MODELING THE RESOURCE BASE

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I would like to start off by giving a rough idea of the magnitude of fish populations available to the San Pedro wetfish fleet. The population of northern anchovy appears to have the largest stock in the area. Estimates based on larval surveys are in the neighborhood of 2,000,000 tons. This species is followed by the jack mackerel. Admittedly crude estimates based on larval surveys place the jack mackerel population in the eastern Pacific at 2,000,000 tons. However, the San Pedro fleet harvests only relatively young jack mackerel at the southeastern edge of the population. Pacific mackerel also occur in the area. Pat Tomlinson of the California Department of Fish and Game has been studying the population dynamics of this stock. Although the stock is currently at a very low level, he has estimated that the stock could withstand a harvest of about 20,000 tons at its optimum level. The fleet has been taking about 7,500 tons of bonito per year in recent years. The bonito population has not been sufficiently studied to place an estimate on its potential. The fleet has also taken considerable amounts of bluefin tuna in the past, but this population appears to be at a depressed level and is also poorly understood. Two other commercial species occur in significant numbers in the area, the Pacific saury and squid. Attempts presently are being made to develop a fishery for saury, and hopefully we will know more about this species in the near future. About 5,000 tons of squid are landed per year. The potential appears to be much higher. Finally, I will mention the Pacific sardine. If the population ever recovers to its previous status, Murphy estimates that it will be capable of yielding about 450,000 tons per year. Perhaps half of this figure would be obtained from this area. These tonnages are impressive but meaningless until the fish are actually landed. Changes in the structure of the industry and government regulations are needed before the potential benefits from the resource can ever be obtained. Jack Baxter of the California Department of Fish and Game will present in the next talk potential landings under current conditions. I am involved in the development of a computer simulation model of the fishery to aid us in evaluating alternative methods of developing and managing the fishery.

The first figure is a block diagram of the model. The model is composed of several sections centered about the management policies section, for the amount of profit to the fishery, the ultimate goal of any commercial enterprise, is dependent on the ability of management to estimate and interpret conditions of the fish stocks, market, and fishery. The management policies section also obtains information on external factors—for example, regulations of the north-

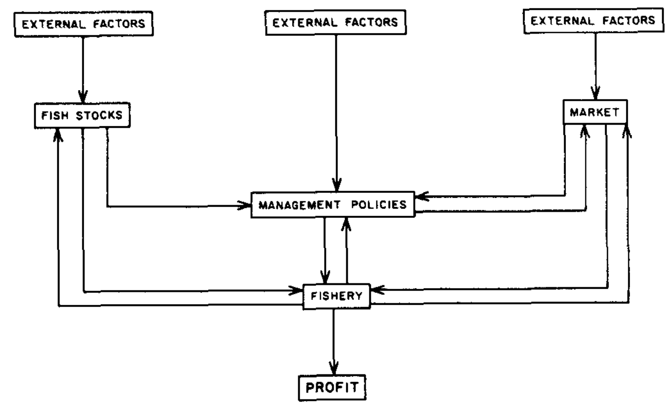

FIGURE 1. Block diagram of model of San Pedro wetfish fishery.

ern anchovy fishery are based on strong political pressure to avoid conflicts between the commercial and sport industries. Management policies affect the fishery section and possibly to some extent the market section. The fish stocks section may be subdivided into abundance and availability sections. Abundance is defined here to be the tonnage of a population's standing stock. Availability is the portion of the population that is susceptible to the fishery. The abundance model is based on the following equation: standing stock is equal to the previous standing stock plus recruitment plus growth minus natural mortality minus yield to the fishery. Over a long period the maximum average catch for the fishery is achieved by setting each year's catch to adjust the standing stock to the level that will produce in the next season the maximum sustainable yield. The management section estimates this parameter and uses it as a factor to determine how to reach the goal of maximum profit. A simulation of availability is achieved by allowing a simulated population to migrate along shore and on and off shore. Portions of the population that are in designated areas are not available to the fishery. Again the management section uses an estimate of the availability of the population as a factor in determining how to achieve this goal. I have been talking in terms of one population, but in actuality the management policy section takes into account factors concerning several species in order to maximize profits. I plan to use linear programming techniques to do this.

