NOAA Technical Memorandum NMFS SEFC - 17

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EVERYTHING YOU ALWAYS WANTED TO KNOW ABOUT MSY AND OY (BUT WERE AFRAID TO ASK)

J.R. Zuboy and A.C. Jones

June 1980

U.S. DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary
National Oceanic and Atmospheric Administration
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National Marine Fisheries Service
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Subject: Everything you always wanted to know about MSY and OY (but were afraid to ask) by J. R. Zuboy and A. C. Jones

ERRATA SHEET

Cover: Should read: NOAA Technical Memorandum NMFS-SEFC-17
Add affiliation -- (at bottom) Southeast Fisheries Center
75 Virginia Beach Drive
Miami, Florida 33149

Page 8: Equation (3) should be: $Y_e/f_e = a - bf_e$

where Y_e/f_e = equilibrium catch per unit of effort

f_e = equilibrium fishing effort.

Page 9: Equation (5) should be: $MSY = F\ (0.5\ B_o)$.

Page 19: The following should be added after "instantaneous rate (0.69)" :

would add to 2.07, which corresponds to a mortality rate of 87% of the original number of fish after three years.

An analogy which may further help to demonstrate the difference between annual and instantaneous rates is simple versus compound interest in banking. Simple interest is analogous to annual growth rate; compound interest is analogous to instantaneous growth rate. A deposit of $100 in a savings account at 5% simple interest accumulates to $105 when the interest rate is applied once at the end of the year (annual rate). The same $100 accumulates to $105.13 if the 5% rate is applied daily (close to instantaneous).

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The eight fishery management councils established by the Fishery Conservation and Management Act of 1976 are mandated to manage U.S. marine fisheries resources occurring in the fishery conservation zone based on the concepts of maximum sustainable yield (MSY) and optimum yield (OY). Fulfilling the mandate requires a thorough understanding of these concepts. It is the purpose of this paper to present a non-technical discussion of maximum sustainable yield and optimum yield to facilitate understanding by the councils, which are composed largely of laypersons, so that they may carry out their duties under the Act. (Author)

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Everything You Always Wanted to Know About MSY and OY (But Were Afraid to Ask)[1]

J. I?. Zuboy And A. C. Jones[2]

ABSTRACT

The eight fishery management councils established by the Fishery Conservation and Management Act of 1976 are mandated to manage U.S. marine fisheries resources occurring in the fishery conservation zone based on the concepts of maximum sustainable yield and optimum yield. Fulfilling the mandate requires a thorough understanding of these concepts. It is the purpose of this paper to present a nontechnical discussion of maximum sustainable yield and optimum yield to facilitate understanding by the councils, which are composed largely of laypersons, so that they may carry out their duties under the Act.

INTRODUCTION

Two of the most bantered about terms in the world of fishery management today are maximum sustainable yield (MSY) and optimum yield (OY). The MSY concept has been with us for a long time and actually reached its pinnacle in the 1950's. OY is a concept of the 1970's. Many people feel that MSY has outlived its usefulness now that OY has arrived on the scene. In fact, Larkin (1977) went so far as to tender "An Epitaph for the Concept of Maximum Sustained Yield" in his keynote address at the annual meeting of the American Fisheries Society in 1976. While we agree that managing strictly for MSY is outdated in this energy-hungry, limited-resource world, the fact of the matter is that MSY will remain a functional concept for many years to come. There are two reasons for this: 1) the Fishery Management and Conservation Act (FCMA) of 1976 (Public Law 94-265) has given MSY a new lease on life by making MSY the basis on which OY is prescribed, "as modified by any relavent economic, social, or ecological factor," and by requiring MSY as well as OY to be speci-

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'A nontechnical paper on the fisheries concepts of maximum sustainable yield (MSY) and optimum yield (OY). Presented at a meeting of the Caribbean Fishery Management Council in Santurce, Puerto Rico.

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fied in any fishery management plan prepared under the Act, and 2) the complexities of arriving at a consensus as to what constitutes OY for a particular fishery are such, that for many cases OY is likely to be designated as equal to MSY--at least for the foreseeable future.

Given then that the Regional Councils will have to deal extensively with both concepts and that the Council members in general are decisionmakers, not fishery scientists per se, it is the purpose of this paper to provide a functional (nontechnical) perspective of the concepts to facilitate understanding and thereby aid the Councils in fulfilling their duties under the Act. First we'll discuss MSY--what is it, how do we estimate it, how reliable is our estimate--and then give some examples. Then we'll do much the same for OY. Hopefully, by the time all is said and done, a clear picture of the concepts and their application will begin to emerge.

MAXIMUM SUSTAINABLE YIELD

As defined by Ricker (1975), MSY is the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. Thus, MSY is strictly a biological concept, giving no consideration to economic, social, or political factors. The concept of MSY is based on the reasonable postulate that a fish stock produces its greatest harvestable surplus when it is at an intermediate level of abundance. There are three reasons for lessened surplus production at maximum abundance or high stock densities:

1) Near the maximum stock density, efficiency of reproduction is reduced, and often the actual number of recruits is less than at smaller densities.
2) When food supply is limited, food is less efficiently converted to fish flesh by a large stock than by a smaller one. Each fish of the larger stock gets less food individually: hence a larger fraction is used merely to maintain life, and a smaller fraction for growth.
3) An unfished stock tends to contain more older individuals, relatively, than a fished stock. This makes for decreased production, in at least two ways.
    a. Larger fish tend to eat larger foods, so an extra step may be inserted in the food chain, with consequent loss of efficiency of utilization of the basic food production.
    b. Older fish convert a smaller fraction of the food they eat into new flesh, partly, at least, because mature fish divert much substance to maturing eggs and milt.

Under reasonably stable natural conditions the net increase of an unfished stock is zero, i.e., on the average, growth is balanced by natural deaths, and there is no surplus production. Introducing a fishery increases production per unit of stock due to one or more of the reasons above, and so creates a surplus which can be harvested (Ricker 1975). The problem, then is how do we estimate the surplus production?

