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ASSESSMENT OF INTERACTION BETWEEN NORTH PACIFIC ALBACORE, *THUNNUS ALALUNGA*, FISHERIES BY USE OF A SIMULATION MODEL

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ABSTRACT

Using a simulation model of a typical year in the North Pacific albacore fisheries in the 1970s, we tested for the degree to which the activity of fleets affects the performance of other fleets. The results show that rather drastic (factor of two) changes in the activity of any of the three principal albacore fleets have only a mild effect on the catch of the other fleets. With the overall exploitation rate in the model close to the exploitation rate determined from tagging results (6%), the maximum degree of interaction was a 7.5% drop in longline catch resulting from doubling the baitboat effort. The mild degree of interaction was insensitive to exploitation rate up to approximately 10% exploitation, although interaction became more severe at higher levels of exploitation.

Fishery interaction, the effect of one fishing fleet on another, is a phenomenon of growing concern to those involved in the management and development of pelagic fisheries. This concern has arisen from the growing awareness that oceanic fishery resources are not unlimited and from the evolution of exclusive economic zones to protect local interests against large international fishing fleets. Assessing the potential for interaction between tuna fisheries in different island countries was one of the principal reasons that the South Pacific Commission conducted the Skipjack Survey and Assessment Programme (Kearney 1983). Workshops on this topic have been held during international tuna fishery meetings, and a Tuna Fisheries Interaction Programme has been proposed within the Indo-Pacific Tuna Development and Management Programme.

Because there is a multiplicity of fleets and nations involved in harvesting albacore, *Thunnus alalunga*, a tuna, in the North Pacific, there is a potential concern about interaction between these fleets. A history of North Pacific albacore fishing since the 1950s is summarized by Laurs (1983). Three principal fleets have been responsible for the catch: the Japanese baitboat, the Japanese longline, and the United States jigboat fleets (Fig. 1). In the 1970s these accounted for more than 90% (60%, 15%, and 18%, respectively) of the total catch. In recent years, Japanese gill net gear has become important, accounting for approximately 20% of the total catch from 1981 through 1983 (Fig. 1). Detailed statistics on this emerging fishery are not currently available.

Among the three principal fleets, the U.S. fleet tends to take the smallest fish, and the longline the largest, but the size distributions in the catch overlap to a large extent (Fig. 2). The geographic distribution of the fleets is indicated in Figure 3, but the overlap is overemphasized because there is seasonal separation in many cases. Nevertheless, the migratory nature of albacore makes for potentially significant interaction between fleets that are separated in time and space.

Because there have been no clear trends in catch or in catch per effort (Laurs 1983), it has been assumed that the albacore stocks have not been adversely affected by the fisheries, and such woes as the fishermen have had have not been blamed on poor status of stocks. Therefore there has been little reason for fleets to accuse one another of depleting the stocks and thus little concern about fishery interaction. To verify that sanguine view, we have estimated the degree of interaction between the three principal albacore fisheries in the North Pacific. We defined interaction to be the degree to which changes in the activity (effort) of one fleet affect the performance (catch) of another fleet. The magnitude of this kind of interaction cannot be calculated directly from fishery data, nor can controlled, real-life experiments be conducted on the grand scale necessary to address this topic. However, experiments conducted on simulation model are feasible. The results of such experiments with an

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Manuscript accepted July 1987.
FISHERY BULLETIN: VOL. 85, NO. 4, 1987.

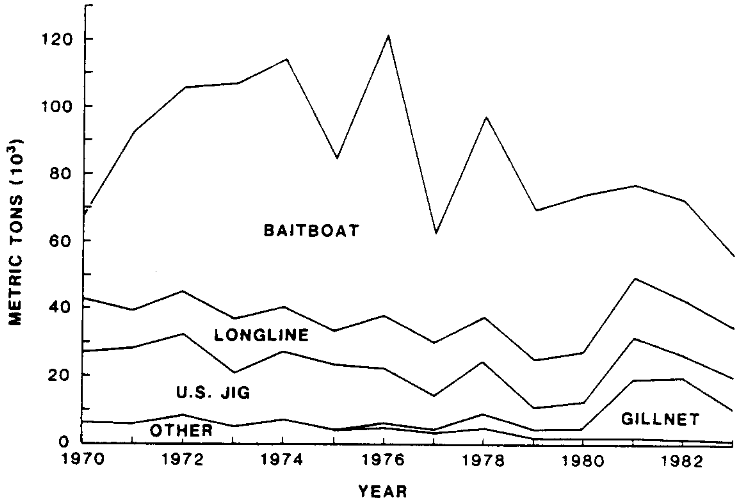


FIGURE 1.—Annual catch of albacore by gear type. [Data from Majors and Miller. 1985. Summary of the 1984 North Pacific albacore fishery data. U.S. Natl. Mar. Fish. Serv., Southwest Fish. Cent. Admin. Rep. LJ-85-14, 45 p.]

albacore simulation model are the subject of this report.

