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FURTHER ANALYSIS ON SPAWNER/RECRUIT RELATIONSHIPS FOR THE NORTH ATLANTIC ALBACORE

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SUMMARY

This paper investigates the use of different indices of parent and recruitment abundances for fitting spawner-recruit models to North Atlantic albacore fishery data. Estimates of confidence intervals for different spawner and recruit relationships are done using both linear approximations and simulation analysis methods. Results indicate that "smoothing" of the parent stock index and shifting of estimated age at recruitment has little effect on results. The use of an alternate recruitment index and shortening the data series produces results differing from those previously presented.

RESUME

Le présent document évalue l'emploi de différents indices de l'abondance du stock parental et du recrutement pour ajuster les modèles géniteurs/recrues aux données de la pêche au germon dans l'Atlantique nord. L'intervalle de confiance a été calculé, pour divers rapports géniteurs/recrues, par la méthode d'approximation linéaire comme par celle de l'analyse de simulation. Les résultats montrent que le "lissage" de l'indice du stock parental et de déplacement de l'âge estimé de recrutement affectent peu les résultats. L'emploi d'un autre indice du recrutement et l'écourtement des séries de données donnent des résultats différents de ceux obtenus auparavant.

RESUMEN

Este documento investiga la utilización de los diferentes índices de abundancia de reclutamiento y stock reproductor para ajuste de los modelos reproductor-recluta a los datos de pesquería del atún blanco en el Atlántico Norte. Se han hecho estimaciones de intérvalos de confianza para relaciones diferentes entre reproductores y reclutas, utilizando tanto métodos de simulación lineales como analíticos. Los resultados indican que " alisamientos" del índice del stock reproductor y desplazamiento de la edad estimada al reclutamiento, tienen poco efecto en los resultados. La utilización de un índice alterno de reclutamiento y reducción de las series de datos, produce resultados diferentes, de los presentados anteriormente.

INTRODUCTION

At the meeting of the Standing Committee on Research and Statistics (SCRS) held prior to the first special meeting of the International Commission for the Conservation of Atlantic Tunas (ICCAT), the SCRS expressed serious concerns about the health of the North Atlantic albacore (*Thunnus alalunga*) stock. According to the Committee (ICCAT, 1979):

"The most concern related to recruitment. Data presented to the 1978 meeting again showed an apparent decline in recruitment as an average trend since 1960, and a considerable, and increasing, variability in the recruitment. In the spawner-recruit relations presented, it was indicated that the spawning stock is apparently at a low level of about 1/5 of its original size. Further, the period of large fluctuations in recruitment is associated with the period of low parent stock abundance. These symptoms have been followed in a number of stocks of herring and similar small pelagic species (but not so far in any tuna stocks) by a more or less complete failure in recruitment, and a collapse of the fishery. The Committee could not say how likely it is that similar events will happen in the albacore stock, but the situation is certainly one that the Commission should view with serious concern."

These comments were based on analyses presented at the 1976, 1977, and 1978 SCRS meetings.

The North Atlantic albacore spawner/recruit (SR) situation has been examined by different investigators (Bard, 1977, 1978; Bard and Gonzalez-Garces, 1979; Bartoo, 1979). Different forms of SR relations e.g. Beverton-Holt (Beverton and Holt, 1957) and Ricker (Ricker, 1975) were examined.

Ricker SR curves for North Atlantic albacore fitted by Bard and Gonzalez-Garces (Figure 1A), and by Bartoo (Figure 1B), are similar:

$$R = 8.835Pe^{-0.221P}$$ (Bard and Gonzalez-Garces, 1979)

$$R = 10.381Pe^{-0.308P}$$ (Bartoo, 1979)

where: R = Index of Recruitment
P = Index of Parent Stock (spawners)

Differences between relations (1) and (2) are due to the index of recruitment chosen. The recruitment index used in equation (1) is based on numbers of recruits to age 2 as estimated by cohort analysis. The equation 2 index is the CPUE of troll caught albacore of catch class "Bonite" (age 1), as sorted by the troll fishery (Bard, 1974); representing abundance of fish apparently from a single age group (Bard, 1974, Bartoo, 1979).

The P index used in both equations (1) and (2) is the CPUE of longline taken adult albacore as estimated by Shiohama (1979).

The purpose of this paper is to extend previous spawner/recruit analyses by estimating confidence intervals around selected SR curves, and evaluating the effects of changing spawner or recruit indices used in fitting these SR curves. This analysis deals specifically with Ricker SR relation, however, as demonstrated by Paulik (1973), the Ricker SR relation will approximate the shape of the Beverton-Holt SR relation if the data require it. The Ricker curves were fit using the regression procedure outlined by Ricker (1975).