"Plan" is a key word in this talk. We have developed some of the components involved but still have a ways to go before we can show any results. We are very hopeful that this symposium will provide us with ideas on how to develop the remaining components and perhaps correct any misconceptions that we have.

I would now like to present some results of a simple model of the Pacific sardine fishery that I have developed using the results of Murphy. I hope that these results will illustrate some of the information that can be obtained from the use of simulation models.

This model consists only of a fish stock section, management policies section, a simple fisheries section, and an external factors section. The fish population is simulated by a production model using Murphy's estimates of natural mortality, growth, and spawn-recruitment relationship. The model is a stochastic one in that deviations from the spawn-recruitment relationship are allowed. The occurrence of strings of successful and unsuccessful spawning years is simulated by using an auto-regressive function in generation of the deviations from the spawn-recruitment relationship. The management uses estimates of the standing stocks and recruitment to determine the amount of fishing effort needed to maintain the population at its optimum level. Errors in management's estimates of standing stock and recruitment are allowed. I used this model to study the sensitivity of yield and yield-per-effort to the accuracy of estimates of standing stock and recruitment.

Figure 2 illustrates yield as a function of accuracy. The X axis is the maximum error factor expected in 95% of the observations. For example, at the point of 3 on the X axis the maximum error in the estimate of standing stock and recruitment is within a factor of 3 of the actual value for 95% or more of the observations. The Y axis is the annual yield of sardines in tons. Four management policies were investigated. The white dots connected by the solid line in the figure represent the average annual yield from a policy of varying instantaneous rate of fishing mortality from 0 to 0.8 depending on the condition of the stock. The black dots connected by a dashed line represent the average annual yield from a policy of varying instantaneous rate of fishing mortality from 0.4 to 0.8. The explanation of the two other curves in the figure

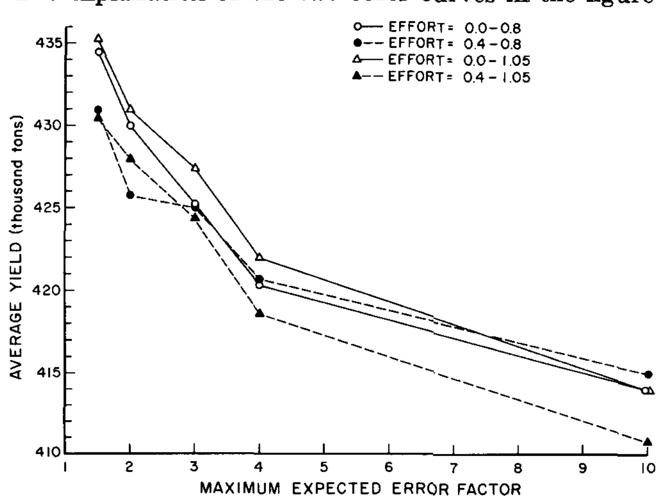

FIGURE 2. Yield of simulated Pacific sardine fishery as a function of accuracy of estimates of stock and recruitment and variability of fishery effort.

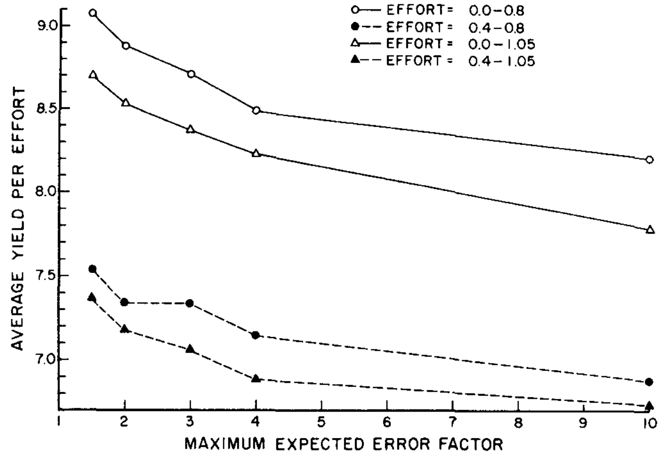

FIGURE 3. Yield per effort of simulated Pacific sardine fishery as a function of accuracy of estimates of stock and recruitment and variability of fishery effort.