THE MODEL

We used a model that incorporates recruitment, growth, migration, natural mortality, and harvest of albacore by the Japanese baitboat fleet, the Japanese longline fleet, and the United States surface fleet (primarily jig gear). Our approach was to manipulate the effort of one fleet at a time and note the effect on the catch of the other fleets.

A full technical description of the model is given by Kleiber and Baker[2]. We discretized fish size into 5 cm length classes and the North Pacific range of albacore into nine geographic zones (Fig. 3). The basic dynamics within a size class and zone are described by the following differential equation:

$$\frac{dP_{s,z}(t)}{dt} = G_{s-1}P_{s-1,z}(t) + \sum_{\hat{z}} \mu_{\hat{z}\to z} P_{s,\hat{z}}(t) - \left[M + G_s + \sum_{\hat{z}} \mu_{z\to\hat{z}}\right] P_{s,z}(t) - \sum_{g} c_{s,z,g}$$

[2]Kleiber, P., and B. Baker. 1987. The North Pacific albacore simulation model. U.S. Natl. Mar. Fish. Serv., Southwest Fish. Cent., Admin. Rep. LJ-87-2, 38 p.

where $c_{s,z,g} = q_{s,g}\, f_{z,g}(t)\, P_{s,z}(t)$ is the catch rate (number per unit time) by size, zone, and gear. The symbols are defined as follows:

s —index for size class
z —index for geographic zone
$\hat{z}$ —index for zone adjacent to z
g —index for gear type
$P_{s,z}(t)$ —population (numbers) by size and zone at time t

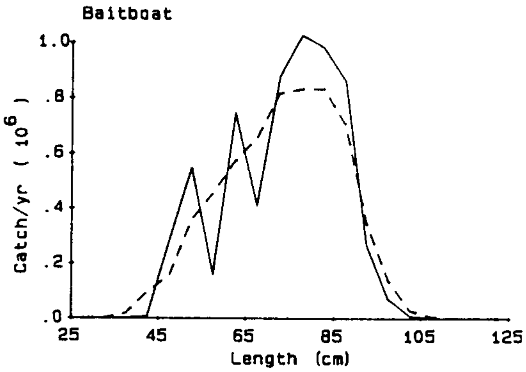
the following being input parameters:

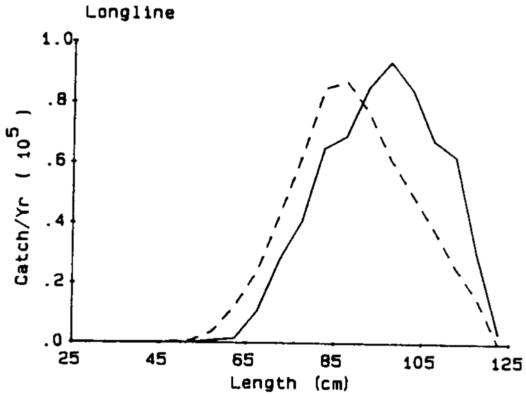
$P_{0,z}(t)$ —recruitment rate by zone at time t
G_s —proportion growing out of size s per unit time
G_0 —always = 1 (so that $P_{0,z}(t)$ is recruitment rate)
$\mu_{z_1\to z_2}$ —coefficient of migration from zone z_1 to zone z_2
M —natural mortality
$q_{s,g}$ —catchability by size and gear
$f_{z,g}(t)$ —effort by zone and gear at time t.

INPUT PARAMETER VALUES

Full details of how input parameters were estimated are given by Kleiber and Baker (fn. 2). The following is a summary.

