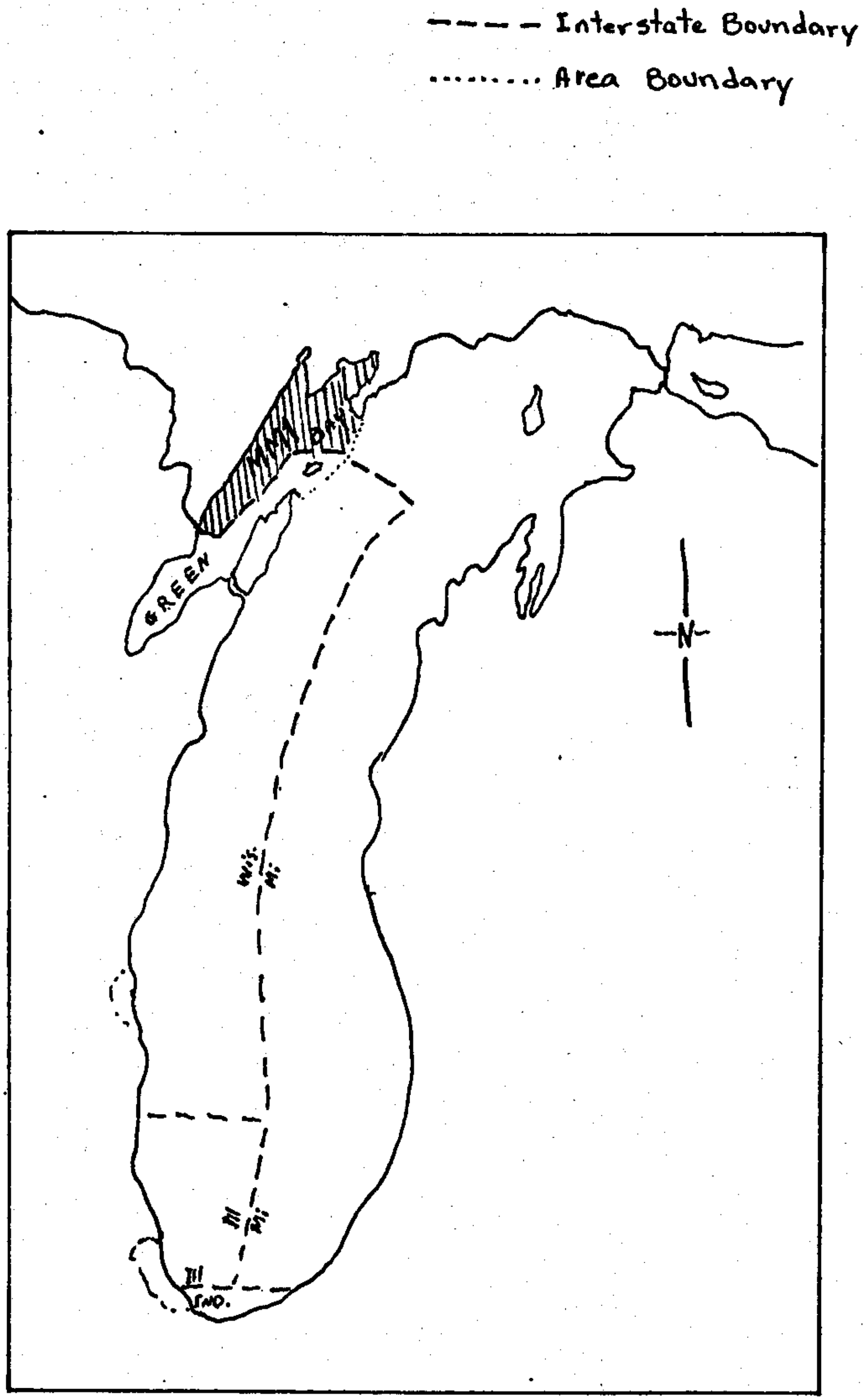
1. Define the problem and its domain.

2. Review literature useful for estimating the economic values of commercial fishery.

3. Develop a bioeconomic model for estimating the value of Michigan's whitefish industry.

4. Discuss the data availability for the relevant variables.

FIGURE I-1. Lake Michigan



II. FISHERIES ECONOMICS LITERATURE

One of the first published articles on fishery economics in economics literature is that of Gordon (1954). He emphasized the importance of the common property nature of the fishery, and defined the optimum degree of utilization of any particular fishing ground as that which maximizes the net economic yield, the difference between total cost, on the one hand, and total receipts (or total value of production), on the other. He was one of the first to point out that biologists in their treatment of the principles of fisheries management have overlooked essential elements of the problem by taking maximum physical landings as the objective of management, thereby neglecting the economic factor of input cost. He expressed total cost and total production as a function of the degree of fishing intensity ("fishing effort"), so that a simple maximization solution is possible. The model is expressed in terms of four variables and four equations:

II-1. $B = B(TR)$

II-2. $TR = Pf(B,E)$

II-3. $TC = h(E)$

II-4. $\Pi = TR-TC$

Where, B (biomass) represents the population of the particular fish species on a particular isolated fishing bank; TR (total revenue) the value of the total quantity landed by man; E (effect) the intensity of fishing or the quantity of "fishing effort" expended; and TC the total cost of making such effort.

He applied the model in examining two different equilibria:

a) as it occurs in the state of uncontrolled or unmanaged exploitation of a common property resource, where TR = TC (equation II -4).

b) as it occurs in the state of a socially optimum manner of exploitation, where TR - TC is being maximized.

The conclusion of this comparison was that common property natural resources, which are free goods for the individual and scarce goods for society, can yield no rent under unregulated private exploitation. In the long run, rent can be obtained only by methods which make the resource private property or public (government) property, in either case subject to a unified directing power. He also concluded that competition among fishermen eliminates the rent and is the main reason for fishermen not being wealthy.

The question of sole ownership versus competitive exploitation was further examined by Scott (1955). He showed that in the long run sole ownership of such a resource is much superior to competition. In the short run, however, because of the diminishing returns to fishing, there is little difference between the efficiency of the two.

Schaefer (1957) developed the following biological model:

II-5. $\dot{B} = \frac{dB}{dt} = f(B)$

II-6. $Y = Y(B,E)$

II-7. $B = B(E)$

II-8. $f(B) = t_1 B \cdot (M-B)$

II-9. $Y = q\ EB$

where M is maximum biomass (carrying capacity), t is time, $\dot{B}$ is growth of biomass and t_1 and q are constants. The constant, q, represents the "catchability" of the fish.

The difference between this model and that of Gordon's is in equations II-1 and II-7. In the first model biomass is a function of yield while in the second it is a function of effort. Also equation III-5 is a new feature in this model which estimates growth, or the change in population over time. Equations II-8 and II-9 specify the approximate form of B and Y. In equilibrium, yield (catch) equals the rate of natural increase (growth) in biomass, equation II-10.

II-10. $Y = qEB = t_1\ B \cdot (M-B) = f(B)$

Equation II-11 which is now known as "Schaefer's yield function" is derived from equation II-10.

II-11. $Y = qE\ (M-\frac{q}{t_1}E)$

In 1969 Crutchfield converted Schaefer's biological model to a bioeconomic model by multiplying both physical yield and fishing effort by relevant prices in order to get dollars revenue and cost. He then applied the model to the Pacific Salmon Fisheries to analyze the three cases of production, MSY, OSY, and competitive exploitation.