is similar. In all examples, if the estimated standing stock drops below 300,000 tons, the fishery is stopped. Each point represents a value of three simulations of 200 years. As expected, the average yield is highest when management has the most accurate information and can vary the fishing effort the most. When a management policy of using constant fishing effort at the maximum sustainable rate of 0.78 is used, the yield is 390,000 tons. This is even lower than when management uses very poor information with a varying rate of fishing mortality. Under the best management policy tried, the yield is increased about 10% over the maximum sustainable yield.

Figure 3 illustrates yield per effort as a function of accuracy. This measurement is more meaningful than yield alone because it is an index of revenue per cost. Again the best results are obtained when management is well informed. The results are considerably better if the fishery is stopped when the population falls below the level of about one million tons rather than when it falls below the 300,000 ton level. The poorest result is about 40% above the result that is obtained when the population is fished at the maximum sustainable rate.

Management must take factors other than yield and yield-per-effort into consideration. One of these factors is stability of yield. Figure 4 illustrates standing stock and yield over a 200 year simulation. The maximum expected error factor was 1.5 and instantaneous rate of fishing mortality was varied between 0 and 0.8. The fishery was stopped when the spawning stock dropped below 1,000,000 tons. Even though the yield and yield-per-effort are high, very few people would be willing to accept a policy that results in such an unstable fishery. The fishery was stopped in approximately 25% of the years.

Figure 5 illustrates what happened when fishing mortality was varied from only 0.4 to 0.8 and the maximum expected error factor was 3. Yield is much more stable than in the previous case. You will note there are very few cases of when the fishery was ac-