The most complete catch and effort data sets that were available to us and that cover the three





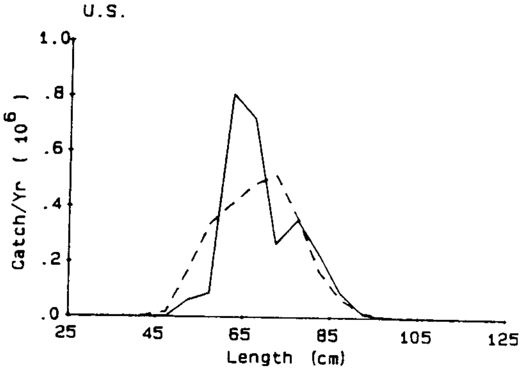


FIGURE 2.—Average albacore annual catch-at-size in numbers (solid lines), and annual catch-at-size predicted by model under nominal conditions (dashed lines), 1970-80.

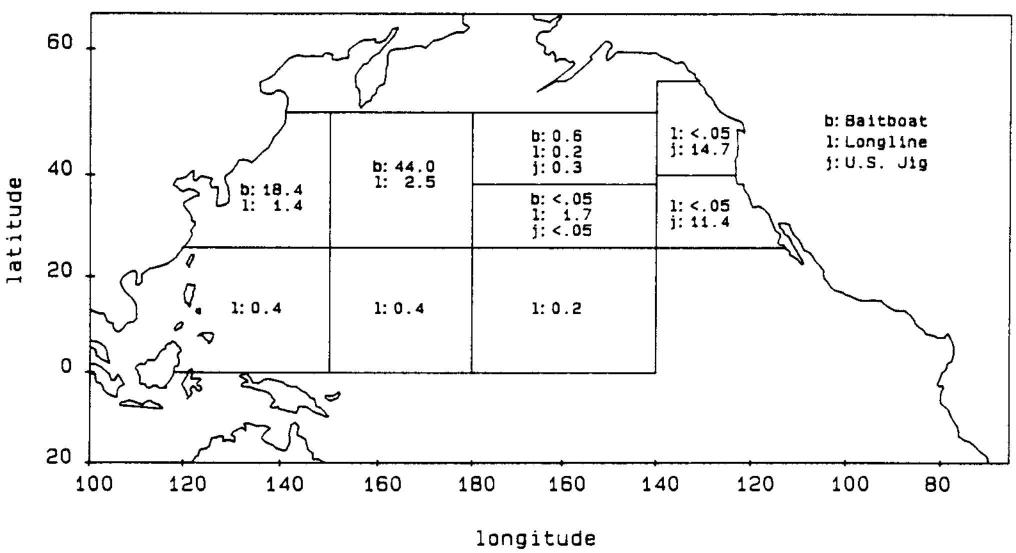


FIGURE 3.—Model zones with average annual albacore catch (numbers × 10^5) by gear type, 1970-80.

major fleets span the years 1970 through 1980. We processed the data into an "average year", that is, the average (over the years 1970-80) of catch by size, zone, month, and gear and the average of effort by zone, month, and gear (Kleiber and Baker[3]). The effort values were used directly in the model and the catch and effort used to estimate other input parameters.

We estimated the 1970-80 average recruitment and preliminary catchability values by size and gear by use of a size-structured cohort analysis (Jones 1981). The catch-at-size vector necessary for this cohort analysis was obtained from the average year by aggregating over zones, averaging over months, and smoothing over size classes.

To conduct the cohort analysis, we needed to specify an average final cohort size, which was unknown to us. We tried a series of values and chose results for which the overall exploitation rate (catch divided by recruitment estimate) was close to the overall exploitation rate estimated from tagging. Tagged albacore have been released in the U.S. fishery at an average size of approximately 65 cm, and approximately 6% of the tags have been recovered (Laurs[4]). Nonreporting losses are small for the major fisheries that recovered the tags (Laurs[5]). Assuming a value of 10% for nonreporting and Type I and II tag losses of 12% and 0.098 year^{-1} respectively (Laurs et al. 1976), the exploitation rate of recruits to 65 cm should be approximately twice the raw recovery percentage. But the exploitation rate in the cohort analysis and the simulation model is based on recruits to 25 cm which should be approximately twice as numerous as recruits to 65 cm (based on growth and natural mortality rates used in the model). Therefore, the exploitation rate of recruits to 25 cm should be approximately equal to the raw tag recovery percentage (6%). We chose a cohort analysis with an exploitation rate of 6.3% as the basis for the results presented below except where we discuss sensitivity to exploitation rate for which we repeated the analysis several times starting at this point with a series of cohort analyses at a series of higher exploitation rates.

