A New Tool for Forecasting Maximum Sustainable Yield in Developing Fisheries

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ABSTRACT

We are currently working on a method of looking at fishing effort that appears to yield better estimates of Maximum Sustainable Yield (MSY) by allowing the use of pre-MSY catch/effort statistics to determine how rapidly a fishery will decline if MSY is exceeded. The technique is applicable to any fishery where the fishermen must actively search for fish and involves examining patterns in catch as a function of the number of standard vessels in a fishery as well as the proportion of the available fishing time used to search for fish.

We will present the results of our statistical and graphical analyses and discuss their potential application to fisheries in the Caribbean. Our intention is to alert fishery managers to what we feel is a potentially powerful tool, especially when it is applied to developing fisheries.

INTRODUCTION

The management of fisheries which involve an active search for fish has proven to be particularly difficult. Many of these fisheries, such as those on whales, herrings and sardines, have collapsed suddenly and apparently without a warning signal of stock depletion. Others, though still healthy, are operating without a critically needed index of stock abundance. Clark (1985) stated the dilemma most effectively when he asked, "how can a fishery be managed if no method exists for preventing imminent collapse?"

In this paper, we hope to show how our redefinition of fishing effort for these fisheries has left us with a very sensitive index of relative stock abundance as well as with a method of forecasting (in the sense that weather is forecasted) post-MSY conditions from a pre-MSY data. Though the example we will use is derived from our work with the Louisiana-Mississippi based gulf menhaden fishery, we want to stress initially that the techniques are applicable to many of the Caribbean fisheries. Some that come readily to mind are those on conch, spiny lobster, billfish, tuna and reef fish. And though we will often be talking about how a fishery declines, we will show how the technique is most useful when applied to developing fisheries.

What do the gulf menhaden, conch and the recreational fishery on blue marlin have in common? They are hunter fisheries. The fishing time in these hunter fisheries is divided into two main activities. The first is an active search for visual signs of fish. Once fish are located, the searching is discontinued and the fishermen begin their second activity, the actual harvest. Only after the harvest is completed do fishermen continue their search for additional signs of prey.

In this paper we will first show how we redefined fishing effort to account for these two important types of fishing time: searching and handling. Then we will discuss how the inverse relationship between searching time and stock abundance makes searching time a sensitive index of stock abundance during the time when one is needed, i.e., during times of low stock abundance. Finally, we will show how our redefinition of fishing effort allows us to make inferences of post-MSY conditions from pre-MSY data.

REDEFINITION OF FISHING EFFORT

We begin with Fox's (1974) generalized stock production model (GSPM),

$$(1) \qquad Y = f\,(a + bf)^{1/(m-1)},$$

where Y is the equilibrium yield, f is fishing effort, and a, b, and m are constants. We depart somewhat from the normal treatment of f by considering:

$$(2) \qquad f = f'\,t_s$$

where f' is a physical measure of the total fishing gear in use and t_s is the proportion of the total fishing time (t) which is available for and used in searching.

If we assume that searching is constant and independent of stock abundance we would remain consistent with traditional fishery models. However, we know that searching time is not constant, but dependent upon stock abundance, since the act of harvesting fish once sighted reduces the total amount of time used in searching.

So we depart from traditional fishery models in that we attempt to account for this dependence of searching time on stock abundance. Though more complex models may actually apply, we use a Holling Type II curve as our model (Holling, 1959), and define searching time as

$$(3) \qquad t_s = t - t_h\,(C/f'),$$

where t_h is the handling time per unit of catch. With decreasing stock abundance this equation predicts a curvilinear decline in catch and a curvilinear increase in searching time (e.g., Condrey, 1984).

APPLICATION TO DATA ON THE GULF MENHADEN FISHERY

The case example we will use comes from our analysis of the Captain's Daily Fishing Reports of the US gulf menhaden fishery.

These reports, initiated in 1978, provide a detailed record of a vessel's activity, including information on the date, starting time, ending time, estimated catch and location of each set. We used the 1978 and 1981 records to obtain estimates of handling time per set, catch per set and total fishing time per season. We then used these estimates in an examination of the historical catch-and-effort data under the assumption that they were constant across years.

We fitted the GSPM to our back-calculated estimates of catch and effort varying m from 0.1 to 4.0 by 0.1 intervals. We selected these values of m because they gave us models which ranged from those predicting imminent collapse (e.g., m = 4.0), through the standard Schafer model (m = 2.0), to fisheries characterized by a flattop-production curve (e.g., m = 0.1).

Despite the dramatic difference in the predicted response of these models to post-MSY conditions, we found little difference in their fit to the data. While there appears to be a direct relationship between the residual sums of squares and m, there are a number of important exceptions to this trend as the scatter of the residuals increases with m (Fig. 1).

To illustrate these minimal differences in fit, we plot the equations for three of our four models of best fit: those with m's of 0.6, 2.2 and 2.9 (Fig. 2a). The individual curves coalesce at the origin, diverge slightly before converging at the end point of the data, and diverge a final time as their MSY estimates are approached and exceeded.

If we had used a traditional fishery modelling approach, our analysis would be over at this point. But the approach we used allows us to examine how the data and models behave when we partition fishing effort into its two component parts: the number of vessels and the searching time. We will do this in the next three figures. The essential point to remember is that the curves you will see are derived from the curves fit to the data in Figure 2a. They are not fit directly to the data in the following figures.