Basically, there are two models used to estimate potential yield from a fishery, either in terms of MSY or in terms of maximum yield per recruit (Y/R). They are the production model (Synonyms: surplus production model, stock production model, logistic model, and Schaefer model) and the yield per recruit model (synonyms: dynamic pool model, Beverton and Holt model).

Production Model

The production model has its roots in the logistic "law" of population growth, which was first advanced by the French mathematician Verhulst in 1838. He described logistic population growth by the differential equation:

$$dN/dt = (rN)\ (K-NJ/K \qquad (1)$$

where
- N = population in numbers
- r = reproductive capacity (rate of surplus production, in our sense)
- K = maximum population size that can exist in a given ecosystem.

A plot of the Verhulst equation yields an S-shaped curve which in mathematical jargon is termed a logistic Curve (Fig. 1). In words, Equation (1) simply says that the rate of change of population numbers over time, in a limited environment, is a function of the reproductive capacity and the size of the population. This. simple concept was extended by Graham (1935) to account for the change in biomass (weight rather than numbers) of a fish stock over time as a function of the rate of surplus production (recruitment plus growth less natural mortality). He further' demonstrated that under equilibrium (steady state) conditions, when fishing removes the surplus production of the stock at the same rate it is produced, the population

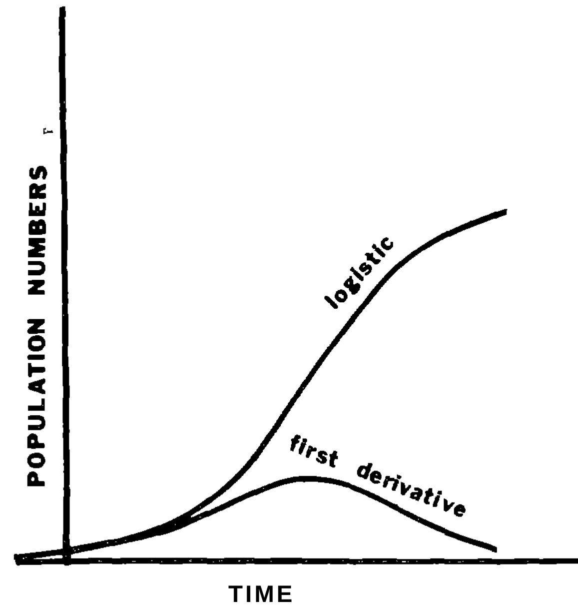


Figure 1.--The logistic curve and its first derivative. (After Pearl 1927.) The peak of the first derivative curve corresponds to the inflection point of the logistic curve, i.e., the point where rate of surplus production is a maximum. Analogously, the peak of the yield curve is the point of maximum yield.

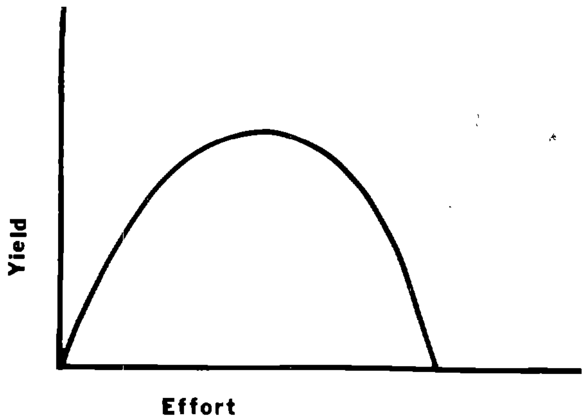


Figure 2.--Schaefer model of the relationship between effort and yield.

size remains constant and the annual catch becomes the annual equilibrium yield. It remained for Schaefer (1954, 1957) to extend the concept to relating yield directly to fishing effort by the simple parabola we are familiar with today (Fig. 2). There have been a number of modifications to the production model in recent years, but we will do no more than reference them here (Gulland 1961: Pella and Tomlinson 1969: Fox 1970, 1975; Walter 1973, 1978; Ricker 1975; Marchessault, Saila, and Palm 1976; Schnute 1977). If we can elicit an understanding of the basic production model, its data requirements, assumptions, and applications, we will have achieved our purpose.

The beauty of the production model is its simplicity. The only data needed to apply the model are catch and effort for a series of years. The usual method of applying the model to the data is to statistically fit a straight line (linear regression) to the relationship of catch per unit effort (CPUE) and effort (Fig. 3,

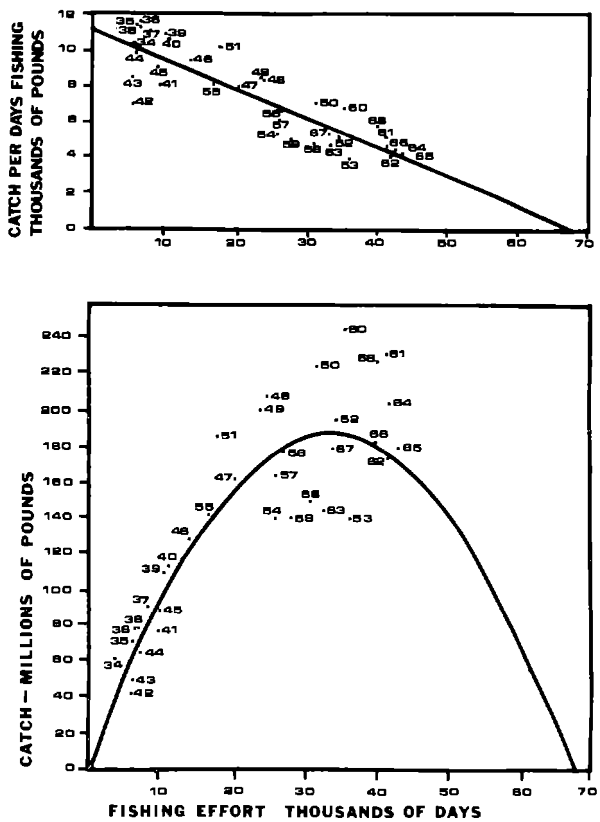


Figure 3.--The relations between fishing effort and catch per unit effort (upper figure) and total catch (lower figure) in the yellowfin tuna fishery. (from IATTC Annual Report 1968).

upper), thereby estimating the constants necessary for fitting the parabola (Fig. 3, lower) to the annual yield and effort data. The same constants are used in the appropriate equations to estimate the highest point of the parabola (which corresponds to the MSY) and the optimum fishing effort associated with the MSY.

