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# A production model analysis of the North Pacific albacore population including estimates of the sensitivity of results to measurement errors in input data

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## Abstract

A production model analysis is done for a single stock of North Pacific albacore using total catch and standardized fishing effort data. A sensitivity analysis using a Monte-Carlo simulation is done to estimate the sensitivity of predicted results to errors in both catch and effort data. Results indicate that best fitting estimates of Maximum Sustainable Yield (MSY) are robust with respect to errors in input data of up to plus or minus 20% and range for 71,000 to 108,000 tons. Further, it is shown that errors in catch and effort have relativly independent effects on the predicted results. Effects of assumptions underlying the production model analysis are discussed.

## Background

The North Pacific albacore resource has been fished since the turn of the century by Japanese and United States fishermen. Early records indicate landings in the United States were in the 7,000 to 13,000 tons range from 1916 to 1925, near zero between 1926 and 1937, and again in the 5,000 to 10,000 tons range from 1938 through 1947 (CLEMENS and CRAIG, 1965). Available records for the Japanese albacore fishery indicate that a fishery for albacore existed since about the turn of the century, with catches during the 1927 to 1936 period ranging from about 8,000 to 18,000 tons and averaging about 12,000 tons (AIKAWA, 1949). From 1936 through 1946, Japanese catches were low. Following 1946 landings by both Japanese and United States fishermen increased rapidly. In the early 1950's Japanese landings were in the 50,000 to 68,000 tons range and United States landings ranged from 16,000 to 26,000 tons. Landings have remained high to the present.

Although catch data for a long period of time exists, only recently, since 1961, has relatively complete data on fishing effort been collected for both Japanese and United States fisheries. To help assess the overall condition of tuna stocks the generalized production model along with other evidence can be used. The production model affords a useful estimate of the

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relation between expected equilibrium catch and exploitation rate or fishing effort (SCHAEFER, 1954, 1957; FOX, 1975).

This analysis applies the generalized production model to North Pacific albacore data from 1961 to 1981. Additionally, a sensitivity analysis is performed to determine how the model results behave with respect to various levels of random error in the input catch and effort data.

## Data and Preparation

Data on catch and effort used here are shown in Table 1. These data were taken from a working document by SHIOHAMA as reported in the Report of the Eighth North Pacific Albacore Workshop (BARTOO and KUME, 1984) and are considered to be essentially complete and correct for the time period concerned.

The standardization of effort among the longline, pole-and-line and troll gears was done by the method of SHIOHAMA (1979) which is essentially the same as used by COAN and FOX (1977) for Atlantic yellowfin tuna. Within each gear, the time series of CPUE values is scaled so that the mean CPUE has a value of 1.0; this is standardized CPUE (Table 1). Standardized effort is calculated by dividing the catch in tons by the appropriate standardized CPUE. This is done by gear and year. Total standardized effort for each year is the sum of the standardized effort for each gear (Table 1).