[3]Kleiber, P., and B. Baker. 1986. Development of catch and effort data base for the North Pacific albacore simulation model. U.S. Natl. Mar. Fish. Serv., Southwest Fish. Cent., Admin. Rep. LJ-86-26, 21 p.

[4]Laurs, R. M. 1979. Results from North Pacific albacore tagging studies. U.S. Natl. Mar. Fish. Serv., Southwest Fish. Cent., Admin. Rep. LJ-79-17, 10 p.

[5]R. M. Laurs, Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038, pers. commun. March 1987.

The cohort analysis yielded a Pacific-wide recruitment estimate. We apportioned one third of this recruitment to each of the three southern zones, where albacore larvae are predominantly found (Nishikawa et al. 1984).

Size-specific overall fishing mortalities obtained from the cohort analysis were apportioned to gear type by the proportion of the total catch at each size that is taken by each gear type in the average year. We then converted the fishing mortalities into catchabilities by dividing by the overall average effort for each gear type.

Size-specific growth coefficients, G_s, were the growth rates in length (dl/dt) at the upper end of each size class divided by the length of the size classes (5 cm). We estimated the growth rates from the derivative form of the von Bertalanffy growth equation

$$\frac{dl}{dt} = k(l_\infty - 1)$$

where l_∞ is 135.6 cm and k is 0.014 month^{-1} (Clemens 1961). We used these same values in the size-structured cohort analysis, which required input of growth information.

A value for natural mortality was also needed both in the cohort analyses and in the model. We used a value of 0.017 month^{-1} (0.2 year^{-1}) (Suda 1966).

The tag data would be a good source of information to estimate migration coefficients except that the tag recovery effort is not uniformly distributed and analytical techniques to deal with that situation are not well developed. To get a reasonable set of migration coefficients, we quantified the experience of three experts, scientists knowledgeable about the North Pacific albacore fisheries and the available tag data. We first asked the experts to identify the significant paths (movement from one zone to an adjacent zone) for each of a series of broad (10 cm) size classes. For each path we then asked how the intensity of migration via that path is distributed over the months of the year and we evaluated the average intensity by asking the experts the following question: On average, during the season of this migration, if 100 fish of the given size class are now in the origin zone, how many of these (irrespective of mortality) would be expected to be in the destination zone one month from now? We calculated the average migration coefficient for the particular path by

$$\bar{\mu} = \ln \left[\frac{100}{100 - X} \right]$$

where X is the answer to the above question. The monthly migration coefficients were then obtained by scaling the distribution of intensity over months so that the average was equal to $\bar{\mu}$. The migration coefficients for the 10 cm size classes were then assigned to the smaller (5 cm) size classes used in the model, and the coefficients smoothed over size to soften discontinuities.

The pattern of movement represented by the migration coefficients can be summarized as follows: For immature fish (<85 cm) in the zones north of 25° north the pattern is vigorous seasonal movement toward the east in the summer and toward the west at other times. New recruits, which appear in the southern zones, migrate mainly northward throughout the year and are entrained in the east-west excursions of the northern zones. Mature fish (>85 cm) accumulate in the southern zones with brief movements northward in April and May.

RESULTS

When we ran the model with input values estimated as described above and with the effort of all fleets set at nominal levels, that is, the average seasonal and geographic pattern and magnitude of effort for the 1970s with the pattern repeated year after year, we found that after 10 years of simulation the seasonal and geographic pattern and magnitude of catch closely repeated itself year after year. Therefore in making comparisons of model results under different conditions, we allowed the model to run at least 10 years under a given repetitive annual regime before recording the catch results during 1 year of simulation.

In using the preliminary catchability values in the model, we found that the predicted catches were too low and the exploitation rate achieved (2.6%) was less than half the exploitation rate in the cohort analysis, which estimated those catchability values (6.3%). This is because the cohort analysis could not deal with geographic and seasonal variability. The fleets were presumed to be harvesting the ocean-wide population rather than the fish in a localized area and time as in the simulation model. We therefore scaled the catchabilities of each fleet upward to make the annual catches in number in the model (after 10 years of simulation) close to the real average annual catches (Kleiber and Baker fn. 2). With the corrected catchabilities, an exploitation rate of 5.1% was achieved and we took the results in this case to be our nominal (control) results (Fig. 2, Table 1).

We then made runs in which the original seasonal and geographic pattern of effort was maintained but the magnitude of effort of one of the fleets was either doubled or halved. We could then compare the annual catch of each fleet under the changed (experimental) conditions with the annual catch under nominal conditions.