There are a number of suumptions involved with the production model (indeed with all mathematical models), and herein lies the rub--rarely are the assumptions completely satisfied. The major assumptions associated with the production model are:

1) The fishery is in equilibrium, i.e., stock structure has adjusted to and stabilized at the current level of fishing effort.
2) Environmental factors are constant.
3) The fishery is operating on a "unit stock," i.e., a stock capable of independent exploitation or management and containing as much of an interbreeding unit or as few reproductively isolated units as possible (Royce 1972).
4) The number of recruits and the natural mortality rate are constant regardless of stock size.
5) One unit of fishing effort produces the same relative effect on the stock, that is, it catches the same percentage of the stock, regardless of the time or place it is applied or regardless of the size of the stock.
6) The rate of natural increase of the stock responds immediately to changes in population density, i.e., the time lag between spawning and recruitment of progeny to the catchable stock is ignored.
7) The rate of natural increase at a given weight of population is independent of the age composition of the population.

As one can easily see, all of the assumptions can never be met. However, assumptions not withstanding, the model still provides us with a first rough estimate of the potential yield that can be expected from a given stock of fish. Now let's look at some examples.

Schaefer's (1957) paper on Pacific yellowfin tuna is the classic on production modeling. The biological characteristics of the beast and the nature of the fishery lend themselves nicely to production model analysis. The model provided a reasonably good description of what was happening in the fishery until the mid-1950's (Fig. 3, lower). After that time, however, there is much more scatter evident in the points about the curve. If the data for 1969 and 1970 were included, the scatter would be even more obvious, as the catches for those years were 253 and 284 million pounds, respectively. The primary reasons for the failure of the model to adequately describe the fishery in recent years are: 1) a progressive change in the type of fishing effort from bait boats to super seiners, and 2) a progressive expansion of the fishing grounds beyond the area covered by the original analysis. The model did, however, provide the basis for adequate scientific advice to industry and fishery management decision-makers for many years.

To bring the discussion a little closer to home, here are a few examples[3] of the

[3]The example in Figures 4, 5, and 6 are for illustrative purposes only and do not necessarily reflect the current status of the stocks.

production model applied to fisheries in the Southeast Region. We won't discuss all the assumptions and analytical problems specific to each case, but just show the production curves to provide a "feel" for how the model is applied to different fisheries.

Figure 4 is an example of the producon model applied to the Gulf of Mexico menhaden fishery. Note that the data points are for the most part very close to the curve in the early years of the fishery, but as the fishery approaches MSY there is considerable variation from the curve. This is the usual picture presented by the production model. The model shows that the fishery has been producing above the level of MSY for the last years, but that the level of effort is also above the optimum. The menhaden fishery is relatively easy to deal with in terms of standardizing fishing effort because there is no recreational fishery to consider and no foreign fishing effort.

Figure 5 shows a production model fit to Gulf of Mexico brown shrimp data. The model suggests that this particular fishery is operating at about MSY. Note that yield is given in both heads-off and live (heads-on) weight.

Figure 6 shows the production model fit to the grouper fishery off the west coast of Florida. This fishery is difficult to assess because a large number of species are involved and there are domestic commercial, foreign, and recreational fisheries to be considered (just to mention

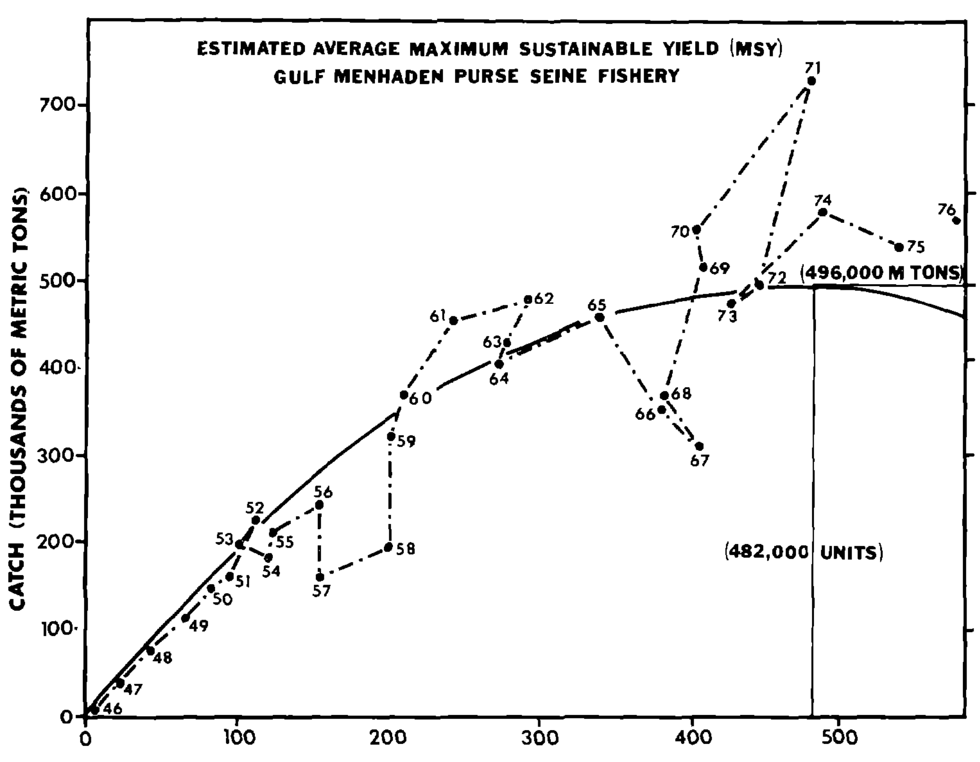


Figure 4. --Production model of the Gulf of Mexico menhaden fishery (NMFS, Beaufort Lab.).