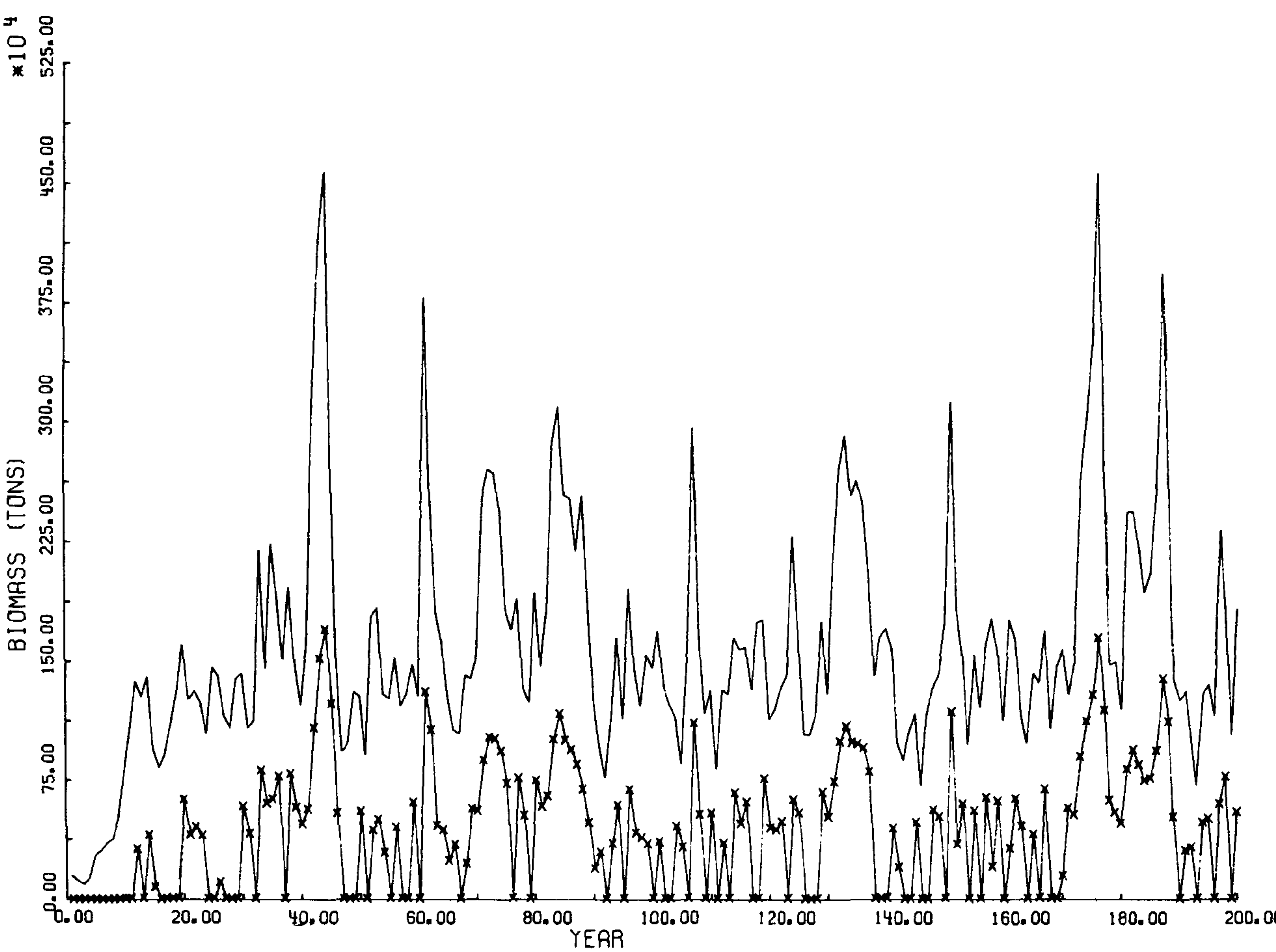

FIGURE 4. Solid line is biomass of spawning stock of simulated Pacific sardine populations. Line connecting x's is yield of simulated Pacific sardine fishery. Fishing mortality was varied between 0 and 0.8. The maximum expected error factor was 1.5. Fishing was stopped when spawning stock dropped below 1,000,000 tons.

tually stopped. In this case the fishery was only stopped when the population dropped below 300,000 tons. The average yield under this policy is only slightly less than under the previous policy.

Figure 6 illustrates the results under a policy of constant fishing at the maximum sustainable rate except when the population falls below the 300,000 tons. It is slightly more stable than the previous case. Yield is considerably less, and the yield-per-effort very much less.

Power spectra were calculated from yield under two management policies: a policy of maximum sustainable yield, and a policy of varying fishing mortality from 0.2 to 0.8. The spectra are quite similar. The power of the spectrum from the constant model is relatively slightly lower at high frequencies than that from the varied effort policy. In other words the short-term fluctuations of the yield are slightly more important in the more intensively managed fishery.

Perhaps I have stressed stable yield too strongly. As Dr. Sette has pointed out at a previous conference, we are working with a multi-species fishery. It is possible that fluctuations in profit from a properly managed multi-species fishery will be quite small. Almost all populations of fish undergo considerable fluctuations, we should strive to develop better ways of living with them.