TABLE 1.—Average albacore annual (1970-80) catch in numbers and metric kilotons (kt) by baitboat, longline, and U.S. fleets plus annual catch from model after at least 10 years of simulation under nominal conditions and under various conditions of altered fishing effort.

		baitboat		longline		U.S.	
		number (10^6)	kt	number (10^6)	kt	number (10^6)	kt
average catch		6.29	57.52	0.68	13.30	2.65	19.56
nominal effort		6.87	55.12	0.66	9.47	2.67	18.32
baitboat effort	× 2	12.89	102.00	0.62	8.76	2.63	18.05
	÷ 2	3.55	28.69	0.69	9.86	2.69	18.46
longline effort	× 2	6.85	54.91	1.32	18.79	2.67	18.30
	÷ 2	6.88	55.23	0.33	4.75	2.67	18.33
U.S. effort	× 2	6.80	54.43	0.65	9.23	5.19	35.41
	÷ 2	6.90	55.49	0.67	9.59	1.35	9.32

The catch-at-size for the three fleets under nominal and experimental conditions is plotted in Figures 4 to 6. Changes in effort in one fleet appear to have little effect on the size distribution in the catch of any of the fleets.

The effect on amount caught is another matter. Total catch of all sizes, both in numbers and in weight, is given in Table 1. We obtained catch in weight by converting the number caught in each length category to weight using the length-weight relationship of Clemens (1961) and then by summing over length categories. The effects are summarized in Tables 2 and 3 where the change from nominal catch for each fleet is given for each experimental treatment. By far the largest effect of a change in effort of any fleet is the effect on its own catch. A doubling of the baitboat effort causes the largest between-fleet effect, which is a 7.5% depression of the longline catch in weight, a loss of approximately 700 t (Table 3). A similar loss to the baitboat fleet, due to doubling of U.S. effort, is only a 1.3% decrease in the baitboat catch (Table 3).

We tested the sensitivity of our results to the

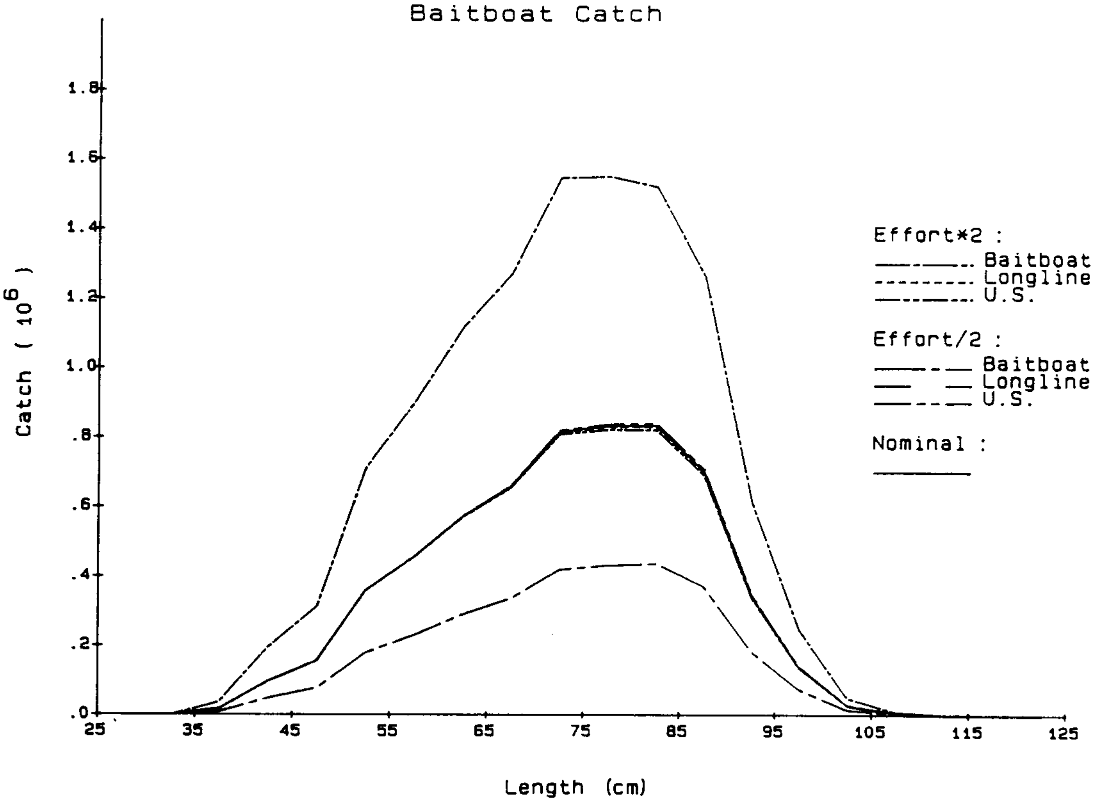


FIGURE 4.—Annual albacore baitboat catch-at-size in numbers predicted by the model under nominal and experimental conditions.