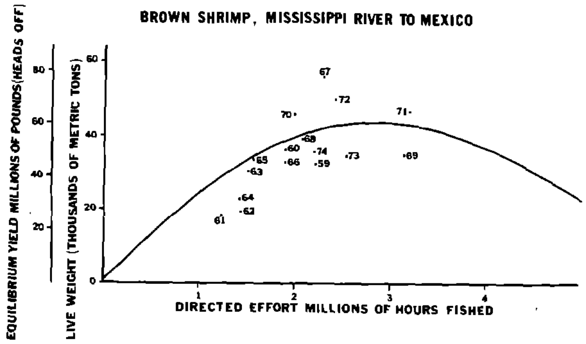


Figure S.--Production model for Gulf of Mexico brown shrimp (NMFS, Galveston Lab.).

two of the problems). The model shows that the fishery, if all the data and assumptions are- correct, is not yet at MSY but is approaching that level.

This discussion and examples so far have revolved around fitting the production model using a time series of catch effort data. The three variables: catch, effort, and catch per unit effort(CPUE) are, of course, related. Knowing any two, the third can be calculated directly.. In

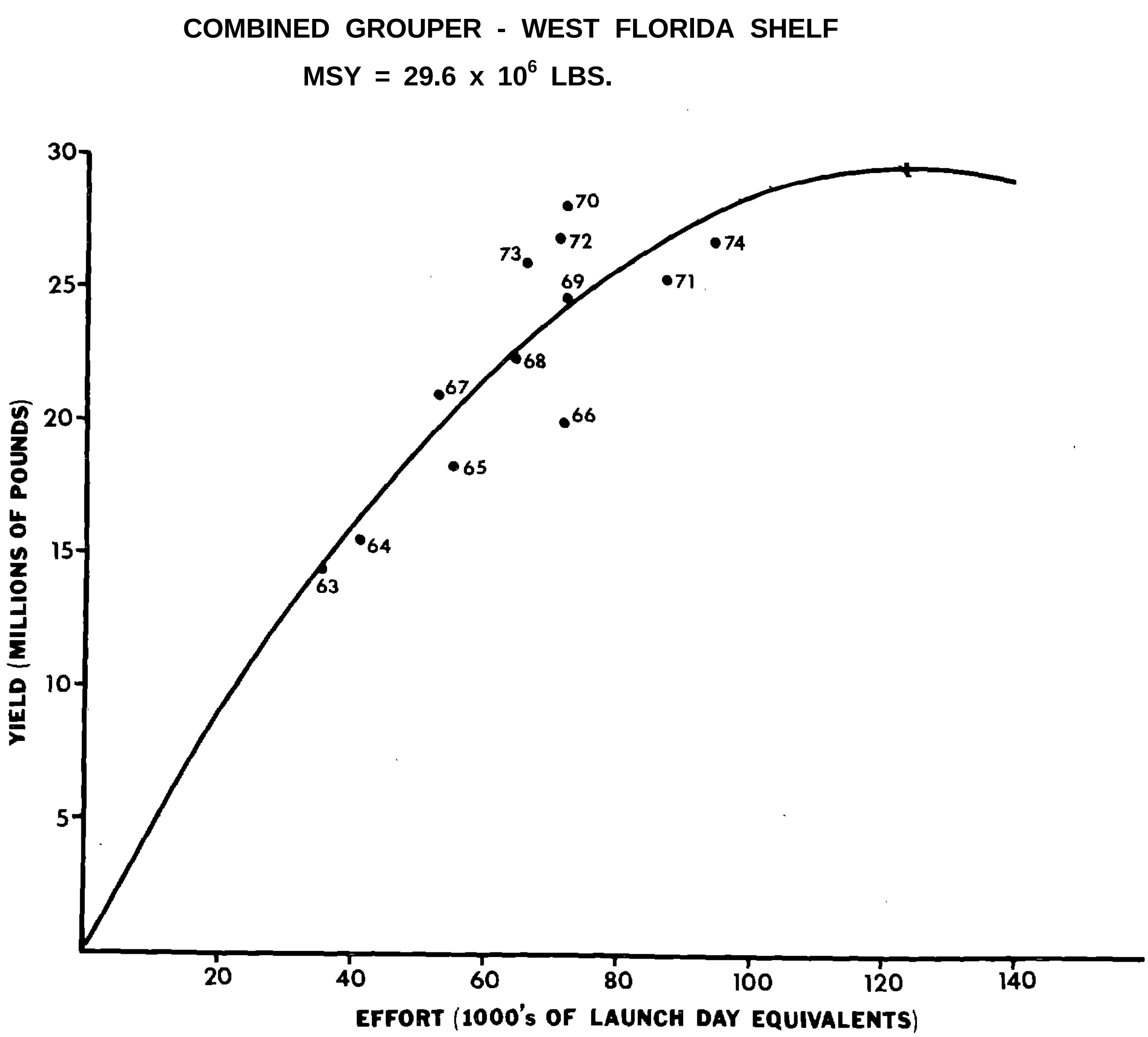


Figure 6.--Production model of the West Florida Shelf grouper fishery (NMFS, Miami Lab.).