Turvey in his 1964 article tried to compromise between economists and biologists by emphasizing the biological factors such as the impact of net mesh size on the age distribution, weight and size of the fish stock. Although he emphasizes the relationship of fisheries regulations to optimum resource allocation, he believed that if overall optimization is impossible then suboptimization is still desirable. Some of the relationships of his static model are as follows:

III-12. Fishing Mortality = f(E)
III-13. Natural Mortality = g(age distribution)
III-14. B(biomass) = h(age distribution
III-15. TR = ℓ(weight, size of fish, freshness)

He believed that the optimum marketable size of fish should determine the mesh size. He stated that in the short run the use of a larger mesh size may cause losses to the individual fishermen (by increasing the number of hauls necessary to achieve any given weight of catch), yet, in the long run, this may lower the costs of all fishermen together (by increasing the number of large fish to be caught later).

He also stated that an increase in demand for fish generally causes an increase in the competitive equilibrium catch. However, if fishing effort has been carried beyond the point of maximum yield, a greater employment of resources in the industry leads to a smaller total product.

Finally, he concluded that with the existence of these external diseconomies in both level of fishing effort and in the choice of mesh size, to achieve the optimum resource allocation, regulation of both these variables is required. As alternatives, he also considered suboptimum conditions in which only one of the two is regulated.

Turvey's model differs from the others in addressing the biological and mechanical factors in more detail. This can be considered a positive step towards further clarification of the relationships between economic and biological factors.

In 1971 Fullenbaum et al., developed the following model:

II-16. $\Delta B = f(B,Y)$

II-17. $g = g(B,E'')$

II-18. $Y = E''g = E''g(B,E'')$

where

$$\frac{\partial g}{\partial B} = g_1 > 0$$

$$\frac{\partial g}{\partial E''} = g_2 < 0$$

II-19. $TC = E''V$

II-20. $\Pi = PY - TC = PE''g\ (B,E'') - E''V$

II-21. $E'' = \delta_1\ \Pi,\ \Pi > o$

II-22. $E'' = \delta_2\ \Pi,\ \Pi < o$

Where ΔB is stock growth under exploitation; E" is effort (number of homogeious operating units or vessels); g is yield per vessel; Eg=Y is total quantity landed; V is total annual cost per vessel (in constant dollars), including opportunity cost[1]; Π is industry profit in excess of opportunity cost (economic rent); P is the real ex-vessel price; and δ_1 and δ_2 represent the rates of entry and exit of vessels, respectively.

One important improvement in this model over the previous models is that this model looks at both individual firms and the industry as a whole while the previous ones look only at the aggregate. The biological part of Fullenbaum's model differs from Schaefer's model in that equation II-16 is growth under fishing exploitation including total landings. Equation II-18 and II-6 are basically the same. One the economic side, Fullenbaum's cost equation II-19 is more explicit than Gordon's II-3. Equation II-20 describing economic equilibrium in Fullenbaum, is also more explicit than in Gordon's model. Equations II-21 and II-22 are very important since they indicate that vessels will

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[1] Opportunity cost is defined as the necessary payment to fishermen and owners of capital to keep them employed in the fishery, rather than finding alternative employment or uses of capital.

enter the industry when excess industrial profits are greater than zero (i.e., greater than that rate of return necessary to hold vessels in the fishery, or the opportunity cost), and will leave the fishery when excess industrial profits are less than zero (i.e., below opportunity cost).

The equilibrium condition for the industry (Π=o) may be formulated as shown below:

II -23. $PE''g\ (B,E'') - E''V = o$

II -24. $P = \frac{V}{g(B,E'')}$

Equation II -24 merely stipulates that ex-vessel price is equal to average cost per pound of fish landed (i.e., no excess profits).

Some important properties of the Fullenbaum model are as follows. First, the optimum size of the firm is given and may be indexed by V. Second, the long-run catch rate per vessel per unit of time (g) is beyond the individual firm's control. It is, in effect, determined by stock or technological externalities. Finally, it is assumed that the number of homogeneous vessels is a good proxy for fishing effort. Alternatively, Fullenbaum et al. suggest that we may employ fishing effort directly in the system by determining the number of equivalent units of fishing effort applied to the resource per vessel.

In 1974 the Fullenbaum model was applied to the Maine Lobster Industry by Dow et al. (1974). One of the unique characteristics of this research is bringing together and discussing the fisheries biology and population dynamics, as well as economic relationships. Also, before explaining the bioeconomic simulation model they discuss some of the most important behavioral factors of the fisheries over some period of time, such as ex-vessel prices, fishing effort, earnings, and catch under conditions of free access to fishery resource.

Herfindahl and Kneese (1973) had a different way of looking at the fisheries, involving the services of capital, K, in their model. They assumed a constant returns Cobb-Douglas production function with two inputs, the services of the stock of fish, measured by biomass (b), and the services of capital (K). They also assumed unitary operation of a fishery and freedom to choose any output and population, but required a steady state (equilibrium) solution.

The Herfindahl model is as follows:

II-25. $\frac{\dot{B}}{B} = f(B),\ f' \gtrless o,\ f'' < o$

II-26. $Y = g(B,K)$

II-27. $\dot{B} = Bf(B) = F(B)$

II-28. $\Delta B = F(B) - Y = F(B) - g(B,K)$

Equation II-25 defines the relative rate of growth of the fish population. This aspect differs from the previous models. Equation II-25 is assumed to have one maximum not at $B=o$. Equation II-26 is a production function with capital as one of the two inputs. Equations II-27 and II-28 define natural growth and net change in biomass over time.

Since the steady state is assumed, the problem is to maximize Π (profit) in equation II -29, subject to II -30.

II -29. $\Pi = TR - TC = Pg(B,K) - wK$

II -30. $\Delta B = F(B) - g(B,K) = o$

Here P is the constant price of the product and w is the price of one unit of capital services.

Herfindahl used the Lagrange Multiplier technique to find the maximum:

II -31. $L = Pg(B,K) - wK + \lambda\ (F(B) - g(B,K))$

II -32. $\frac{\partial L}{\partial K} = P\frac{\partial g}{\partial K} - w - \lambda\frac{\partial g}{\partial K} = w - (\lambda - P)\frac{\partial g}{\partial K} = o$

II -33. $\frac{\partial L}{\partial B} = P\frac{\partial g}{\partial B} + \lambda(\frac{\partial F}{\partial B} - \frac{\partial g}{\partial B}) = o$

II -34. $\frac{\partial L}{\partial B} = F(B) - g(B,K) = o$

The λ can be interpreted as the implicit or shadow price of one unit of fish in stock (i.e., remaining in the water after fishing).

This model has the advantage of looking at the fishery from a different angle, involving a new variable (K) in the production function.

All the bioeconomic models so far have been applied to various parts of the U.S. fish industry. Unfortunately, there have been no known bioeconomic analyses of Great Lakes commercial fisheries. In the biological side, however, there have been some recent studies.

In 1976, Jensen applied the logistic surplus production model[2] to the commercial whitefish yield and effort

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[2] "Surplus production" is the amount of biomass that can be removed by a fishery without changing the size of the stock.

data of selected districts of the Michigan waters of Lake Superior, Lake Huron, and Lake Michigan. He investigated a set of biological goals such as carrying capacity (M), biomass levels (B), maximum sustainable yield (MSY), fishing effort that produces the maximum sustainable yield, and the relative importance of commercial fishing and sea lamprey predation. The equation of the surplus production model[3] based on the logistic equations are:

II -35. $\frac{dB}{dt} = kB - \frac{k}{M} B^2$

II -36. $Y = qEB$

II -37. $\Delta B = kB - \frac{k}{M} B^2 - qEB$

In the steady state, $\Delta B=o$, and annual equilibrium yield is

II -38. $Ye = kB - \frac{k}{M} B^2 = qEB$

where: k is a population growth constant; $\frac{dB}{dt}$ is the natural growth of the biomass, and ΔB is the growth under fishing exploitation.

The only difference between this model and Schaefer's is that of notation. By setting $k=t_1M$, this model can be converted to that of Schaefer's.