BASELINE SR RELATION AND CONFIDENCE INTERVALS

The basic SR relation used is estimated using the recruit index of equation 2, the CPUE of troll caught age 1 albacore (Table 1). The parent index is based on the CPUE of adult longline captured albacore (as used in equations (1) and (2)) smoothed by a 2-year moving average (Table 2).

Using a moving-average P index reduces some of the minor year-to-year variation. The raw P index (Shiohama, 1979) Table 2, shows a definite declining trend (Figure 2) with some increase in the late 1960's and a slow decline in the 1970's. It was determined by inspection that a two-year moving average allowed the general trends in the raw data to remain while removing some of the minor variation (Figure 2).

The following Ricker SR curve was fitted to smoothed P indices (Table 2) paired with appropriate age 1 R indices (Table 1), according to year of spawning (Bartoo 1979).

$$R = 10.761Pe^{-0.335P}$$

where R = index of recruitment
P = index of parent stock

The resulting curve (Figure 3) is nearly identical to equation (2), indicating that the smoothing of the P index had relatively little effect.

CONFIDENCE INTERVALS ON EQUATION (3)

Quantifying the most likely location of the actual SR curve (fit to sample data) is highly desirable. However, owing to intractability in the mathematics associated with the procedures used to fit Ricker SR curves (Ricker, 1975), confidence intervals are not analytically derived. It is possible, however, to estimate the confidence intervals associated with equation (3) by applying:

1) a linear approximation and associated estimators to the portion of the SR curve of interest or

2) a simulation analysis approach and generating empirically derived curves.

LINEAR ANALYSIS

Linear approximation was used to determine confidence intervals, for the portion of the SR curve at low P index values, the region of interest in equation (3) (Figure 3). The 1964-1976 data are in this region. The following least-squares linear regression, forced through the origin, (0, 0), of the form y=ax, was fitted to the 1964-1976 data.

$$R = 8.119\ P \qquad (4)$$

where: R = index of recruitment
P = index of parent stock

Equation (4) is shown as a straight line through the origin in Figure 3. A detail of the data, the SR curve, equation (3), and the linear approximation, equation (4) is shown in Figure 4. The linear approximation follows the SR curve reasonably well; the greatest deviation between the two being at the larger P values.

Ninety-five percent confidence intervals for R index points (Figure 4) were connected to form 95 percent confidence bands around equation (4). Confidence intervals of R given P were calculated according to the standard methods of Neter and Wasserman (1974). Given many points, P_j, the confidence interval

$$P(R_L \leq E(R_j) \leq R_h) \leq 0.95$$

is uniquely determined by the confidence interval on the constant in equation (4):

$$P(5.1497 \leq a \leq 11.0883) \leq 0.95$$

This interval is shown in Figure 4.

Fitted confidence bands can be used to estimate the probability that the next data point will fall outside some designated zone around equation (4). Again, the procedures of Neter and Wasserman (1974) were employed to estimate confidence bands[1/] shown in Figure 5. Thus, we can say, for example, given that equation (4) is correct and given some measured value of P (say 1.4); the probability that the next R value will be less than 3.0 is less than 10 percent; the probability that the next R value will be greater than 19.0 is also less than 10 percent.

Given P values in the 0.9 to 1.1 range (the current level of parent stock index), the probability is between 10 and 15 percent that the next R value may fall below the value of 1.0 (Figure 5). The probability that the next new R value will be lower than some chosen level, R', is shown in Figure 6 as a function of P.

SIMULATION ANALYSIS

Because the linear approximation deals with only a small portion of the SR curve and may be biased, a simulation analysis was done to estimate confidence intervals around all of equation (3).

The simulation analysis involved generating a series of "new" or simulated sets of R values corresponding to the observed P values. The new R values were generated as random deviates distributed normally with mean u and variance α^2. To each new set of data points (each point an observed P value and a new R value), a single Ricker SR curve was fit. This procedure was repeated 1000 times for each of several different hypotheses on the values of u and α^2. At the end of each 1000 repetitions, distributions of expected R values from the fitted SR curves for each P were generated. These empirical distributions can be interpreted as probability distributions and hence the loci of the probability distributions as confidence bands on the location of the mean expected SR curve.