some fisheries where total catch is known but total effort is not, CPUE for a selected (well-behaved) part of the fishery can be used to estimate total effort by:

$$\frac{\text{total catch}}{\text{CPUE (selected)}} = \text{total effort.} \quad (2)$$

The model is then fit by regressing CPUE against total effort. This is a neat trick, and perhaps the only way to fit the production model in some fisheries, however, a word of caution. It has been shown (Knights and Pope 1975) that when calculated this way, the result is a parabola even if both catch and CPUE are random numbers! Thus, even if there is no relationship between CPUE and effort a correlation can be shown. The same spurious results are obtained when fitting the production model by averaging effort for a number of years to simulate equilibrium conditions as suggested by Gulland (1968) or when using efficiency factors. In the latter case, a small allowance for increase in the efficiency of fishing effort is included in the calculations. Calculated this way, if actual CPUE and effort were constant for all years, the addition of a 4% annual increase in efficiency factor would produce a parabola. Thus, if CPUE varied randomly and effort were constant, the use of efficiency factors would tend to produce a correlation where one did not previously exist.

Before leaving the production model we would like to mention briefly two methods of estimating MSY which are based on the model, but do not require a time series of catch and effort data. We'll call these the equilibrium period (EP) approach and the virgin stock biomass (VSB) approach.

Under equilibrium conditions, surplus production is a parabolic function of rate of fishing (F) and of fishing effort (f) as well as stock size. The relationship can be fitted with the equation:

$$Y_e/f_e = bf_e \quad (3)$$

where Y_e = equilibruim catch per unit of effort
f_e = equilibrium fishing effort.

Hence, values of yield per unit effort and effort for two equilibrium periods can be substituted in Equation (3) and by solving the two simultaneous equations thus obtained, values for the parameters (constants) a and b can be derived (Ricker 1975). Having values for a and b, MSY is calculated from:

$$MSY = a^2/4b. \quad (4)$$

This approach was used to estimate MSY in the Puerto Rico spiny lobsters fishery. A time series of catch and effort data was not available; however, an estimate of catch and effort for two periods, 1951 and 1976, was available. These years were assumed to be periods when the fishery was in equilibrium. The data were:

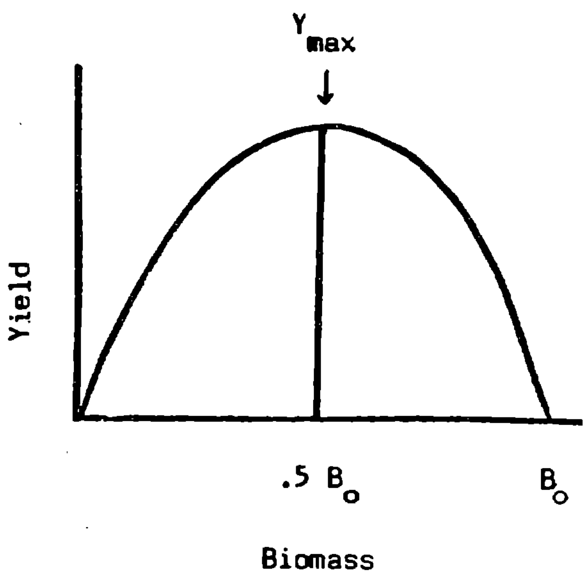
	1951	1976
Fish pots	4,473	8,271
Pounds	467,000	480,000
Pounds/fish pot (CPUE)	104	58

Employing the EP approach, MSY

was estimated as 516,000 lb at an effort level of about 6,500 fish pots.

The VSB approach can be used when there is no catch and effort data available, but where biomass of the virgin (unexploited) stock can be estimated (Gulland 1971). Biomass estimates are sometimes available from exploratory fishing surveys, egg or larval studies, acoustic or echosounding surveys, and gut contents of predatory species.

The VSB approach is based on the logistic model of population growth, in which the maximum yield (Y_{max}) is taken when the population biomass is half the unexploited or virgin stock biomass (B_o) as shown below.



Assuming fishing rate to be equal to natural mortality rate in the virgin stock, the equation for estimating MSY is:

$$MSY = F\ (0.5b_0). \qquad (5)$$

In words, Equation (5) says that MSY is equal to one-half the virgin stock biomass (B_o) multiplied by the fishing mortality rate (F).

The EP and VSB approaches both enable a quick and dirty estiate of MSY to be made when there may be no other alternative. The estimate thus derived is obviously very gross, but it may be all that we have and may at least be on the right order of magnitude.

A final word on modeling for predictive purposes. Prediction, based on a model, is most reliable when the entire range of conditions has been observed. Predicting the behavior of a phenomenon beyond the range of observed data is usually ill-advised (but often necessary). The production model, therefore, like other models, is best at predicting MSY after MSY has been exceeded but this is when management measures are usually more difficult to apply.

YIELD PER RECRUIT MODEL

The first attempt to describe a fishery in terms of the vital parameters of recruitment, growth, and mortality instead of only in terms of population size is generally attributed to Baranov (1918). This type of yield model is formulatated by following a group of recruits through their life from entry into the fishery (t_c) until the end of their fishable life span (t_m). The general form of the equation which describes this situation is

$$Y = \sum_{t_c}^{t_m} FN_t w_t dt. \qquad (6)$$

In words, this equation says that Y from a year-class (cohort) during its life in the fishery is determined by taking into account the number (N_t) remaining each year, converting that number to weight using an appropriate growth function (W_t) deriving the proportion of the weight which is removed by fishing mortality (F), and then summing from t_c to t_m. Under equilibrium conditions the total catch each year is equal to the total harvest from a year-class during its life, thus Equation (6) represents the annual equilibrium yield. Unfortunately, we seldom know anything about the level of reruitment, and so the dynamic pool model is usually employed to estimate only yield per recruit, i.e.,

$$Y/R = \sum_{t_c}^{t_m} (FN_t/R)\ w_t dt. \quad (7)$$

At times yield per recruit has been treated as if it were total yield leading to much confusion between the result of this model and the result of a prodution model which gives estimates of total yield (MSY). Yield per recruit and total yield are equivalent only if the absolute recruitment is constant for all values of population size (Schaefer 1968).