**Table 1.** Annual yield in tons, CPUE and standardized effort for the North Pacific albacore, 1961-1981.

| Year | CPUE ($d_{ik}$) | | | Standardized CPUE ($S_{ik}$) | | | Catch in tons ($W_{ik}$) | | | | Standardized effort ($E_{ik}$) | | | | Number of age |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pole-and-line | Long-line | U.S.A. Surface | Pole-and line | Long-line | U.S.A. Surface | Pole-and-line | Long-line | U.S.A. Surface | Total | Pole-and-line | Long-line | U.S.A. Surface | Total | |
| 1961 | 4.40 | 0.25 | 69.17 | 0.80 | 0.78 | 0.75 | 18,636 | 17,437 | 16,250 | 52,323 | 23,295 | 22,355 | 21,667 | 67,317 | 4 |
| 1962 | 7.22 | 0.30 | 124.59 | 1.31 | 0.94 | 1.36 | 8,729 | 15,764 | 22,520 | 47,013 | 6,663 | 16,770 | 16,559 | 39,992 | 4 |
| 1963 | 6.29 | 0.32 | 132.09 | 1.14 | 1.00 | 1.44 | 26,420 | 13,464 | 28,740 | 68,624 | 23,175 | 13,464 | 19,958 | 56,597 | 4 |
| 1964 | 6.86 | 0.40 | 97.61 | 1.25 | 1.25 | 1.06 | 23,858 | 15,450 | 22,627 | 61,943 | 19,086 | 12,366 | 21,346 | 52,798 | 4 |
| 1965 | 6.26 | 0.33 | 89.07 | 1.14 | 1.03 | 0.97 | 41,491 | 13,701 | 17,624 | 72,816 | 36,396 | 13,302 | 18,169 | 67,867 | 4 |
| 1966 | 5.94 | 0.54 | 90.45 | 1.08 | 1.69 | 0.98 | 22,830 | 25,050 | 17,401 | 65,281 | 21,139 | 14,822 | 17,756 | 53,717 | 4 |
| 1967 | 6.09 | 0.40 | 126.83 | 1.11 | 1.25 | 1.38 | 30,481 | 28,869 | 22,795 | 82,145 | 27,460 | 23,095 | 16,518 | 67,073 | 4 |
| 1968 | 5.34 | 0.38 | 135.23 | 0.97 | 1.19 | 1.47 | 16,597 | 23,961 | 27,326 | 67,884 | 17,110 | 20,135 | 18,589 | 55,834 | 4 |
| 1969 | 4.95 | 0.28 | 112.57 | 0.90 | 0.88 | 1.23 | 32,107 | 18,006 | 23,545 | 73,658 | 35,674 | 20,461 | 19,142 | 75,277 | 4 |
| 1970 | 6.13 | 0.31 | 127.39 | 1.11 | 0.97 | 1.39 | 24,376 | 15,372 | 26,631 | 66,379 | 21,960 | 15,847 | 19,159 | 56,966 | 4 |
| 1971 | 6.94 | 0.21 | 96.68 | 1.26 | 0.66 | 1.05 | 53,198 | 10,915 | 27,029 | 91,142 | 42,221 | 16,538 | 25,742 | 84,501 | 4 |
| 1972 | 6.25 | 0.30 | 61.08 | 1.13 | 0.94 | 0.66 | 60,762 | 12,622 | 31,545 | 104,929 | 53,772 | 13,428 | 47,795 | 114,995 | 4 |
| 1973 | 5.49 | 0.38 | 82.89 | 1.00 | 1.19 | 0.90 | 69,811 | 16,000 | 19,246 | 105,057 | 69,811 | 13,445 | 21,384 | 104,640 | 4 |
| 1974 | 7.81 | 0.34 | 105.17 | 1.42 | 1.06 | 1.15 | 73,576 | 12,952 | 26,900 | 113,428 | 51,814 | 12,219 | 23,391 | 87,424 | 4 |
| 1975 | 5.98 | 0.23 | 99.81 | 1.09 | 0.72 | 1.09 | 52,157 | 9,931 | 23,513 | 85,601 | 47,850 | 13,793 | 21,572 | 83,215 | 4 |
| 1976 | 6.13 | 0.30 | 69.22 | 1.11 | 0.94 | 0.75 | 85,336 | 15,738 | 20,032 | 121,106 | 76,879 | 16,743 | 26,709 | 120,331 | 4 |
| 1977 | 3.01 | 0.26 | 59.90 | 0.55 | 0.81 | 0.65 | 31,934 | 15,512 | 12,181 | 59,627 | 58,062 | 19,151 | 18,740 | 95,953 | 4 |
| 1978 | 3.58 | 0.23 | 86.80 | 0.65 | 0.72 | 0.95 | 59,877 | 12,888 | 17,535 | 90,300 | 92,118 | 17,900 | 18,458 | 128,476 | 4 |
| 1979 | 3.50 | 0.24 | 45.41 | 0.64 | 0.75 | 0.49 | 44,662 | 14,174 | 6,920 | 65,756 | 69,784 | 18,899 | 14,122 | 102,805 | 4 |
| 1980 | 4.44 | 0.33 | 36.78 | 0.81 | 1.03 | 0.40 | 46,743 | 14,660 | 8,367 | 69,770 | 57,707 | 14,233 | 20,918 | 92,858 | 4 |
| 1981 | 3.05 | 0.31 | 80.11 | 0.55 | 0.97 | 0.87 | 27,426 | 17,876 | 16,038 | 61,340 | 49,865 | 18,429 | 18,434 | 86,728 | 4 |
| $\Sigma d_{ik}$ | 115.66 | 6.64 | 1928.85 | | | | | | | | | | | | |
| $\bar{d}$ | 5.51 | 0.32 | 91.85 | | | | | | | | | | | | |