The plot of catch versus vessel tonnage is not very exciting or helpful (Fig. 2b). As with effort, the curves coalesce at the origin, diverge slightly midway through the data, and converge for a last time as the MSY levels are approached and exceeded. It is of more than passing interest, however, that there is a much steeper post-MSY decline in catch with vessel tonnage than with effort.

The patterns predicted for searching time (Fig. 2c) are far more exciting than those in Fig. 2a and b and differ in two important ways from those observed for effort and standard vessel tonnage. First, with searching time, the ascending arms of the MSY curves are steeper than the descending arms, regardless of the value of m. This pattern reflects the inverse relationship predicted between search time and population abundance and differs from that seen for effort, in which the descending arm of the surplus-production curve is steeper than the ascending arm for values of m greater than 2.0. As such, searching time, and not standard vessel tonnage or effort, is the most important parameter for management to monitor and

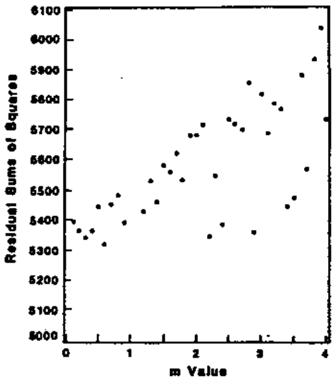

Figure 1. Comparison of the residual sums of squares as a function of m when the menhaden yield (Y) and effort (f) data were fit to the generalized stock production model,

$$(1)\quad Y = f(a - bf)^{1/(m-1)}$$

where a and b are constants and m was varied from 0.1 to 4.0 by units of 0.1.

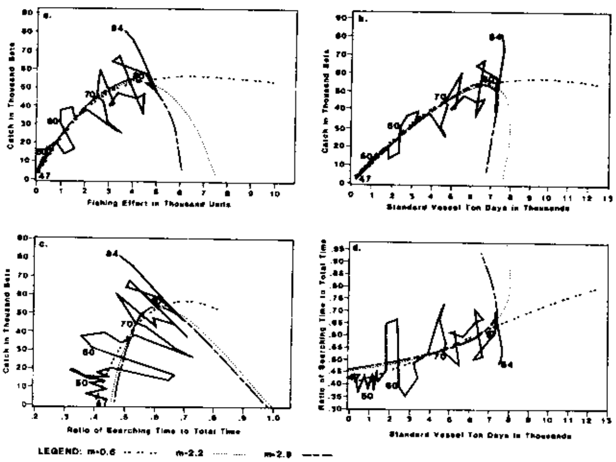

Figure 2. These graphs compare the fit of the gulf menhaden yield (Y) and effort (f) statistics to three forms of the generalized stock production model,

$$Y = f\ (a + bf)^{\ 1/(m - 1)}$$

where a, b and m are constants. The curves drawn were fitted directly to the catch/effort data, with values of m set at 0.6, 2.2 and 2.9. Curves were fitted directly to the data in Panel A and transformed to see how they tracked the data in plots of catch versus standard vessel tonnage (Panel B), catch versus searching time (Panel C), and searching time versus vessel tonnage (Panel D).

regulate when attempting to restore an overexploited stock to a level that will support MSY.

Second, with searching time there is a substantial difference in the fit of the surplus-production curves to the pre-MSY data. This difference is greatest in virgin populations and increases as a function of m. Though these differences diminish as the curves approach their respective MSY's, they suggest the real possibility that searching time could serve as an important tool in selecting appropriate ranges of m for a particular fishery. For example, the curves suggest that the menhaden fishery is more appropriately described by surplus-production models in which m is less than 1.0.

These differences in fit of the various surplus-production curves to the data are enhanced when we examine the relationship between searching time and standard vessel tonnage (Fig. 2d). Apparently, a linear relationship of searching time and standard vessel tonnage exists over the range of available data. The curve predicted for m = 0.6 is again most consistent with the data in terms of fit and form. As the value of m is increased above 1.0 the curves diverge increasingly from the general trend predicted by the data, especially at low and high values of vessel tonnage.

DISCUSSION

The patterns exhibited in Figure 2c and d suggest to us that management can use searching time as an extremely effective index of stock abundance if the catch-and-effort data are adequately sampled and assessed. Such an index would enable management to make enlightened, rather than overly cautious, estimates of the status of the stocks.

Additionally, the results suggest to us the exciting possibility that a graphical procedure, similar to that developed by Lineweaver and Burk (1934) for testing models of enzyme kinetics, can be developed to distinguish between "acceptable" and "unacceptable" members of the GSPM. Our reasoning is based upon the behavior we noted when we tracked the surplus-production curves (which we fitted to the catch/effort data) through plots of searching time and vessel tonnage. While plots of sets versus effort (f) or standard vessel tonnage (f') gave no real clue as to which type of production curve provided the best fit, this did not occur when we plotted catch as a function of searching time. Rather, in these plots of menhaden fishery appeared to be more adequately described by a flattop production curve than by one predicting a rapid collapse. This distinction became clearer when we compared the data and curves in plots of searching time versus vessel tonnage. In these plots, the menhaden fishery appeared to be consistent with the essentially linear relationship expected between searching time and vessel tonnage in flattop production models and almost entirely inconsistent with the curvilinear pattern predicted by models for a rapidly collapsing fishery.

Application of these techniques to the developing fisheries in the Caribbean need not involve an intensive data collection program. Rather a statistically valid sampling program could be implemented to periodically interview fishermen for the required estimates of catch per unit of harvest, handling time and total time per day during which fishing occurs. By providing additional stability to the management of these fisheries, we should enhance their full and wise use.

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