TABLE 2.—Interaction matrix for annual albacore catch in numbers. The values given are the differences between the catch under altered effort and the nominal catch (percent of nominal catch in parentheses).

cause ⇓ / effect ⇒		Δ catch: number × 10⁶ (%) baitboat	longline	U.S.
baitboat effort	× 2	6.02 (87.6)	−0.04 (6.1)	−0.04 (1.5)
	÷ 2	−3.32 (48.3)	0.03 (4.5)	0.02 (0.7)
longline effort	× 2	−0.02 (0.3)	0.66 (100.0)	0.00 (0.0)
	÷ 2	0.01 (0.1)	−0.33 (50.0)	0.00 (0.0)
U.S. effort	× 2	−0.07 (1.0)	−0.01 (1.5)	2.52 (94.4)
	÷ 2	0.03 (0.4)	0.01 (1.5)	−1.32 (49.4)

TABLE 3.—Interaction matrix for annual albacore catch in weight. The values given are the differences between the catch under altered effort and the nominal catch (percent of nominal catch in parentheses).

cause ⇓ / effect ⇒		Δ catch: kt (%) baitboat	longline	U.S.
baitboat effort	× 2	46.88 (85.1)	−0.71 (7.5)	−0.27 (1.5)
	÷ 2	−26.43 (47.9)	0.39 (4.1)	0.14 (0.8)
longline effort	× 2	−0.21 (0.4)	9.32 (98.4)	−0.02 (0.1)
	÷ 2	0.11 (0.2)	−4.72 (49.8)	0.01 (0.1)
U.S. effort	× 2	−0.69 (1.3)	−0.24 (2.5)	17.09 (93.3)
	÷ 2	0.37 (0.7)	0.12 (1.3)	−9.00 (49.1)

overall exploitation rate by repeating the whole analysis at higher exploitation rates, starting with the cohort analysis, correcting catchabilities to give a new set of nominal results, and finally measuring the most sensitive interaction, the effect of doubled baitboat effort on the longline catch (Fig. 7). The degree of interaction is not affected very much when the exploitation rate is below 10%, but it rises quickly at higher exploitation rates.

DISCUSSION

Our results support the notion that fishery interaction is not of great consequence, at least for the North Pacific albacore fisheries typical of the