The shape of the yield per recruit curve is determined by the growth and natural mortality rates (instantaneous) of the stock in question. A stock with a low growth rate and/or a high natural mortality tends to have a flat-

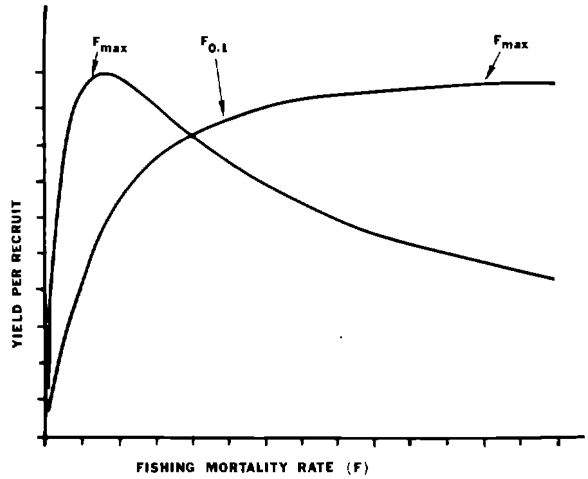


Figure 7.--The two basic shapes of the yield per recruit curve as determined by growth and natural mortality rates.

topped Y/R curve (Fig. 7). This type of curve suggests that there is no reduction in yield even at very high fishing mortality rates. There is no clearly defined maximum point (F_{max}) on the curve. This poses a problem since the implication is that the stock can sustain high fishing mortality without fear of overfishing, which may not be true if recruitment is dependent on the size of the adult stock. To deal with this problem, fisheries scientists have designated $F_{0.1}$ as the optimal fishing mortality rate. This rate is determined as the point at which the slope of the yield per recruit curve is one-tenth of the slope at the origin (Fig. 7). Thus, although some amount of yield is lost by designating $F_{0.1}$ as the optimal fishing mortality rate, the stock is protected from overfishing.

A low natural mortality rate and high growth rate produces a Y/R curve which is dome-

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[4]See Appendix for discussion of instantaneous rates.

shaped (Fig. 7). This type of curve has an obvious F_{max} at a rather low level of fishing mortality and tends to drop off substantially at high F levels. The management implication of this curve is that overfishing is a distinct possibility even at low fishing mortality rates.

Even if one selects the F_{max} (or $F_{0.1}$), which maximizes yield on a per recruit basis, there is no guarantee that this F value will produce the maximum total yield. This is because a yield per recruit analysis is based on the existing exploitation pattern which in turn can cause major changes in yield per recruit and hence total yield.

The yield per recruit model suffers many of the assumptions mentioned for the production model. In addition, one must be able to estimate values for the vital parameters, such information being scarce or entirely lacking in most fisheries; and, once again, the model does not provide an estimate of MSY, but only an estimate of yield per recruit under specified conditions. Since we are primarily interested in MSY and OY in this paper, examples of yield per recruit curves will not be provided here. However, this brief treatment of the Y/R model should not be interpreted to mean the model is of little importance. Y/R analysis, under the appropriate circumstances, is an invaluable tool for fisheries stock assessment.

We have looked at the two primary methods of assessing the biological potential of a fishery now how do we get from MSY to OY?

OPTIMUM YIELD

BY now the definition of OY as stated in the FCMA should have the status of a household word, however, it won't hurt to state it once more, just to set the stage for our discussion.

The term "optimum," with respect to the yield from a fishery, means the amount of fish 1) which will provide the greatest overall benefit to the Nation, with particular reference to food production and recreational opportunities; and 2) which is prescribed as such on the basis of MSY from such fishery, as modified by any relevant economic, social, or ecological factor.

Thus, FCMA defines OY but gives no specific guidance as to how it should be determined. If it were possible to quantify all of the economic, social, and ecological factors involved in any given fishery, it would be relatively simple to calculate an OY using some type of mathematical optimization routine. However, this is not possible now and may never be possible. So it seems that OY will have to be determined subjectively based on expert (hopefully!) opinion, at least for the time being. There are probably a number of ways of soliciting expert opinion and trying to bring about a consensus. We will mention just two approaches here.

American Assembly Approach

In this approach a number of experts are assembled at one time and place, and they attack the problem as a group. Each person brings his/her own particular expertise (e.g., economics, fishery biology, or sociology) to bear on the problem. The group, after considerable interaction, integrates all of the relevant data that has been shared, into a consensus, and thus arrives at. a specification for OY.

The major problem with this approach (and each approach has its own inherent problems) occurs in any group interaction. Some members of the group tend to dominate the discussion while others remain quietly on the sideline. There is a natural tendency for some people to be reserved in group discussions for fear of saying something stupid or being put down. In other words, there is a lot of ego involvement in group interaction, and this may have a negative effect on the results produced in this type of atmosphere.

The American Assembly approach was used at the University of Miami to obtain descriptive and quantitative socioeconomic information about mackerel fisheries (Austin et al. 1977). People working "in" the fisheries (fisherman and processors) and "on" the fisheries (biologists and managers) contributed their ideas, understanding, and opinions about the fisheries during a workshop discussion. The discussion was based on background papers prepared from previous contact with the individual participants and from published materials. The background papers were a starting point for the discussion, and the technique allowed a consensus to be formed in some cases, or at least divergent opinions to be stated in others.

The Delphi Technique

The Delphi Technique may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem (Linstone and Turoff 1975). The major features of a Delphi are: Some feedback in individual contributions of information and knowledge, some assessment of the group judgment or view, some opportunity for individuals to revise views, and some degree of anonymity for the individual responses.