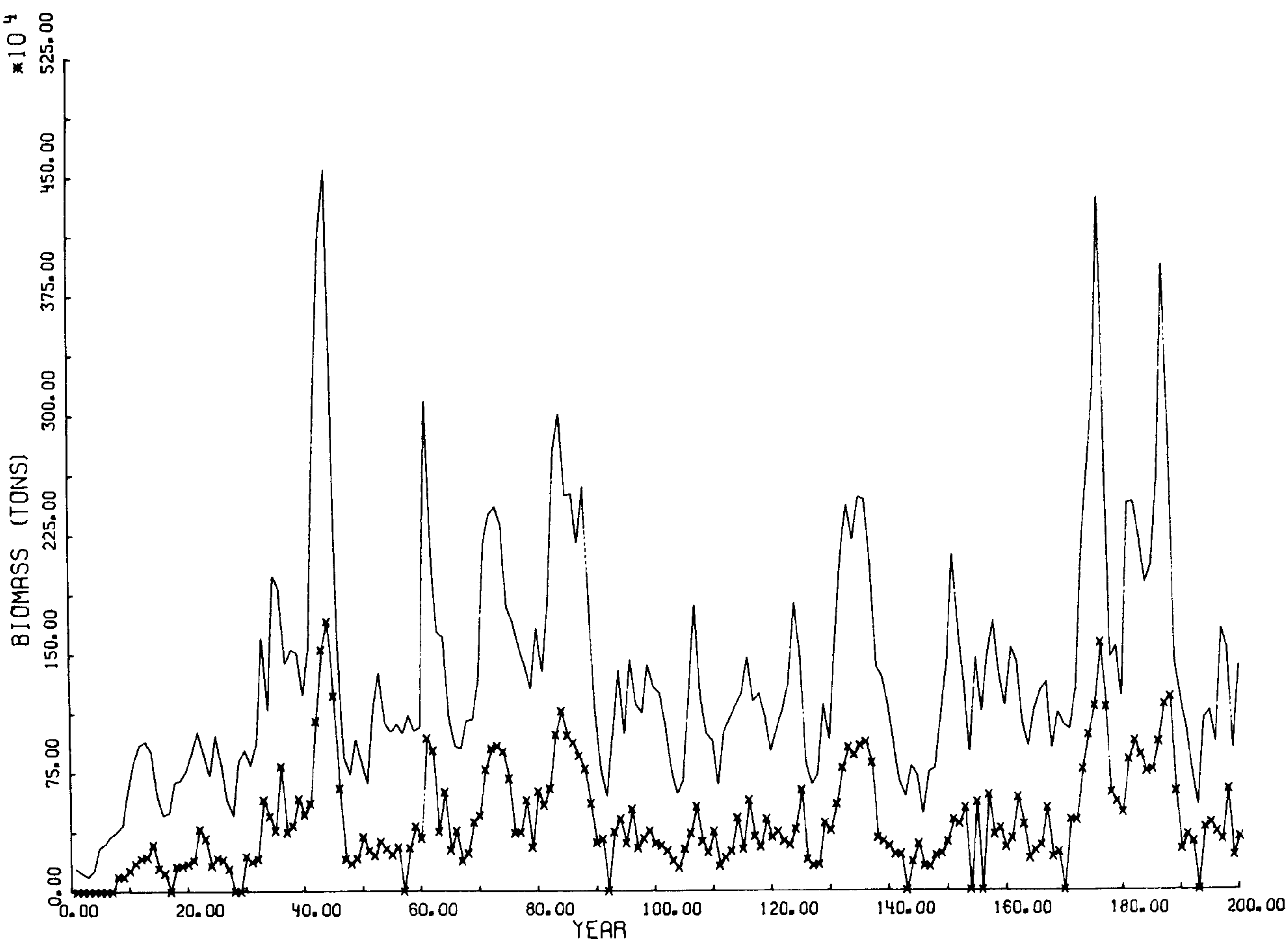

FIGURE 5. Solid line is biomass of spawning stock of simulated Pacific sardine populations. Line connecting x's is yield of simulated Pacific sardine fishery. Fishing mortality was varied from 0.4 to 0.8. The maximum expected error factor was 3. Fishing was stopped when spawning stock dropped below 300,000 tons.