By "linearizing" equation II-35 and applying least squares, Jensen was able to estimate three of the parameters, k, M, and q for three districts: MM-1 (district one of Michigan's Lake Michigan), MS-4 (District four of Michigan's Lake Superior), and MH-1 (district one of Michigan's

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[3] The logistic surplus production model was developed by Hjort et al. (1933) and by Graham (1935).

Lake Huron). The calculations were adjusted to assume 4 1/2 inch gill nets as the standard gear, with and without lamprey predation.

In all districts the observations were greatly scattered about the equilibrium stock production curve. However, most observations for Lake Michigan (MM-1) were scattered at low level of biomass. This indicates that over the years too much effort has been applied to the fishery, forcing the biomass to stay below its optimum level. This condition is considered overexploitation. An example of overexploitation is shown in Figure II-1.[4] In studying the sea lamprey, Jensen plotted the biomass removed by fishermen and the biomass estimated to have been removed by sea lamprey predation. The result shows a tremendous impact of the sea lamprey on the whitefish population as compared to the small impact of commercial fishing.

> "These estimates of sea lamprey predation are accurate enough to conclude that although the whitefish stock in this district has been consistently overexploited, the decline in whitefish biomass during the 1950's was caused by the sea lamprey and not by overfishing."[4]

The results for Lake Superior (MS-4) were considerably different. For this district observations appear to be available for all stages of the fishery, which indicates the absence of overexploitation.

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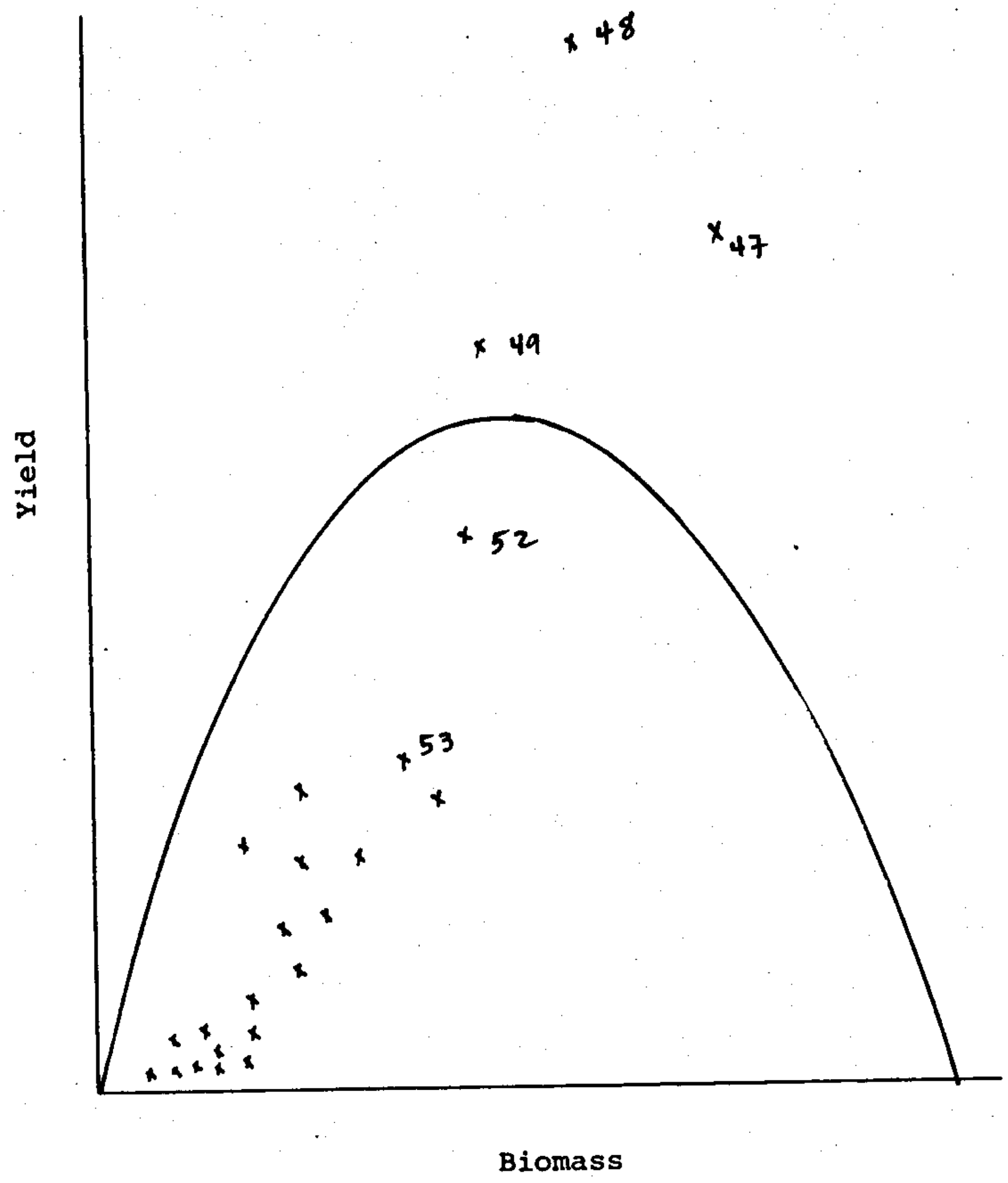
[4] Jensen (1976), page 754 and 756.

FIGURE II -1. An Example of an Overexploitation Situation



In Lake Huron (MH-1) the whitefish stock appeared overexploited when poundnets were used as the standard gear, but underexploited when using gillnets.

Another biological study of the Great Lakes is that of M. H. Patriarche in 1976. The object of the research was to establish quotas for whitefish in order to assure a stabilized population and fishery. In the study Patriarche modified Ricker's dynamic pool model, and applied it to statistical districts, MM-1 and MM-3 in northern Lake Michigan.

He recommended a quota based on the premise that the annual harvest of a population should be confined to the weight gained each year by the harvestable proportion of the population (surplus production). He claimed that this would maintain the population at status quo.

He stated that one of the keys to successful management of a fishery, among the biological factors, is information on the size of the population being managed. Since direct counts were impossible for populations in a lake as large as Lake Michigan, Patriarche developed an indirect means of estimating the biomass.

> "With estimates of either exploitation rates or mortality and survival rates at hand, along with total catches by age group, it is possible to compute the numbers of whitefish of different age groups."[5]

The results of Jensen's study (using the logistic surplus production model) agree closely with computed biomass in

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[5] Patriarche (1976) page 17 .

this study.[6]

The method developed in this study can be used for stabilizing the fishery at the current population level by matching yield with production. This strategy should be satisfactory for obtaining sustained yield but there is no provision for building up a depleted stock. The study does not address itself to explain how one can move to optimum sustained yield.

He suggests two ways to increase the current level of population, by a) arbitrarily cutting the equilibrium quota and permitting more spawners to survive for additional egg production, and b) changing the minimum size limit in order to allow greater escapement of immature fish, thereby building up the number of spawning fish. However, the study did not address the question of whether the number of spawning fish has any effect on the recruitment of fish into an age class.

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[6] For the breakdown of the population in terms of the different ages see Patriarche (1976) table 7, page 30.

III. A BIO-ECONOMIC MODEL

This section introduces a bio-economic model developing in this study. Based upon this model, a detailed discussion is presented of:

1) the point of maximum sustainable yield (MSY),
2) the point of optimum sustainable yield (OSY), and
3) the competitive equilibrium point.

Some of the simplifying assumptions of the model are:

1) it is long run and static,
2) it is concerned with a single fishing ground containing only one species of fish (whitefish),
3) all the fishing (production units are to be homogenous,
4) all factors of production are to be in perfectly elastic supply,
5) perfect mobility of assets,
6) real ex-vessel price (p) is given,
7) effort and output can be controlled in order to reach optimum sustainable yield (OSY),
8) Cobb-Douglas production function.