## Results of production modeling and sensitivity analysis

The data series described previously was used as input data for the generalized production model (FOX, 1975). Additionally, a Monte-Carlo sensitivity analysis was done to estimate the expected changes in results of the model due to errors in the data.

The results of the production model analysis ara similar to those presented by SHIOHAMA (MS.). Under various forms of the model, $m$ (shape parameter)$=0.0$, 1.0, and 2.0, predicted MSY values are 136,000 tons, 87,000 tons and 86,000 tons respectively. These were obtained without weighting, averaging four significant ages in the catches. The goodness of fit ranged from 50% to 56%. The best fit case was approximately $m=1.1$ (in the interval 1.00-1.09). The predicted MSY was 89,000 tons (Fig. 1). Equilibrium effort associated with MSY, FOPT (optimum effort), is predicted to be 134,000 units, approximately the level reached in 1976.

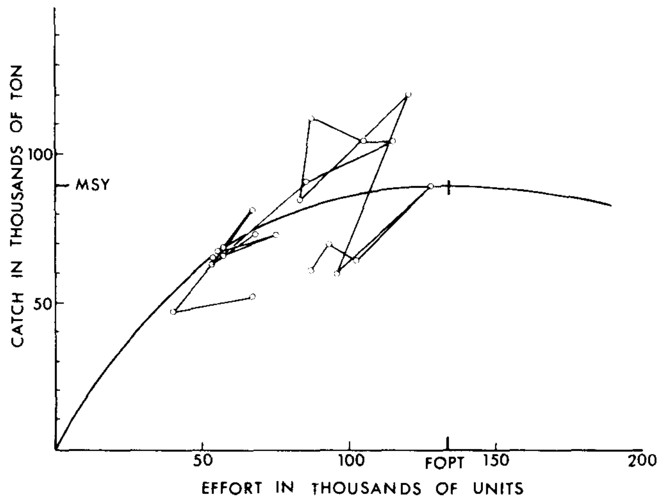


**Fig. 1.** Results of best fitting generalized production model fitted to North Pacific albacore data. Maximum sustainable yield (MSY) and associated effort (FOPT) are shown.

A sensitivity analysis was performed to determine the expected range of MSY and FOPT given various levels of error in the data. The method is the same as used by BARTOO and COAN (1983) for Atlantic albacore. The Monte-Carlo analysis generated new sets of data to be fitted by the production model. Each new set of data contained catch and effort data corresponding exactly to the actual annual data points values. However, the actual value of each new data point was allowed to vary; this represented the uncertainty of inaccuracy in the original data. Each new point was allowed to vary uniformly about the actual data point + or − some chosen percentage, $X$. For example, if the actual catch was 20,000 tons and the uncertainty level was +