The simulation analysis requires that the u and α^2 of R, which vary with P, be defined in order to generate the new data sets. To closely approximate the actual u and α^2 of observed R values, the data were segmented into groups for which u and α^2 appeared similar. For instance in Figure 3, one group of data might be interpreted as the points at low P values, say 0.9 to 1.6, which appear more variable than points at higher P values. For several cases, different data groupings, the following means and standard deviations were estimated.

1/ Confidence bands for data fitted by linear regression forced through the origin are parallel to the fitted line as contrasted to the more familiar curved bands associated with unconstrained linear regressions.

	Years Grouped	R Distributed With	
		$\hat{u}$	α
Case 1:	1964-1976	9.79	5.6993
	1959-1963	13.34	3.3577
	1957-1958	10.87	5.6781
Case 2:	1964-1976	9.79	5.6993
	1959-1963	13.34	3.3577
	1957-1958	10.87	3.3577(assumed)
Case 3:	1964-1976	9.79	5.6993
	1957-1963	11.53	4.6922

For each case new R values were generated with u's and 's as noted above.

The results for Case 1 (Figure 7) show rather wide confidence bands, skewed toward lower R values, possibly by some bias introduced in the SR curve fitting procedure (Ricker, 1975). The simulation analysis confidence intervals follow the SR curve much better than the linear approximations presented earlier. When compared to the linear approximation, the simulation analysis confidence intervals show slightly lower probabilities of low R values in the P = 0.9 to 1.2 range and slightly higher probabilities of low R values in the P = 1.2 to 1.5 range. The expected mean SR curve for Case 1 as well as equation (1) and equation (3) are all shown in Figure 7. All three SR curves shown fall within the simulation analysis 70 percent confidence bands.

Confidence bands for Case 2 (Figure 8) are similar to those shown for Case 1. The notable difference between the two is that the confidence bands are closer to the mean SR curve at high P values in Case 2. This is due to the lower assumed variance at high P values. Again SR relations equation (1) and equation (3) are shown with the mean expected SR curve for Case 2 in Figure 8. All 3 SR curves fall within the simulation analysis 70 percent confidence bands.

Changing the grouping of data as indicated in Case 3 results in confidence bands (Figure 9) closer to the mean than those for Case 1 and comparable to those for Case 2. The mean expected SR curve for Case 3 and SR curves equations (1) and (3) are shown in Figure 9.

A comparison of results of expected Case 1, 2, and 3 simulated SR curves and analytically fitted SR curves equations (1) and (3) (Figure 10) shows very little difference between Cases 1, 2, and 3 and equation (3) curves. Differences between all the curves are generally larger at larger P values and negligible at low P values. As previously noted, SR equation (2) is essentially identical to SR equation (3). Thus, it can be concluded that for practical purposes at low P index values all of the SR curves shown in Figure 10 (as well as equation 2) are identical.

As was done for the linear approximation to the SR curve, the probability that the R index in Case 1 will fall below some pre-determined value can be estimated, Figure 11. Note that the probabilities are about 1/2 those shown in Figure 5.

EFFECTS OF ALTERNATE R INDICES

The R indices used to this point, estimated recruitment in numbers and CPUE of age-1, troll-caught fish, have produced similar results. One common characteristic of these R indices is their high variability. Will another R index produce different results?

AGE 2 CPUE

CPUE's of troll caught albacore of ages 1, 2, and 3 (Bartoo, 1979) are shown in Figure 12. All three ages exhibit variability, but it appears that age 3 may better sample the fishery due to higher catches and CPUE's in all catch years. The age 3 CPUE also shows more clearly the trend in declining CPUE over time. Several weak cohorts as well as several stronger cohorts can be seen in the CPUE of all 3 ages suggesting that the CPUE of age 3 is at least consistent with the other 2 ages CPUE's.

A SR curve (Figure 13) was fit to age 2 CPUE (Table 1), and the appropriate smoothed P index (Table 2):

$$R = 58.96Pe^{-0.330P} \qquad (5)$$

where: R = index of recruitment
P = index of parent stock

The resulting curve (Figure 13) looks very similar to the curve of equation (3) (Figure 3) as expected because the fitted exponents in equations (3) and (5) are quite close, 0.335 and 0.330 respectively. For both equation (3) and (5) expected maximum recruitment occurs at a P index of about 2.8. The value of the R index at its maximum is due to the change in the R scale. It is concluded that the use of age 2 CPUE as the R index produces results qualitatively similar to results obtained using age 1 CPUE as the R index. The principle difference being a scaler change in the R index.