These assumptions may make the model rather unrealistic, but are important for the model to be operational at this point. In latter stages of development some of these assumptions will be released. For the purpose of this study, however, these assumptions seem to be appropriate.

The Model

In this study a surplus production model (Hjort et al., 1933) and Graham (1935) is used to develop the following bioeconomic static optimization model.

III-1. $\frac{\partial B(t)}{\partial t} = \dot{B} = k\ B_t - \frac{k}{M}\ B_t^m$

In this model parameter, m, is assumed to be equal to two (m=2) which is a parabola.

III-2. $Y = qEB_t$

III-3. $\Delta B = \dot{B} - Y = yB_t - \frac{k}{M} B_t^2 - qEB_t$

III-4. $TFC = CE$

III-5. $TVP = PY = PqEB_t$

III-6. $\Pi = TVP - TFC$

where:

$\dot{B} = \frac{dB_t}{dt}$ = growth in biomass without fishing exploitation,

B = biomass of the fish population,

k = population growth constant,

M = carrying capacity, (maximum sustainable biomass),

Y = dockside quantity of fish landed,

q = "catchability" coefficient,

E = fishing effort (e.g., as used in this study, a list of 1,000 linear feet (almost 300 meters) of 4 1/2 inch gill net),

Em = effort at MSY,

Bm = biomass at MSY,

ΔB = growth in biomass with fishing exploitation,

TFC = total factor cost,

C = cost per unit of effort,

TVP = total value product or value of the total product (yield times price),

P = average ex-vessel price,

Π = producers' surplus.[1]

The model consists of two parts: biological and bioeconomic. On the biological side, the logistic surplus production model (equations III-1, III-2, III-3) has been adapted from the models found in the fisheries literature (e.g., Hjort et al., 1933 and Graham, 1935). This model was applied to the Great Lakes whitefish population by Jensen (1976). On the economic side the physical yield and fishing effort are multiplied by relevant price of whitefish and cost per unit of effort in order to get dollars revenue and cost. The Langrangian multiplier technique is then used to determine the optimum levels of yield, fishing effort and "economic rent" at this point.

Biological Equations

Equation III-1 relates the natural rate of growth to the size of the biomass. It describes the growth of the biomass under no fishing exploitation and can be shown by Figure III-2.

Equation III-2 relates the yield of the fishery to the level of effort and the size of the biomass at any period of time.

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[1] For the definition of "producers' surplus" see footnote I-8.

In the steady state, $\Delta B = o$ (equation III-3), and the equilibrium yield, Ye, as a function of biomass is:

III-7. $Ye = kB - \frac{k}{M} B^2$

Solving equation III-3 for B, where $\Delta B = o$, and substituting that into equation III-7, gives the equilibrium yield, Ye, as a function of effort, equation III-8;

III-8. $Ye = qME - \frac{Mq^2}{k} E^2$

Given equations III-1, and III-2, the "surplus, production" is the amount of biomass that can be removed by a fishery without changing the size of the biomass. Therefore, the fishery will be in long run biological equilibrium when harvest equals natural growth as in equation III-3. Equation III-7 further illustrates this concept. The sustainable yield curve is defined as the locus of all the combinations of yield and biomass for which equation III-7 is satisfied, as in Figure III-1. Maximum sustainable yield (MSY) is the maximum point of the curve, where the slope is equal to zero. To obtain MSY, equation III-7 is differentiated with respect to B; the result is set equal to zero and solved for B max (equation III-9), where B max is biomass at MSY. Substituting B max into equation III-7 gives equation III-10.