Here's how a Delphi would work. The investigator(s) identifies a group of experts on the subject (experience indicates that about eight are necessary). These experts are then polled individually. This insures confidentiality, which is a very important feature of Delphi. In this way, the answers of one person are not influenced by the answers or behavior of another person. The results are collected and tabulated by the investigator, which generally entails determining the range and median for all responses to a given question. This information is then given to each respondent, and they are asked to reanswer the question, considering the new "data" generated by the aggregate responses. If their new responses are outside the interquartile range from the previous round, they must write a short explanation of why they feel their answer is correct. These explanations are then given to the respondents in the next round.

Cycling through this procedure usually results in a consensus by the fourth or fifth round.

Probably the biggest problem in applying the Delphi technique is in getting someone who is either familiar with the technique, or willing to learn about it, to act as the investigator. This person(s) should, ideally, be familiar with the particular problem to some degree, which would help in Posing the right questions.

An example of how the Delphi Technique has been employed in the area of resource management is provided by the Michigan Sea Grant Program (Ludlow 1972). The Michigan Sea Grant Delphi inquiries were designed to obtain and refine an interdisciplinary group of researchers' judgements about issues and developments that should be considered with planning for inteligent management of the water resources of the Great Lakes. The Delphi provided some carefully formulated judgements of a multidisciplinary team of researchers and potential users of researh data regarding: The importance and effects of technical, social, economic, and political developments; sources of pollution and recommended waste-water treatment and disposal systems; and regional opportunities, problems, and planning strategies. More important, a critical evaluation of the method has shown the potential of a Delphi inquiry for improving the dialogue between researchers and regional problem solvers (Ludlow 1975).

These are a couple of ideas about how to functionally attack the problem of obtaining consensus in group communications, Now it may be useful to examine what OY might look like in the real world.

In his summary and critique of the Symposium on Optimum Sustainable Yield, Roedel (1975:85-88) discussed ten possible configurations of OY, as he envisioned the concept being applied. We'll simply list them here.

1. The optimum yield will in certain fisheries be equal to the MSY.
2. The optimum yield may approach zero harvest for substantial stocks that are demonstrated to fill essential niches in the food chain for more desirable species.
3. The optimum yield will for many fisheries approximate the maximum net economic yield.
4. The optimum yield may for limited periods exceed the MSY if economic or social demands so dictate.
5. The optimum yield from certain fisheries will require harvest rates greater than the MSY of some of their component species, particularly in multispecies trawl fisheries.
6. The optimum yield for some stocks will be that which will maintain only' the minimum population necessary to ensure the species' continued existence.
7. The optimum yield from the point of view of a country having control of a stock, might be to let another nation harvest that stock at a predetermined rate in return for cash,

credit, or some other sort of rights.

8. The optimum yield can be less than the conventional concept of maximum net economic yield for certain marine stocks of primary interest to sport fishermen in developed countries.
9. The optimum yield will be zero harvest for species considered to be of greatest value for their aesthetic interest (the California garibaldi), or for inhabitants of fragile environments that could be damaged by intrusion of man or his gear, or of environments that have high scenic values (coral reefs, underwater parks).
10. The optimum yield for "desirable" stocks that are already overharvested will range from zero up, depending on the level to which one desires to restore the stock and the speed with which one wants to reach that level."

Thus, the OY concept provides a set of options for fishery management which were not available under the concept of MSY alone.

What has been the track record for OY so far? It's only been a little over a year since implementation of FCMA, and not many fishery management plans have been written and approved. A quick look at the few plans that have been approved, however, may indicate the future trend of OY management.

The first plan we'll look at is the Atlantic Groundfish Plan (1977) for haddock, cod, and yellowtail flounder. Each species will be discussed separately.

cod.--Two stocks of cod are considered in the plan, the Gulf of Maine (GM) stock and the Georges Hank-Southern New England (GB-SNE) stock, MSY for the GM stock is 10,000 t and 50,000 t for the SNE stock. Available data indicate that the total combined domestic commercial, foreign commercial, and recreational catch has been at or below MSY in both areas in recent years, but that the fishing effort has been higher than the level necessary to produce MSY. This indicates that the stock abundance should be allowed to increase. Fisheries scientists recommended the commercial catches be set at 3,200 t for GM and 15,000 t for SNE to allow the stocks to rebuild. U.S. fishing industry advisors pointed out the potential adverse economic impacts on the harvesting sector if the quotas were implemented. A compromise was reached, and the quota figures were raised to 5,000 t and 20,000 t, respectively. The expected catches by recreational fishermen were 2,300 t for GM and 10,000 t for SNE, thus making the optimum yields for these two stocks 7,300 t and 30,000 t.

Here we have an example of how OY was arrived at with consideration given to the biological status of the stocks, and the economic and sociological effects on the commercial fleet and recreational fishery.

Yellowtail Flounder.--Two stocks of yellowtail flounder are considered in the plan, a Georges Bank (GB) stock and a Southern New England (SNE) stock. MSY's were estimated at 16,000 t and 23,000 t, respectively. Stock assessment indicates that the GB stock is stable but below the level required to produce MSY, and the SNE stock is declining in abundance. From a strictly biological viewpoint, catch from both stocks should be reduced as much as possible to increase spawning biomass and provide a buffer against recruitment failures. However, it was determined that this would cause undue economic hardship for the harvesting sector and coastal communities, so an OY of 10,000 t for GB and 4,000 t (as by-catch only) for SNE was recommended. Recreational fishermen do not take appreciable amounts of yellowtail flounder, so it was not necessary to consider this sector in the analysis.

Once again, we have an OY based on consideration of both economic and biological factors. The exact determination of the OY level was determined subjectively in both cases, as all of the factors involved were not quantifiable.