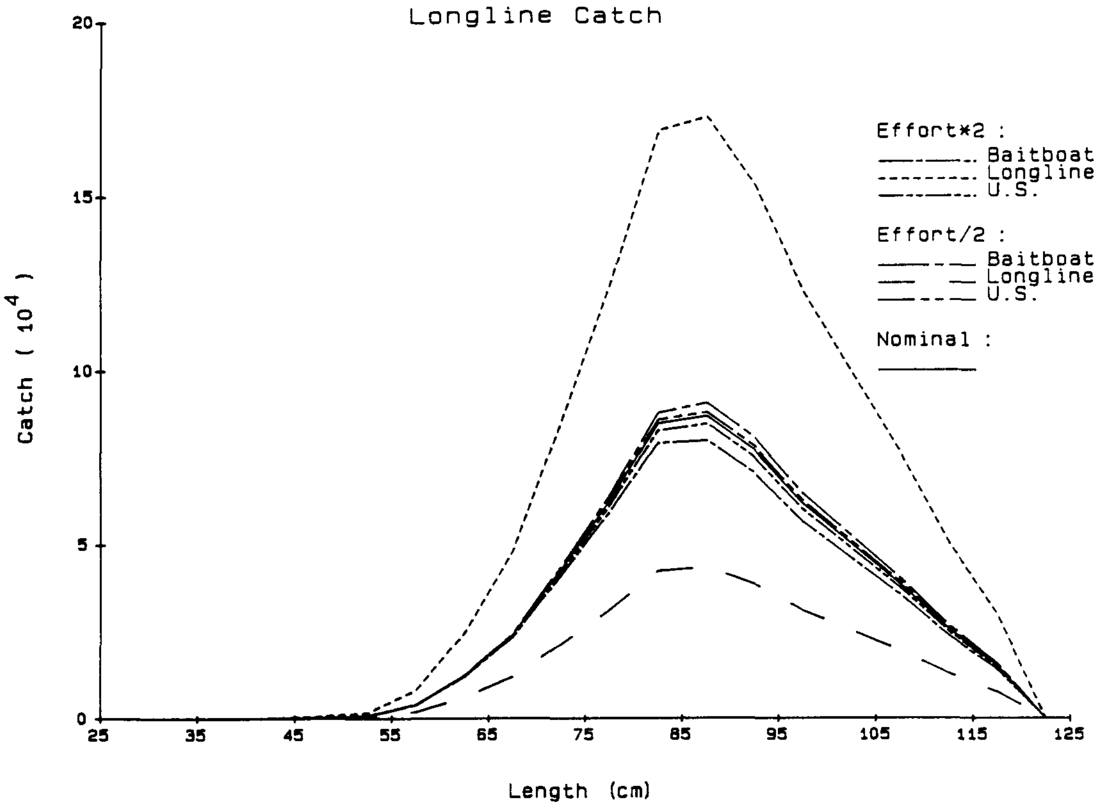


FIGURE 5.—Annual albacore longline catch-at-size in numbers predicted by the model under nominal and experimental conditions.

1970s. The reliability of this conclusion, of course, depends on the reliability of our simulation model, but in evaluating the behavior of the model, we should remember that what is important is the response of the model to experimental manipulation not the exactitude of the nominal behavior in comparison to real data. Of course, if the nominal behavior is outlandish, the responses to manipulation will be suspect. Therefore we used the average year as a signpost to tune the nominal results of the model into the range of plausible behavior, but we did not insist on exact duplication of the average year (itself an abstraction that never happened in reality).

A case in point is the longline catch, which under nominal conditions in the model is less (in weight) than any of the real annual longline catches for the years 1970-80. The average over those years is 13.3 metric kilotons (kt) per year whereas the nominal longline catch in the model is 9.47 kt/year (Table 1). The discrepancy is explained by the fact that the average size of fish in the model longline catch is less than the average size in the real longline catch, because large fish in the model migrate out of reach of the longline fleet more than they should. We have not corrected this problem because we are waiting for further information from tagging studies to get better estimates of migration coefficients. We expect the corrections to be quantitative refinements of the existing values and not a qualitative change in the current migration pattern in the model.

What is important in the current context is that bias in the nominal results is bound to show up in the experimental results as well. The migration coefficients were the same in both control and experimental situations in the model. Therefore, refinements to the coefficients are not likely to make much difference in the relative values in Tables 2 and 3, particularly in the percentages. It is pertinent that our conclusion of low interaction