DELETING DATA

The effect of deleting two data points from the data used to fit equation (5) at very high P values is shown in Figure 13. This was done because these two data points came from the initial period of longline expansion into the Atlantic. The early years CPUE values and hence P values are quite high, perhaps reflecting inadequate sample coverage of the stock. This is further suggested by the observation that the two data points at high P values are nearly 50 percent higher than the rest of the data points despite the fact that the total catches the CPUE values were derived from are less than 1000 MT per year.

Depending on whether or not the two data points noted above are retained (Figure 13), the P level, producing maximum R, shifts from 144 percent of the current R level to 233 percent of the current R level.

The simulation analysis technique described earlier was used to estimate confidence for:

$$R = 70.68\ Pe^{-0.4652P} \qquad (6)$$

where: R = index of recruitment
P = index of parent stock

which excludes the two data points noted above for the reasons mentioned (Figure 13). The data were separated into two groups, and the means and standard deviations were estimated for the simulation analysis:

	Years Grouped	R Distributed With $\hat{\mu}$	α
Case 4:	1972-1975	48.47	21.0020
	1959-1971	52.46	10.6639

The resulting confidence intervals on the mean expected SR curve (Figure 14) are quite narrow, narrower than any previously presented. The SR curve equation (6) matches the mean expected SR curve (Case 4) (Figure 14) very closely.

ASSUMED AGE CHANGES

The effect of changing the estimated age of the recruitment index (age 2 in equation (6), age 1 in all others but equation (1)) was investigated by advancing the R index age by one year, thus matching the ages assigned by Bard (1974), pairing the R indices with appropriate P indices and refitting the Ricker SR curve. By redefining the R values used in equation (2) as age 2, the following SR curve is obtained (Figure 15):

$$R = 9.4880Pe^{-0.2401P} \qquad (7)$$

where: R = index of recruitment
P = index of parent stock

By inspection little difference is evident between equations (2) and (7) (Figure 18 and Figure 14), suggesting that in this case, the assignment of age has no great effect on the results.

By re-aging the R index used in equation (6) as age 3 instead of age 2, pairing with appropriate P index values and refitting the Ricker SR curve, the following SR curve is obtained (Figure 16):

$$R = 67.48Pe^{-0.4491P} \qquad (8)$$

where R = index of recruitment
P = index of parent stock

As shown in Figure 16, equation (8) differs little from equation (6) This suggests, as was the case for equations (2) and (7), that given the data involved, the effects of advancing the age of R by one year has little effect on the resulting SR relations.

DISCUSSION

As a result of the analyses presented, the general trends in the data appear to govern the resulting SR relations far more than small changes in the indices used. For instance both smoothing the P index by a moving average of 2 years and advancing the age of the R index by one year has, by inspection, virtually no effect.

Deleting the few data points at very high P values does produce a difference in the resultant curve. When this is done, conclusions previously reached that the current recruitment level is about 50 percent of the maximum expected level and that the current P index is about 1/5 of that expected to exist in the mid-1950's, changes, so that now we are realizing recruitment of about 65-70 percent of the maximum expected, and the reduction in the P index may be closer to 30-40 percent as opposed to 80 percent.

Variability in the age 1 R index has not changed however, and the possibility of a year class failure as indicated by this R index still appears real. Depending on whether linear approximation or simulation analysis estimated confidence bands are used (Figures 5 and 11), the probability that the age 1 R index will drop below 2.0 at the present P index level is about 17 percent and 7 percent respectively.

The use of CPUE of age 2 (catch class "Demis") as an index of R produces a spawner recruit relation qualitatively very similar to that obtained using an age 1 R index. However, the variation around the line is not as great (the trend is still evident), and the expected confidence intervals around the line are tightened.

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Table 1. Catch and effort of French-Spanish troll fleet by year of catch and age.

Catch year	1 "Bonite"	2 "Demis"	Age 3	4	5	Troll effort (days)
1957	1 240 282	4 406 265	881 253			51 919
1958	1 051 771	4 627 794	1 332 244			70 678
1959	441 220	3 333 666	1 447 309			64 419
1960	700 448	5 393 449	910 582			56 579
1961	710 397	2 525 858	710 397			40 568
1962	486 402	3 296 724	1 567 295			54 972
1963	990 514	2 476 285	1 485 771			63 112
1964	736 221	3 567 841	1 359 178			59 884
1965	603 158	2 865 002	1 357 106			46 741
1966	578 334	3 614 587	626 528			69 483
1967	970 105	4 527 159	970 105			75 144
1968	800 100	2 766 750	1 055 250	21 000		69 419
1969	171 000	2 428 200	555 300	36 000		52 456
1970	749 700	1 367 100	686 980	35 280		38 489
1971	763 600	3 406 300	368 000	27 600		49 181
1972	816 000	2 396 000	1 033 000	207 000	4 000	45 192
1973	145 000	1 880 000	1 063 000	116 000		43 284
1974	87 000	1 497 000	1 515 000	119 000	1 000	35 800
1975	188 000	551 000	599 000	97 000	6 500	24 352
1976	327 881	1 742 416	294 602	168 156		29 902
1977	297 000	2 125 100	692 400	274 600		29 858