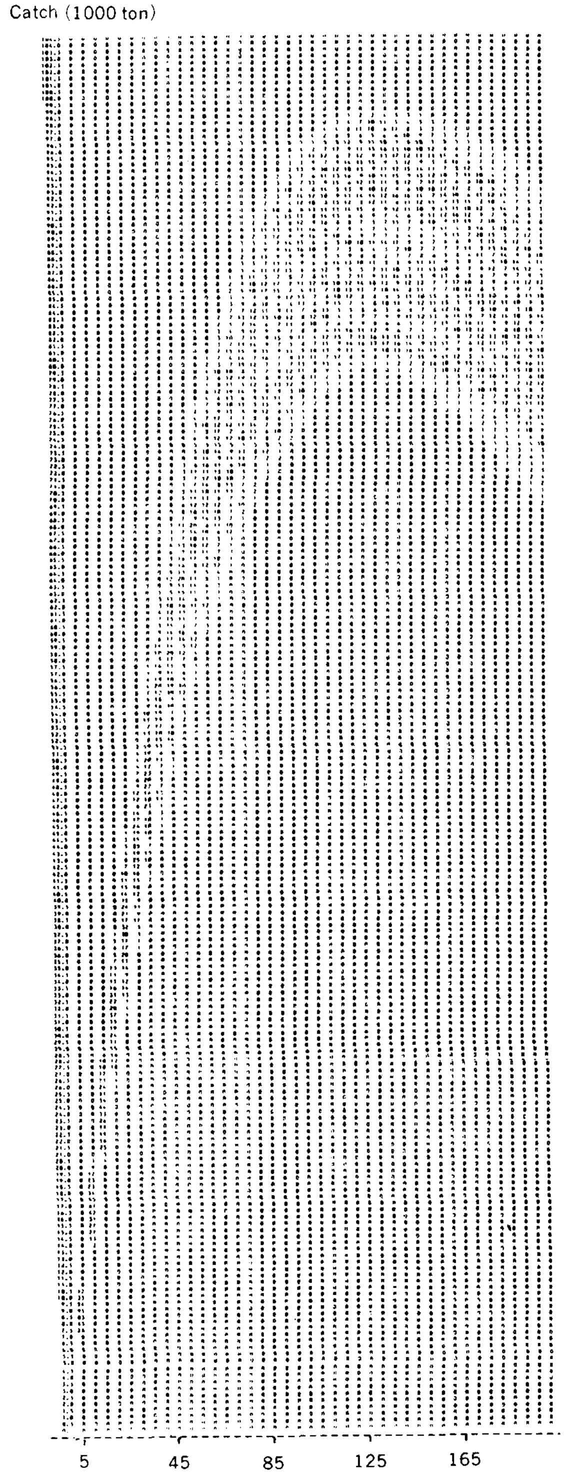


**Fig. 2.** Distribution of results from Monte-Carlo simulation (see text) with errors in both catch and effort of up to + or − 10 %. Number of simulated data cases = 350.

or −10%, each new generated data point could vary between 18,000 and 22,000 tons with all values in this range equally probable.

Each set of data was fitted to the production model and the results saved. This was done 300 times or more for each particular combination of error level. An example of the results is shown in Fig. 2. This is the distribution of results for the case of an assumed error in both catch and error of up to + or −10%.

For all levels of error (up to 20%) in catch, effort, or catch and effort the best fitting model *m* was in the 1.0 to 1.09 range, indicating that with this data set the shape of the model is not likely to change until additional data have been added to the series which deviates from the current trends. The "goodness-of-fit" for all cases was about 50%. This, however, may not be a meaningful measure which can be directly correlated to "confidence" in the results. A good measure of confidence is the range of expected results at different error levels.

Shown in Fig. 3 are the distributions of 99% of the MSY values for varying levels of error in catch, effort or catch and effort. As can be readily seen in Fig. 2 the range of MSY values is very insensitive to errors in effort. However, MSY is sensitive to errors in catch. A + or −20% error in catch causes MSY to vary from +21% to −20% (an asymmetric distribution). For the case of errors in both catch and effort the results are almost identical to the case of catch error alone.