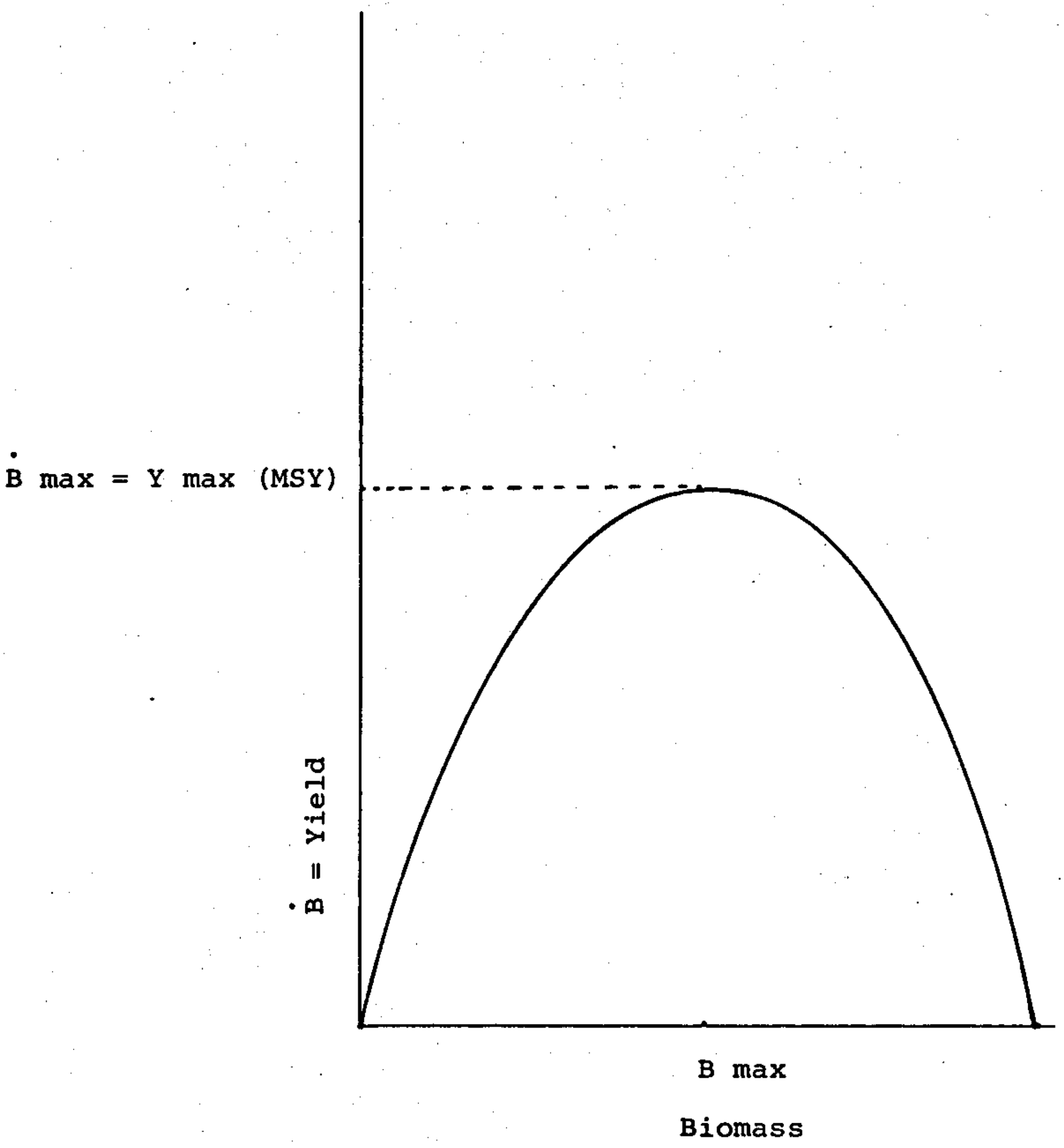
III-9. $B \max = \frac{M}{2}$

III-10. $MSY = kB \max - \frac{k}{M} B^2 \max = \frac{kM}{4}$

The fishing effort at MSY is

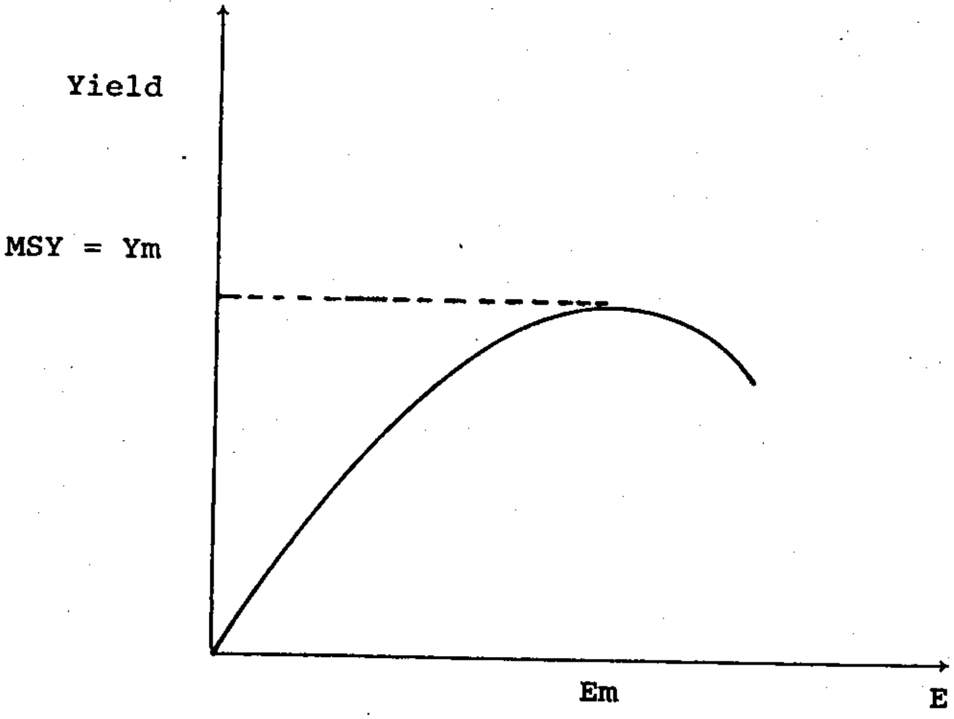
III-11. $E \max = \frac{MSY}{B\max q} = \frac{k}{2q}$

FIGURE III-1. The Sustainble Yield Curve.
Equation (1) where m = 2 (parabola)



Since yield is a function of both biomass and fishing effort (equation III-2), a similar relationship is derived between sustainable yield and fishing effort (equation III-8) and Figure III-2.

FIGURE III-2. Yield-Effort Curve, a Long Run Harvest Function



The above figures (III-1, III-2), however, do not show yield/effort production functions in the normal sense of the term $Y = f(E,\bar{B})$, where $\bar{B}$ is biomass fixed at a certain level, because each point on the curve relates to a different size of the biomass. The curve is rather a locus of long-run equilibrium points[2], because we have specified that Y=B, and in order to change $\dot{B}$, B must change (see equation III-1).

Bioeconomic Equations

Surplus production models are usually applied to determine themaximum sustainable yield (MSY) and the level of fishing effort that will produce the MSY. This information has been considered important in the management of a fishery. The bioeconomic model developed in this study, however, is applied to determine the maximum economic yield (MEY), also called the optimum sustainable yield (OSY). The OSY is the yield at which sustainable economic rent is maximum.

Equation III-4 computes the total factor cost. In the fisheries economics literature this equation is usually called total cost. Parameter C is cost per unit of effort.

III-4. $TFC = CE$

Equation III-5 is the value equation. Since price is held constant in the value equation; PY is the total value product, or the value of the total product.

III-5. $TVP = PY = P\ qEB$

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[2] Starting with a given level of biomass, B_1 and a fixed level of effort, E_1, equilibrium levels of yield and biomass are obtained. Now, if effort is increased to E_2, over a period of time another equilibrium is reached for biomass and yield. Therefore, in Figure III-2 every change in effort causes a change in yield and a change in biomass, which does not satisfy the production function $Y = f(E,\overline{B})$.

Equation III-6 gives Π as the difference between the value of the total product and the total factor cost.

III-6. $\Pi = TVP - TFC$

Total factor cost includes all costs: variable, fixed, and opportunity costs of labor, management and investment.

Variable Π is called "producers' surplus" and is earned because the fish stock is unique, there is a limited number of fishing areas, there are limited market substitutes, and the fact that not all the fishing areas are equally productive.[3]

Equation III-6 is the objective function of this study, which is being maximized subject to equation III-3, a biological constraint, to find the optimum sustainable yield (OSY), optimum level of effort, and economic rent at OSY.

III-3. $\Delta B_t = \dot{B}_t - Y = o = kB_t - \frac{k}{M}B_t^2 - qEB_t$

Equation III-3 specifies that the rate of change in biomass under fishing exploitation is equal to zero.

In equations III-12 and III-13 the Lagrange multiplier technique is used to find the maximum possible rent (Π), subject to the biological constraint $(\Delta B) = o$.[4]

III-12. $\Pi = TVP - TFC + \lambda(\Delta B = o)$

III-13. $\lambda = PqEB - CE + \lambda(kB - \frac{k}{M} B^2 - qEB)$

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[3] The assumption of fixed price of output rules out the monopoly question.

[4] This study concerns only with the static case, dynamic maximization, however, is possible by integrating the rent over time and discounting it by the interest rule.

$$\Pi = \int_0 (TVP-TFC+\lambda(\Delta B=0))e^{-rt}\,dt$$

Where λ is the coefficient of the constraint. It is the change in economic rent when the constraint changes by one unit of fish, or the shadow price of the constraint.

The values of biomass (B), effort (E) and λ, can be found by differentiating equation III-12 with respect to B, E and λ, setting all three equations equal to zero, and solving the system.

III-14. $\frac{\partial \Pi}{\partial E} = PqB - C - \lambda qB = 0$

III-15. $\frac{\partial \Pi}{\partial B} = PqE + \lambda (k - \frac{2k}{M} B - qE) = 0$

III-16. $\frac{\partial \Pi}{\partial \lambda} = kB - \frac{k}{M} B^2 - qEB = 0$

The results are,

III-17. $B^* = \frac{M}{2} + \frac{C}{2qP}$

III-18. $E^* = \frac{k}{2q} (1 - \frac{C}{qPM})$

III-19. $\lambda = P - \frac{C}{qB^*}$

where B* is biomass at OSY, and E* is effort at OSY.

To obtain the optimum sustainable yield (OSY) the values of B* and E* are substituted in equations III-2 or III-4, giving equation III-20.