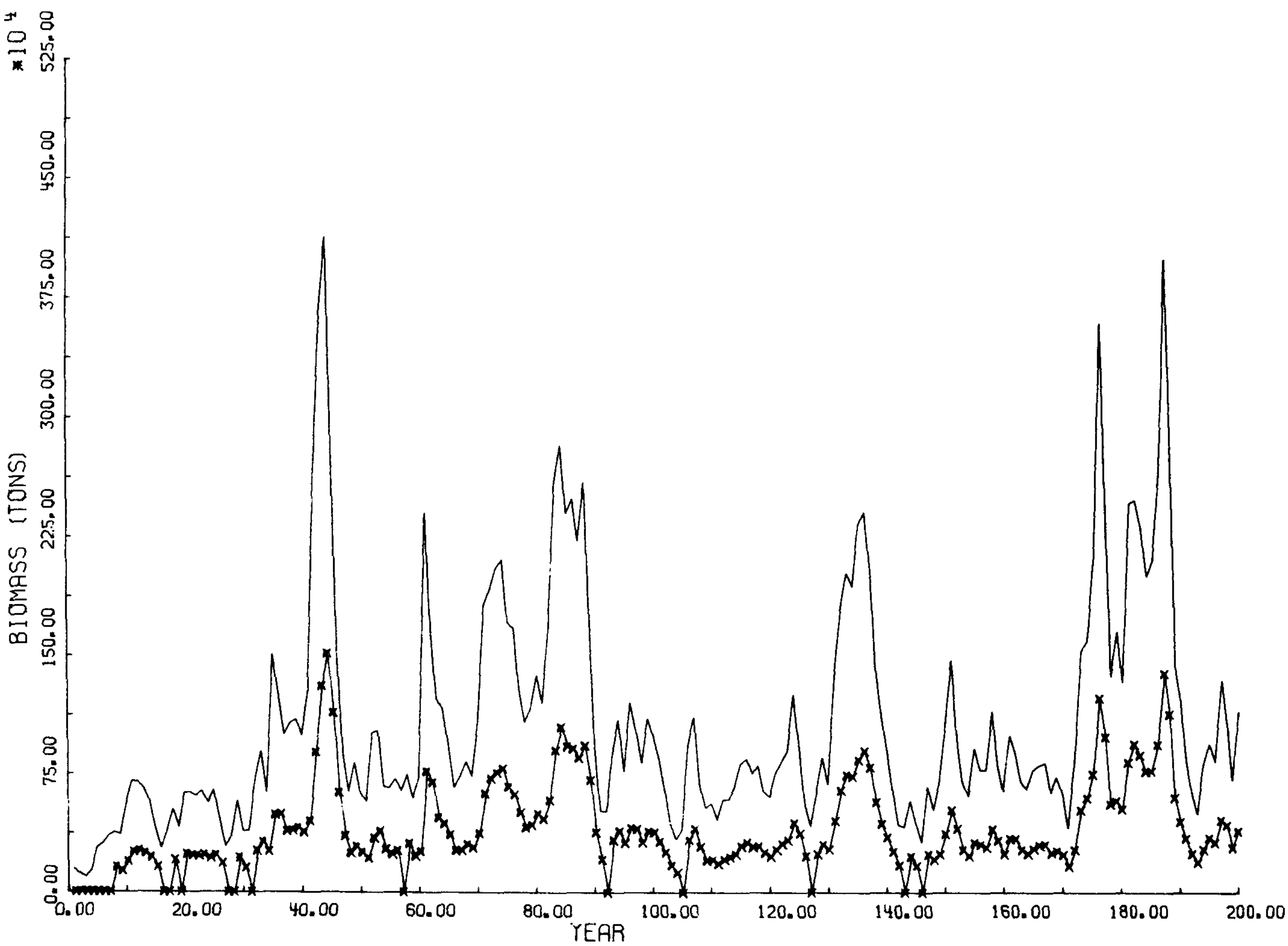

FIGURE 6. Solid line is biomass of spawning stock of simulated Pacific sardine populations. Line connecting x's is yield of simulated Pacific sardine fishery. Fishing effort was held at the maximum sustainable rate except when spawning stock dropped below 300,000 tons.