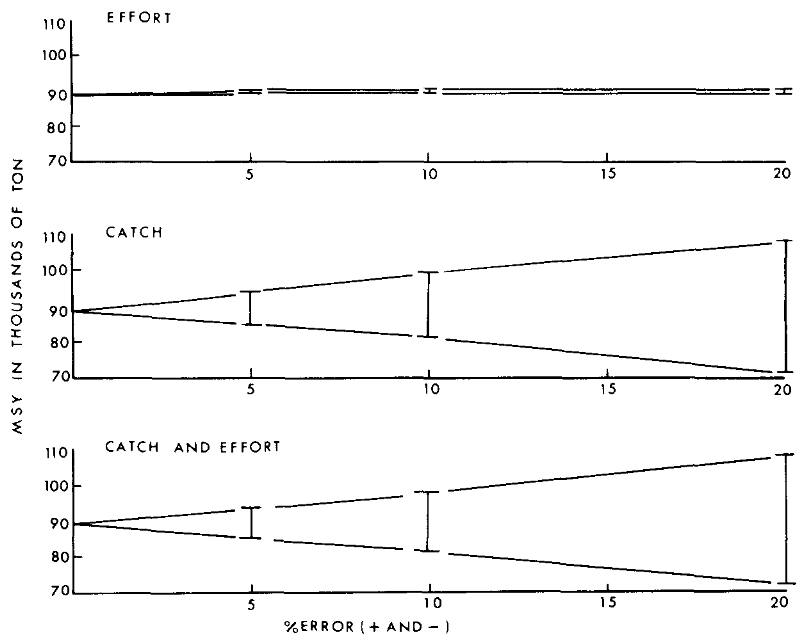


**Fig. 3.** Results of North Pacific albacore production model sensitivity analysis showing the predicted range of MSY values for various lavels of error in the input data.

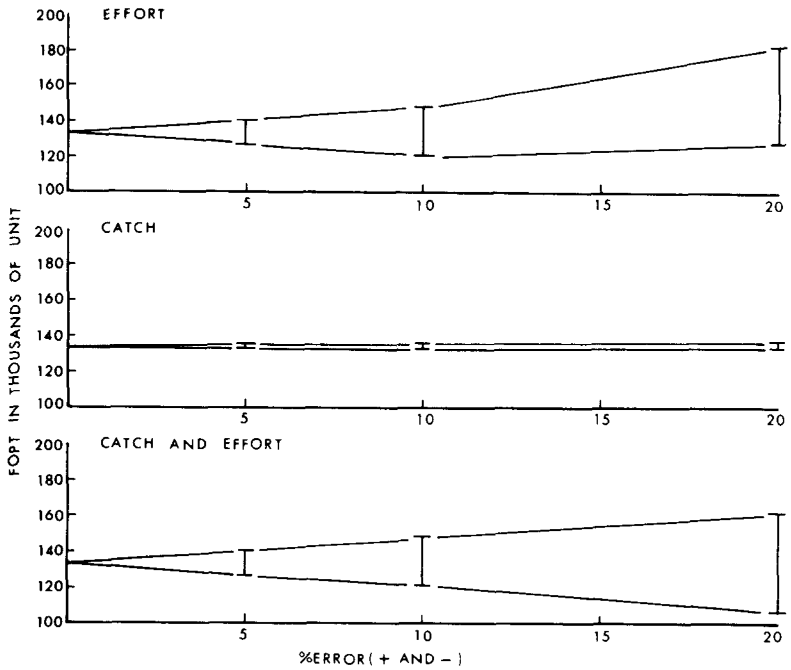


**Fig. 4.** Results of North Pacific albacore production model sensitivity analysis showing the predicted range of FOPT values for lerious vavels of error in the input data.

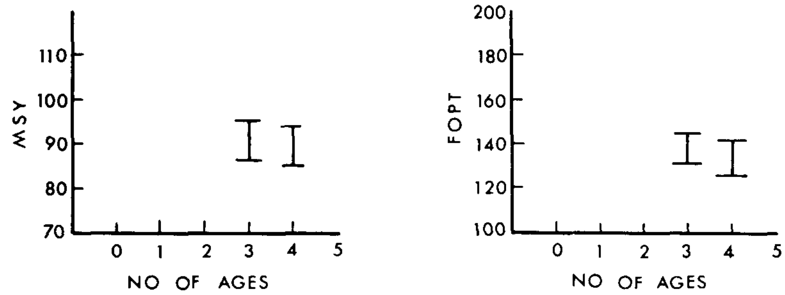


**Fig. 5.** Results of North Pacific albacore production model sensitivity analysis showing the predicted range of MSY values and FOPT values as functions of number of ages assumed significant in the catch (see text).

Fig. 4 shows the distributions of 99% of the FOPT values for varying levels of error in catch, effort or catch and effort. The range of FOPT associated with different levels of catch error is quite narrow. FOPT is not sensitive to errors in the catch. FOPT is sensitive to errors in effort. Errors on the order of + to −20% cause FOPT to vary +35% to −5%, with a slightly skewed distribution. Errors in catch and effort of + and −20% generate a range of FOPT values of +21% to −20%, not nearly as skewed as in the case of effort error alone.