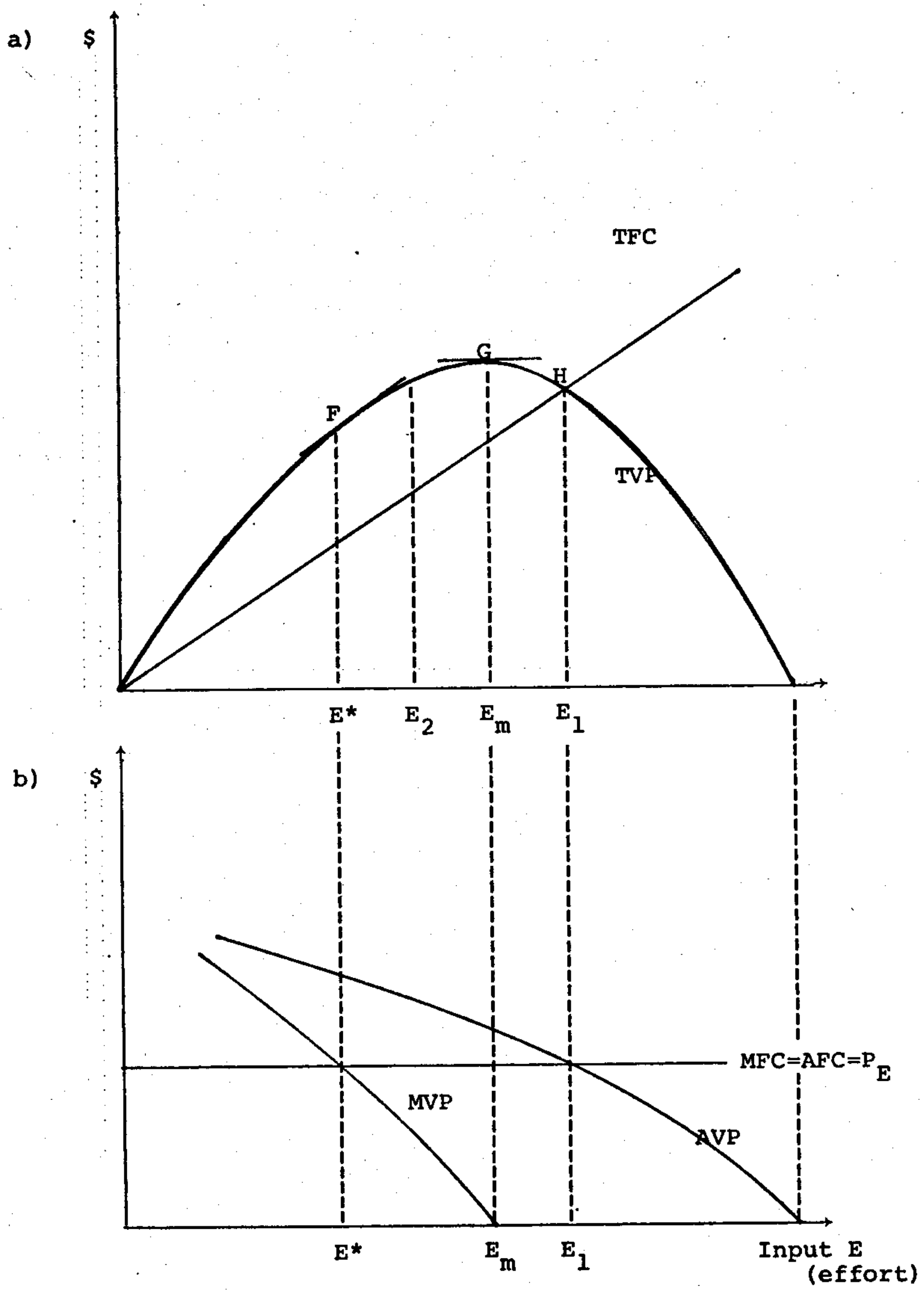
III-20. $OSY = qE^*B^* = kB^* - \frac{k}{M} (B^{*2})$

In Figure III-3 the MSY (point G) and OSY (point F) and the open access equilibrium (point H) can be compared.

The total value product curve (TVP, and the total factor cost curve (TFC) are shown in Figure III-3a.

The factor-product relationship, Figure III-3b shows the average value product (AVP), marginal value product

FIGURE III-3. Comparison of OSY, MSY, and the Open Access Equilibrium (Long Run)



(MVP) curves, and the marginal and average factor cost curves (MFC, AFC).

Point G corresponds to the value of maximum sustainable yield (MSY) which was explained in Figures III-1 and III-2. At this point the slope of the long run marginal revenue function is equal to zero, and total physical yield is being maximized. At point F (OSY), fisheries economic rent is maximized, at this point the value of the marginal product (VMP)[5] of the input is equal to the price of the input, equation III-21.

III-21. $VMP_E = P_E$

where P_E is the price of the input E (effort). To maintain production at point F, however, restrictions on the number of vessels and vessel outputs are necessary. Under free entry, the existence of greater than normal profits would encourage entry of new vessels until average industry revenue is equal to the average factor cost. At this point the average industry profit is zero and marginal value product (MVP) is less than the price of the resource used (the cost of the effort). It is obvious that point H cannot be an optimal point for production because the same harvest and revenue could be earned with far less effort (E_2), at a much lower cost. Point H is called "over-exploitation," because too much resource (effort is expended and the fish stocks are pursued too intensively.

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[5] In this analysis VMP=MVP, because the product price is assumed to be fixed.

Biologists have in the past argued that if the fishery resources were controlled such that entry and effort were restricted, the rational choice for total harvest would be at point G with E_m effort, Figure III-3a, which would maximize total physical product or total value product. This point is MSY, calculated in equation III-9.

Economists, on the other hand, argued that the maximization of sustainable yield can be only a sub-optimal and the optimum depends on the position of the total value product and total factor cost curves, Figure III-3a. To economists, the optimum allocation of the resource is obtained only when equation III-21 is satisfied. In equation III-21, the optimum point of allocation changes as P_E (price of the input, or cost per unit of effort) varies.

Most past fisheries treaties of the U.S. have been written in terms of MSY, but biologists and managers have recently come to accept the concept of OSY. In fact, the U.S. Senate committee on commerce, in S 1988[6] in 1974, defined OSY as ". . . the largest net economic return consistent with one biological capabilities of the stock, as determined on the basis of all relevant economic, biological, political, and environmental factors."

Equations III-9 and III-11 calculate two points related to MSY, and euqations III-17 and III-18 are their equivalents for OSY. The main difference between equations III-9 and III-17 is the addition of the term $\frac{C}{2qP}$ in

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[6] Report No. 93-1079, August 8, 1974.

equation III-17. This term introduces the economic factors of input cost and output price. Optimum biomass, B*, is directly related to fishing cost and inversely related to output price. This relationship shows that if cost per unit of effort (C) increases, <u>ceteris paribus</u>, fishermen cut back in production (effort) and in the long run the equilibrium biomass moves upward. Also, as average price of fish increases, <u>ceteris paribus</u>, fishing becomes more profitable and production increases, which in the long-run foces the equilibrium biomass to decline. Equations III-11 and III-18 can also be compared. The difference is the term $(1 - \frac{C}{qPM})$. Optimum biomass, E*, is inversely related to fishing cost and directly related to output price which is exactly the opposite of that with biomass (B*).

Sources of Data

Great Lakes commercial fisheries have some important characteristics:

a) the most popular kinds of fish gear are gill nets and trap nets,

b) multiple species are usually caught by the same gear,

c) multiple gear types and mesh sizes are used for the same species,

d) species caught fluctuate between seasons, with shifting from one species to another with changes in abundance,

e) fish populations and fishing methods usually differ for different locations and seasons,

f) various regulations have been imposed on fishing activities at different times, including the present limited entry and gear restrictions,

g) various diseases and ecological problems have been very serious at various times, e.g. lamprey, DDT, PCB, etc.,

h) technology has changed rapidly,

i) biological information on catch and effort are insufficient,

j) economic data on size of different firms, labor structure, cost and returns, are insufficient.

At the present time there is no adequate data that can satisfy all these characteristics. In this section we introduce the important variables, the relevant available data, and their sources.

The model will be estimated using mostly annual data. The main variables are total whitefish effort and catch, cost per unit of effort, and the sea lamprey abundance index. A complete listing of all data needed in this study is provided in Table III-1, including the symbolic names, definitions and sources of all data.

Annual data for catch and effort of whitefish by fishing gear type in district one of Lake Michigan (MM-1) are given in Table III-2. Total catch (in pounds), total effort and catch per unit of effort (CPE) using 4 1/2 inch gill net as standard gear from 1963 to 1975 are given in Table III-3. In Figure III-4 catch, effort and CPE for 4 1/2 inch gill net are plotted over time. The sea lamprey index of abundance is presented in Table III-4.