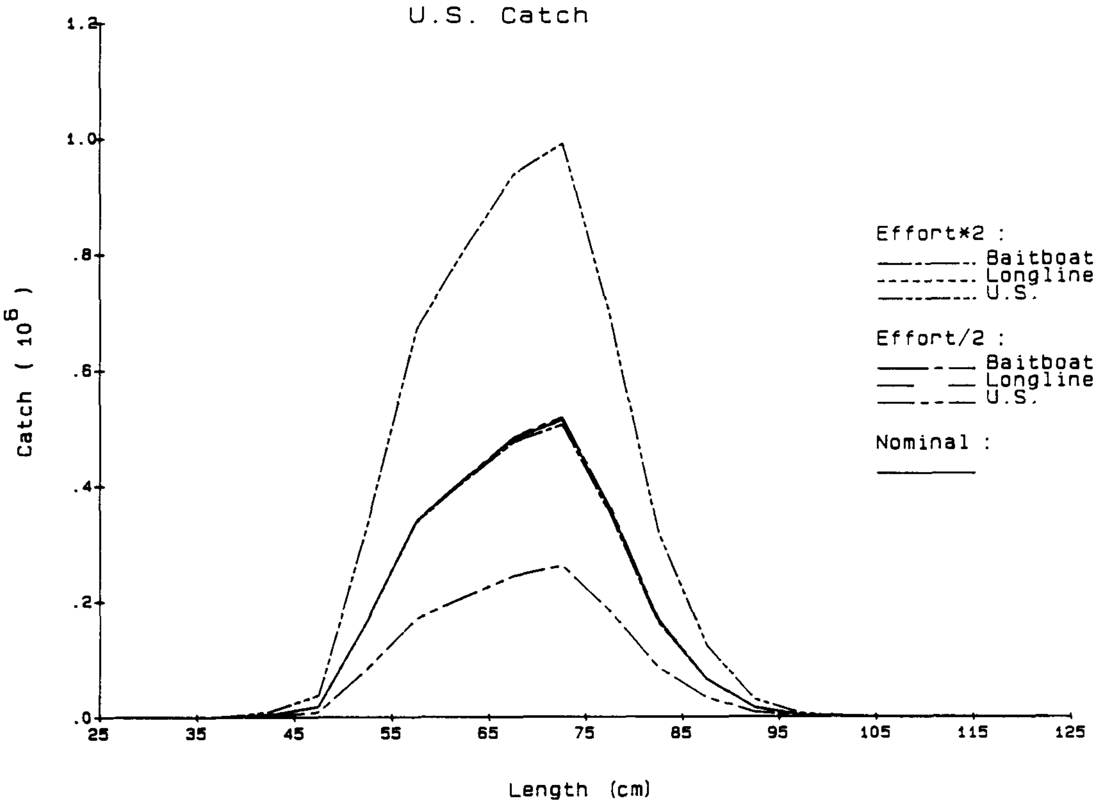


FIGURE 6.—Annual albacore U.S. catch-at-size in numbers predicted by the model under nominal and experimental conditions.

(expressed as percent) persisted through a series of updates of the model (such as changes in configuration of geographic strata) and inevitable updates and corrections of the fishery data base.

Though the nominal behavior of the model need not conform precisely to the mean behavior of albacore fisheries in the 1970s (however that might be defined), the behavior should, nonetheless, be a plausible representation of the albacore fisheries in that period. We have seen, for example, that our conclusion would be suspect if the actual exploitation rate were considerably higher than the 6% value that we assumed (Fig. 7), but such high exploitation levels would be contrary to the tag return results.

We have only tested the effects of changes in the magnitude of effort, not changes in seasonal and geographic pattern of effort, which might cause the fleets to overlap much more than they do. However, our experimental treatment of doubling the effort of a fleet is tantamount to adding

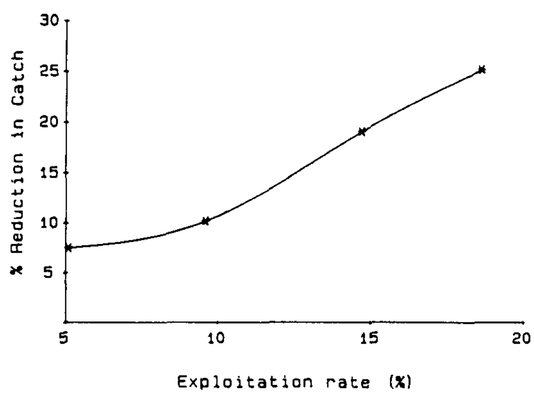


FIGURE 7.—Sensitivity of interaction to overall exploitation rate. The ordinate is the percent reduction from nominal levels in annual albacore longline catch in weight as a result of doubling the baitboat effort.

a completely overlapping, competing fleet. The response of each fleet to doubling of its own effort was close to a 100% increase in catch (Tables 2, 3), indicating that the degree of competition was low. Therefore, it would be difficult to design a realistic experimental treatment that 1) would be simply a shift in the geographic and seasonal pattern of effort in one fleet (not a change in magnitude), and 2) would have a strong impact on another fleet.

A legitimate question is whether our conclusions, which are based on 1970s data, can be extrapolated to the current conditions. The most striking change in recent years is the emergence of the gill net fishery for albacore, which now takes approximately 20% of the total catch. However, because the total catch has not increased, the exploitation rate must still be mild, and we would expect that interaction between fleets would also still be mild. We cannot use our model to estimate interaction quantitatively in this situation because we lack detailed data on the gill net fishery.

CONCLUSIONS

The implication of our results is that fleet interaction is not likely to be significant if the pattern and magnitude of effort in the 1970s are maintained. This assessment could change if the overall exploitation rate increases considerably. The recent emergence of the gill net fishery could be of significance in this regard. The levels of annual catch that have been reported by this fishery are not likely to be of concern, but the significance cannot be confidently evaluated unless detailed catch, effort, and size distribution data are made available.

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