[a]Data from Bard and Gonzalez-Garces, 1979

[b]Ages assigned according to Bartoo, 1979

Table 2. Parent stock indices (P) used in spawner/recruit relations by year of catch.

Spawning or catch year	Adult[a] CPUE	Smoothed[b] adult CPUE
1957	4.78	4.34
1958	3.02	3.90
1959	2.21	2.62
1960	2.37	2.29
1961	1.79	2.08
1962	1.54	1.67
1963	1.74	1.64
1964	1.38	1.56
1965	1.14	1.26
1966	1.16	1.15
1967	1.37	1.27
1968	1.52	1.45
1969	1.14	1.33
1970	1.34	1.24
1971	0.93	1.12
1972	0.90	0.92
1973	1.02	0.96
1974	1.06	1.04
1975	0.80	0.93
1976	1.40	1.10

[a]Taken from Shiohama, 1979

[b]Smoothed by a moving average of 2 years

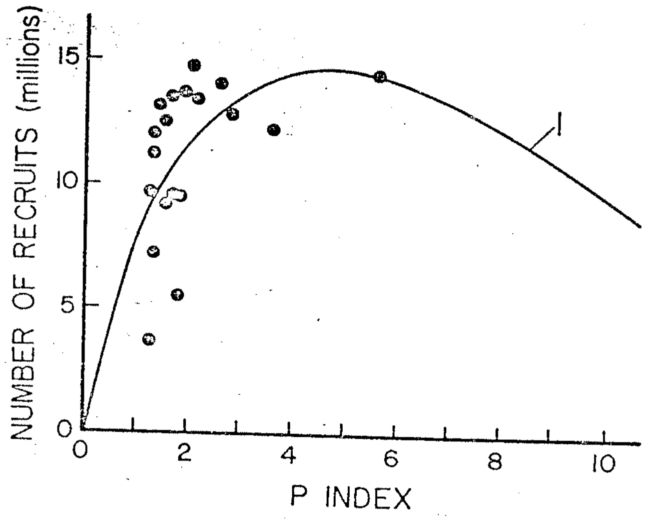

Fig. 1A. Spawner-Recruit relationship of Bard and Gonzalez-Garcés (1979), text equation 1. P. index is the parent stock index.

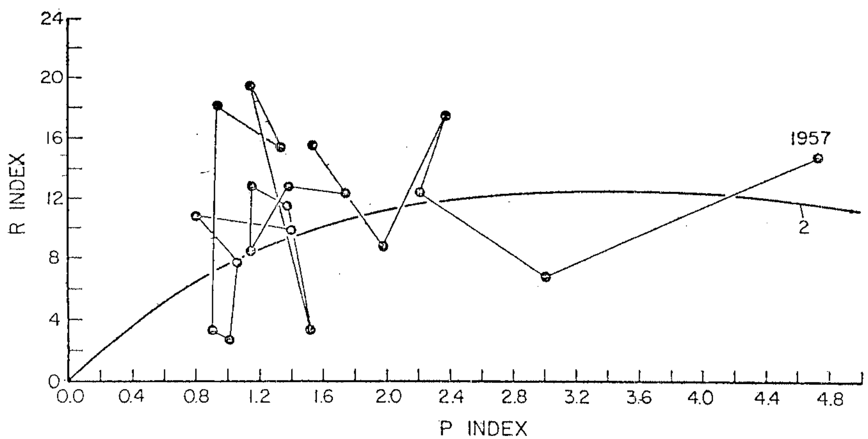

Fig. 1B. Spawner-Recruit relationship for text equation 2. P index is the parent stock index; R index is the recruitment index.