The effect of changing the number of ages averaged in the calculations is shown in Fig. 5. The expected ranges for MSY and FOPT are the same using 3 or 4 years smoothing. The mean of the ranges shifts upward somewhat as the number of years goes down.

## Conclusions

Results from the deterministic fitting of the production model to the data indicate a range of MSY values of 86,000 to 136,000 tons with a most likely MSY of 89,000 tons ($m=1.1$). This range of values is not greatly different from the values reported previously (BARTOO and KUME, 1984), although the most likely MSY value is slightly lower than the previously estimated. Some of these changes are due to fitting the model without weighting the recent data heavier than earlier data (*i.e.* assuming that the whole data series is of good quality). From the results of the sensitivity analysis it appears that the most likely fitting form of the model, $m=1.1$, is relatively robust. Even with large errors in the input data the best fitting model was always close to $m=1.1$. In another analysis on Atlantic albacore (BARTOO and COAN, 1983) noted that with moderate errors assumed in the input data the distribution of the best fitting models included several values of $m$, as different as $m=0.5$ and $m=1.0$. We therefore conclude that with the given data and their treatment the $m=1.1$ model is quite robust and is not likely to change without a marked change in the data or their treatment.

The actual value of MSY is less sure. The point estimate is 89,000 tons. However, as seen in the results of the sensitivity analysis random errors in the catch data cause a range of expected MSY values. A possible range of error in the measurement of total catch of up to + or − 20% produces a range of MSY values from 71,000 to 108,000 tons. Errors in the estimation of fishing effort have little or no effect on the range of MSY estimates.

The effort level associated with MSY, FOPT, is estimated to be 134,000 units, approximately the level reached in 1976 when a peak catch of 121,106 tons was taken. Effort in 1981 is estimated at 87,000 units, almost 30% lower than FOPT. The sensitivity analysis results show that a range of FOPT estimates result from assumed errors in the effort data. An error range of up to + or −20% gives a range of FOPT values of 107,000 units to 162,000 units. Errors in catch data have little or no effect on the estimation of FOPT.

If the number of ages assumed to be significantly contributing to the catch is reduced to 3 from 4, the range on both MSY and FOPT shifts upward in value about 2%. This is due to reduced smoothing of the data. This increases the likely range of MSY values from 71,000 to 110,000 tons.

The application of the generalized production model to fisheries data requires several assumptions, some of which may not be fully met in the case of North Pacific albacore. Among the most critical assumptions is the assumption that the catchability coefficient, $q$, has been subjected to only random variability. Further, when effort of the several gears is standardized and combined, the average values for $q$ are assumed equal for the various gears. In the case of North Pacific albacore we cannot verify that these assumptions are fully met. This is the same for most applications of the production model. However, in the case of North Pacific albacore the relative level of the catches made by each of the fishing gears has remained approximately the same for the time period under study. This should have the effect of making any absolute bias in the estimation of fishing effort more or less constant, preserving the underlying trends. The results of the sensitivity analysis suggest that the estimates of MSY are robust with respect to errors in effort. Therefore, barring systematic changes in $q$, the current estimates of MSY appear reasonable and may be considered as accurate as others calculated for other tuna stocks.

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# 入力データーの誤差が推定値に与える影響を考慮した北太平洋ビンナガのプロダクションモデル解析

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## 摘　要

漁獲量および標準化した漁獲努力量データーを用いて，プロダクションモデルにより，北太平洋ビンナガの資源解析を行った。さらに，モンテカルロシュミレーションを用いた感度分析により，漁獲量と努力量に与えた誤差に対する期待値の感度を推定した。最大持続生産量（MSY）の最適推定値は±20%までのモデル入力データーの誤差に対しても安定しており，71,000～108,000トンの範囲を示した。また，漁獲量と努力量に誤差を与えた場合でも比較的独立した形で推定値に影響を与えることが示された。プロダクションモデルの適用に際して前提条件の結果に与える影響を論議した。