Table III-1. Data Used in the Analysis (1929-1950) and (1963-1976)

Symbol	Definition-Description	Source
E	Total effort for trap, pound, and gill net, using gill net as standard gear.	National Marine Fishery Service, 1977
Y	Catch from different types of gear in pounds and kilograms	National Marine Fishery Service, 1977
S	Sea lamprey index of abundance	Walter and Hogman, 1971
C	Cost per unit of effort	Research in progress, Fisheries and Wildlife Dept., Sea Grant Project, Michigan State University

Table ~~III~~-2. Catch and Effort and Catch-per-Unit-of-Effort (CPE) for Different Types of Gear for Lake Whitefish in District MM-1

Year	2 in Gill Net		4½ in Gill Net		Pound Net		Deep Trap		Shallow Trap		Other Catch	CPE for Gill Net
	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort		
1929	29.0	0.0	596743.0	32538.0	535227.0	4729.0	0.0	0.0	1195.0	0.0	6435.0	18.34
1930	2.0	0.0	582761.0	38851.0	445969.0	5026.0	37655.0	286.0	2198.0	0.0	9163.0	15.00
1931	44.0	0.0	500828.0	38231.0	575457.0	5470.0	111523.0	1043.0	478.0	0.0	6639.0	13.10
1932	48.0	0.0	353998.0	30438.0	344086.0	4644.0	191979.0	1351.0	570.0	0.0	19425.0	11.63
1933	10.0	0.0	72722.0	10185.0	85755.0	2093.0	77161.0	1412.0	315.0	0.0	2206.0	7.14
1934	23.0	0.0	74682.0	7453.0	130407.0	2328.0	56918.0	763.0	378.0	0.0	597.0	10.02
1935	4.0	0.0	86125.0	9243.0	50246.0	1201.0	22783.0	250.0	90.0	30.0	4273.0	4.32
1936	24.0	0.0	51214.0	6789.0	37899.0	796.0	0.0	0.0	144.0	0.0	178.0	7.54
1937	12.0	0.0	54767.0	7638.0	50039.0	1315.0	0.0	0.0	18.0	0.0	53.0	7.17
1938	23.0	0.0	233314.0	19087.0	120829.0	2243.0	0.0	0.0	0.0	0.0	69.0	12.22
1939	59.0	0.0	100381.0	13565.0	136660.0	2168.0	0.0	0.0	378.0	0.0	31.0	7.40
1940	19.0	0.0	50170.0	6045.0	71015.0	1598.0	0.0	0.0	3.0	0.0	1596.0	8.34
1941	63.0	0.0	73707.0	5915.0	41982.0	1076.0	0.0	0.0	0.0	0.0	0.0	12.46
1942	4.0	0.0	66654.0	7245.0	25884.0	666.0	0.0	0.0	0.0	0.0	4.0	9.20
1943	54.0	0.0	113664.0	11133.0	27185.0	635.0	0.0	0.0	312.0	0.0	7.0	10.21
1944	6.0	0.0	180048.0	14662.0	51540.0	859.0	0.0	0.0	884.0	0.0	16.0	12.28
1945	69.0	0.0	173483.0	15786.0	60227.0	1148.0	0.0	0.0	0.0	0.0	8.0	10.99
1946	110.0	0.0	359150.0	22731.0	154520.0	1842.0	0.0	0.0	2.0	0.0	0.0	15.80
1947	2.0	0.0	1817156.0	64783.0	609838.0	3583.0	0.0	0.0	85.0	0.0	6.0	28.05
1948	18.0	0.0	2131876.0	102666.0	882108.0	5154.0	0.0	0.0	52288.0	218.0	0.0	20.77
1949	9.0	0.0	1526688.0	97985.0	710340.0	6678.0	0.0	0.0	25885.0	278.0	41.0	15.58
1950	207.0	49.0	1007323.0	60175.0	470993.0	5341.0	0.0	0.0	15041.0	505.0	0.0	16.74
1951	0.0	0.0	256166.0	20642.0	179810.0	2818.0	0.0	0.0	5066.0	172.0	0.0	12.41
1952	0.0	31.0	541556.0	31629.0	368168.0	2540.0	0.0	0.0	23243.0	187.0	71.0	17.12
1953	157.0	49.0	352623.0	24745.0	268224.0	2762.0	0.0	0.0	14765.0	287.0	0.0	14.25
1954	0.0	0.0	195954.0	19076.0	297525.0	3404.0	0.0	0.0	8425.0	256.0	0.0	10.27
1955	0.0	0.0	29337.0	4204.0	36026.0	1369.0	0.0	0.0	4408.0	359.0	0.0	6.98

Table III-2 Continued

Year	2 in Gill Net		4½ in Gill Net		Pound Net		Deep Trap		Shallow Trap		Other Catch	CPE for Gill Net
	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort	Catch	Effort		
1956	0.0	0.0	3584.0	870.0	2536.0	176.0	0.0	0.0	5164.0	141.0	0.0	4.12
1957	0.0	0.0	60.0	110.0	456.0	59.0	0.0	0.0	3251.0	44.0	0.0	.55
1958	0.0	0.0	53.0	42.0	866.0	82.0	0.0	0.0	1138.0	0.0	0.0	1.26
1959	0.0	0.0	4.0	1.0	48.0	0.0	0.0	0.0	453.0	0.0	0.0	4.00
1960	0.0	0.0	3760.0	498.0	2252.0	163.0	0.0	0.0	2412.0	138.0	0.0	7.55
1961	11.0	0.0	34122.0	3927.0	11088.0	220.0	0.0	0.0	3572.0	108.0	0.0	8.69
1962	0.0	0.0	13965.0	1374.0	17027.0	190.0	0.0	0.0	3187.0	70.0	0.0	10.15
1963	0.0	0.0	2022.0	257.0	70953.0	277.0	0.0	0.0	661.0	37.0	0.0	7.87
1964	0.0	0.0	45037.0	4373.0	30081.0	353.0	0.0	0.0	6360.0	170.0	0.0	10.30
1965	0.0	0.0	35563.0	3487.0	74217.0	175.0	0.0	0.0	7780.0	103.0	0.0	10.20
1966	0.0	0.0	39194.0	3377.0	46606.0	513.0	0.0	0.0	0.0	0.0	0.0	11.61
1967	31.0	6.0	68680.0	5631.0	45491.0	666.0	0.0	0.0	0.0	0.0	376.0	12.20
1968	0.0	0.0	80775.0	6498.0	31000.0	625.0	0.0	0.0	4.0	1.0	0.0	12.43
1969	5.0	11.0	127051.0	7073.0	81083.0	742.0	1455.0	29.0	0.0	0.0	417.0	17.96
1970	0.0	0.0	222329.0	9797.0	127854.0	1106.0	0.0	0.0	479.0	18.0	1647.0	22.69
1971	20.0	2.0	753747.0	18380.0	205192.0	959.0	0.0	0.0	14477.0	131.0	2135.0	41.01
1972	0.0	0.0	807223.0	17313.0	272485.0	787.0	0.0	0.0	12249.0	149.0	1395.0	46.66
1973	0.0	0.0	956788.0	19569.0	307320.0	1156.0	0.0	0.0	36737.0	218.0	5.0	48.89
1974	0.0	0.0	605749.0	17160.6	390213.0	1158.0	0.0	0.0	48066.0	148.0	70.0	35.30
1975	0.0	0.0	479247.0	12930.5	135640.0	834.0	0.0	0.0	311877.0	1157.0	0.0	37.06
1976	0.0	0.0	372342.0	9566.7	162233.0	562.0	0.0	0.0	749862.0	2508.0	3268.0	38.92