Haddock.--Only one stock of haddock is considered in the plan and MSY is estimated at 47,000 t. The haddock stock is severely depleted, and it was determined that removals should be kept at the lowest possible level to allow for rapid recovery of the stock to the MSY level of abundance. Thus, on strictly biological grounds, the OY was set at 6,200 t, which includes both recreational and commercial catch as by-catch only. This is the amount determined to be unavoidable by-catch. In the case of haddock, then, the overriding consideration was the biological condition of the stock, and hence an OY was recommended based on this single criterion.

The second plan is for Salmon Fishing (1977:22-23) off the coasts of Washington, Oregon, and California. This plan is an excellent example of the complexities involved in arriving at OY. The following is taken directly from the plan.

"Achieving maximum yield levels in pounds would require elimination of ocean troll and sport fishing and the taking of all fish at or near river mouths. This action would be required because rate of growth exceeds rate of natural mortality in the ocean. This plan deviates from MSY by maintaining ocean troll and sport fisheries, but recommends reduced fishing rates to provide increased availability of fish to "inside" fisheries and spawning escapements.

"Net effect of these recommendations on certain major salmon stocks provides an example of the effect of modifying MSY to reflect economic and social (including legal) factors to achieve OY. The plan projects optimum yields (OY) of 18.0 million pounds for Columbia River fall-run chinook (4.3 million pounds less than MSY) and 31.3 million pounds for the five coho stocks described previously (3.9 million pounds less than MSY). The reasons for proposing a harvest of less than MSY are reflected in (1) the high recreational values; and (2) the higher market value per pound for troll relative to net-caught Columbia River fall chinook (due to both real and perceived quality differences and different market channels). Values under the plan include an estimated $19.1 million for Columbia River fall-run chinook ($6.2 million more than the MSY value of $13.7 million) and $43.5 million for the five coho stocks ($8.8 million more than the MSI! value of $34.7 million) .

"Other considerations involved in preserving ocean troll and sport fisheries to achieve OY are:

1. Availability of salmon over a longer annual time period and in greater variety with a troll fishery.
2. Less dislocation and community impact than that which would follow immediate elimination of industries (troll fishery and charter boats) which form significant sectors of coastal employment/alternatives.
3. Preservation of a life-style represented by troll fishing and charter boat operation; activities accessible with modest capital investments.

Factors justifying some significant transfer of fish to the inside fisheries and spawning escapements to achieve OY include:

1. Reduced catches of depleted fish stocks that will provide increased salmon production over the long term.
2. Legal rulings that require certain quantities of fish to be provided for treaty Indian fisheries.
3. A reversal of past trends resulting in the brunt of conservation restrictions falling on inside fisheries in order to assure that adequate spawning escapements are provided.

'Current technology and availability of data do not permit direct quantification of all these factors. Thus, final determination of OY reflects the professional judgments and experience of the working team who prepared the plan, the Scientific and Statistical Committee, and the Council, which also has been influenced by input from the Salmon Advisory Panel, and the citizen input through public hearings."

Here we have an example of a recommended OY which is less than MSY based primarily on consideration of high recreational and economic value, with some sociological factors also included. Once again, note that the factors considered are not quantifiable, and that the estimate of OY was arrived at by a consensus of the people involved in writing the plan.

The last plan we'll look at is for the Surf Clam and Ocean Quahog Industries (1977) off the northeast coast.

Surf Clam.--An MSY of 23,000 t is estimated for surf clam if the populations are allowed to rebuild to their maximum level. Stock assessment indicates that the total harvest for 1977 should be limited to as low a level as possible to permit stabilization of the populations as soon as possible. Industry spokesman indicated, however, that low harvest levels could inflict economic hardships on those individuals in the harvesting and processing sectors. Hence, a compromise OY of 14,000 t was recommended in the plan, which took into consideration both the biological status of the stocks and the economics of the industry. Recreational fishing is not a consideration in either the surf or clam or quahog fisheries.

Ocean Quahog.--The MSY for quahog is estimated as 49,000 t, based on the virgin stock biomass method we mentioned earlier. This is a very gross estimate of the potential yield from the stock. Recognizing this, the plan recommends an OY of 14,000 t as a precautionary figure on biological grounds alone. The feeling being that it is better to err on the conservative side rather than risk potential overfishing, especially of a stock whose biological characteristics would make recovery from overfishing a slow process.

CONCLUSION

Judging by the few plans which have been approved to date, it appears that the Fishery Management Councils have risen to the challenge. A specification of OY was arrived at in each case, based on an estimate of MSY as modified by relevant' economic and social factors, even though these factors were not quantifiable. Thus, the precedent has been set as we embark on the road to a new era in fisheries management.

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APPENDIX

Growth and mortality rates may be expressed as either annual or instantaneous values. Annual rates are easier to understand, but instantaneous rates are more easily manipulated in yield equations. Let us illustrate the difference. The annual mortality rate (A) is taken as one-S, where S equals annual survival. S can be calculated by dividing the number of fish remaining alive at the end of the year (N_1) by the number that were alive at the start of the year (N_0), thus $S = N_1/N_0$ and $A = 1-(N_1/N_0)$. Total instantaneous mortality rate (Z) is related to S by the equation $Z = -\ln S$ (where In means natural logarithm) or, exponentiating both sides, $e^{-z} = S$. The relationship is based on a postulated exponential decline between numbers alive at the beginning of a time period and numbers remaining at the end of the period. The function looks like the following:

For a comparison between annual and instantaneous rates look at the following table:

A	Z
0.01	0.01
0.25	0.29
0.50	0.69
0.75	1.39
0.90	2.30
0.95	3.00

Note that an annual rate can never be greater than 1.0, whereas an instantaneous rate can. Also, annual rates are not additive, whereas instantaneous rates are additive, a property which facilitates the use of instantaneous rates in yield equations. For example, let's consider a fishery having an annual total mortality rate of 0.50. After 3 yr, the total mortality would not add to 1.50. Obviously, mortality can't be greater than 100% (1.0). On the other hand, the equivalent instantaneous rate (0.69)