Table III-3 Total Catch in Pounds and Total Effort for Lake Michigan in District MM-1 (Using 4 1/2 Inch Gill Net as Standard Gear)

Year	Total Catch	Total Effort	Catch/Effort (CPE)
1963	73,636.00	9,359.27	7.87
1964	81,478.00	7,911.35	10.30
1965	117,560.00	11,526.92	10.20
1966	85,800.00	7,392.63	11.61
1967	114,578.00	9,394.13	12.20
1968	111,779.00	8,992.14	12.43
1969	210,011.00	11,691.43	17.96
1970	352,309.00	15,524.61	22.69
1971	975,571.00	23,789.14	41.01
1972	1,093,352.00	23,449.78	46.63
1973	1,300,850.00	26,606.03	48.89
1974	1,044,098.00	29,578.83	35.30
1975	926,764.00	25,004.90	37.06
1976	1,287,705.00	33,085.95	38.92

FIGURE III-2. Trend of Catch (pounds), Effort, and CPE for MM-1, 1929-1976, for 4 1/2 Inch Gill Net Fishing Only

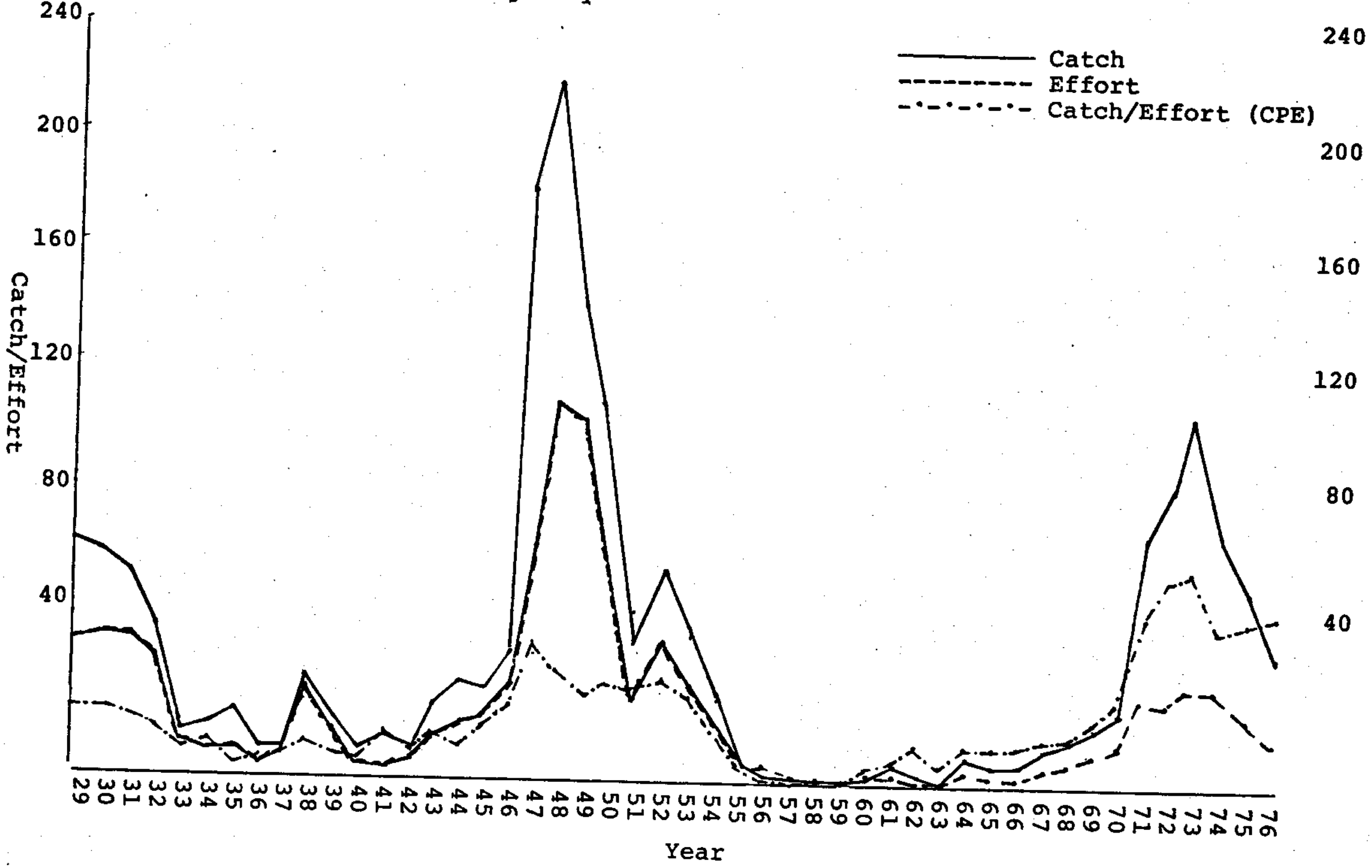

Table III-4. Sea Lamprey Abundance Index

Year	Index of Abundance
1945	1
1946	3
1947	16
1948	27
1949	43
1950	148
1951	345
1952	90
1953	252
1954	199
1955	164
1956	155
1957	165
1958	80
1959	68
1960	52
1961	101
1962	63
1963	59
1964	36
1965	29
1966	9
1967	0
1968	0
1969	0
1970	0
1971	0
1972	0
1973	0
1974	0
1975	0

IV. SUMMARY AND CONCLUSIONS

Great Lakes commercial fishing has changed drastically in the past century. Apparently the overexploitation in the 1930's in Lake Michigan, and the sea lamprey which invaded almost all the lakes from the 1930's until late 1950's reduced some fish stocks drastically, forcing some fishermen out of business. Technological advances in the 1950's and 1960's, on the other hand, improved fishing gear efficiency, so even less fishermen were required to harvest the available fish. The number of licensed fishermen dropped from about 1100 in early 1950's to about 150 at present. The discovery of toxic chemicals such as DDT and PCB in late 1960's and early 1970's affected the supply and consumer demand for all Great Lakes fish, particularly lake trout. The overall situation has not been in favor of the commercial fishermen for a large time, changing the profitable and dominant commercial fishing industry to a small, generally poor, and over-capitalized industry.

In order to better utilize the available fishery resources, more specific knowledge about the economic values are required.

The main purpose of this feasibility study was to provide some tools that can be used to document some of the economic values. The relevant biological, economic, and bioeconomic models were reviewed in this paper, and a bioeconomic model for the Great Lakes whitefish fishery was developed. The present data are not very accurate but the outcome can be a good basis for evaluating future results.

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APPENDIX

APPENDIX

Common and Scientific Fish Names

Common Name	Scientific Name
Yellow perch	Perca flavescens
Walleye	Stizostendion vitreum
Largemouth bass	Micropterus salmoides
Small mouth bass	Micropterus dolomieui
White bass	Roccus chrysops
Bluegill	Lepomis macrochirus
Pumpkinseed	Lepomis gibbosus
Black crappie	Pomoxis nigromaclatus
Rock bass	Ambloplites rupestris
Muskellunge	Esox masquinongy
Northern pike	Esox lucius
Suckers	Catostomidae
Rainbow smelt	Osmerus mordax
Lake trout	Salvelinus namaycush
Rainbow trout (steelhead)	Salmo gairdneri
Brown trout	Salmo trutta
Brook trout	Salvelinus fontinalis
Coho salmon	Oncorhynchus kisutch
Chinook salmon	Oncorhynchus tshowytscha
Pink salmon	Oncorhynchus gorbuscha
Lake sturgeon	Acipenser fulvescers
Carp	Cyprinus carpio
Lake whitefish	Coregonus clupeaformis
Sea lamprey	Petromyzon marinus
Alewife	Alosa pseudoharengus
Chub	Coregonus spp.
Sticklebacks	Gasterosteidae
Sculpins	Cottidae