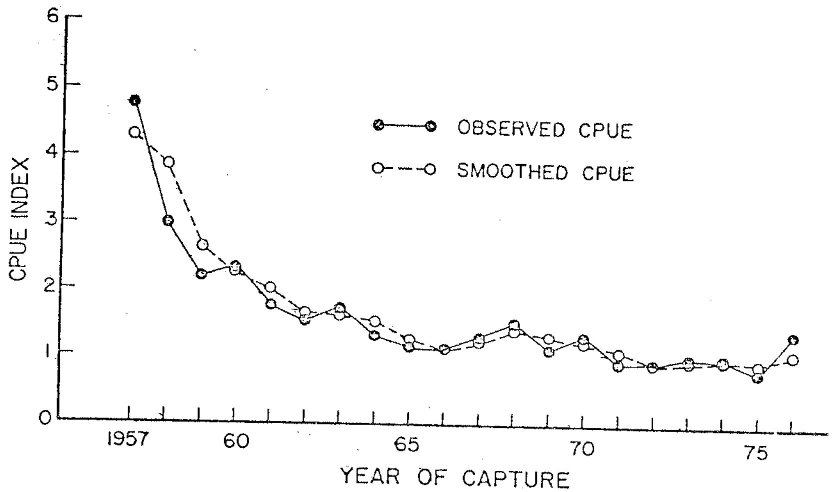

Fig. 2. Observed Catch-Per-Effort (CPUE) and observed CPUE smoothed by a 2-year running average of adult North Atlantic albacore taken by longline versus year of catch (from Shiohama, 1979).

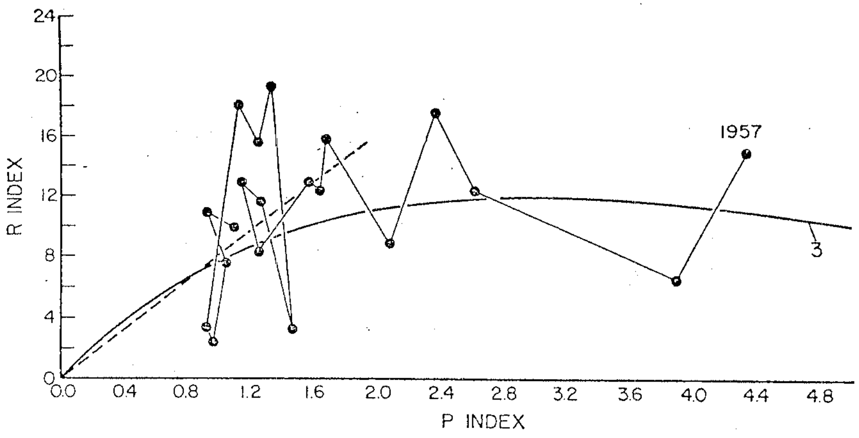

Fig. 3. Spawner-Recruit relationship for text equation 3. P index is the parent stock index; R index is the recruitment index.

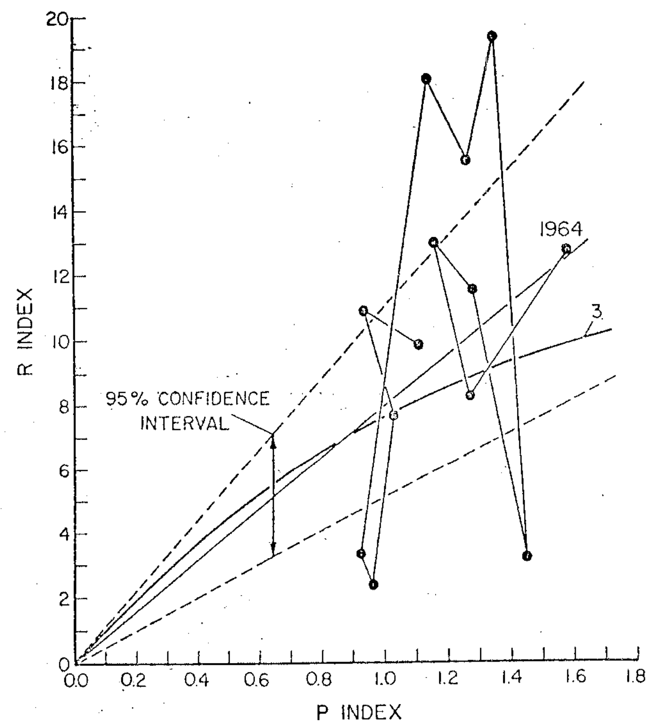

Fig. 4. A "least-squares" straight line, forced through origin, and 95% confidence bands, fitted to a portion of data of spawner-recruit equation 3. P index is the parent stock index; R index is the recruitment index.

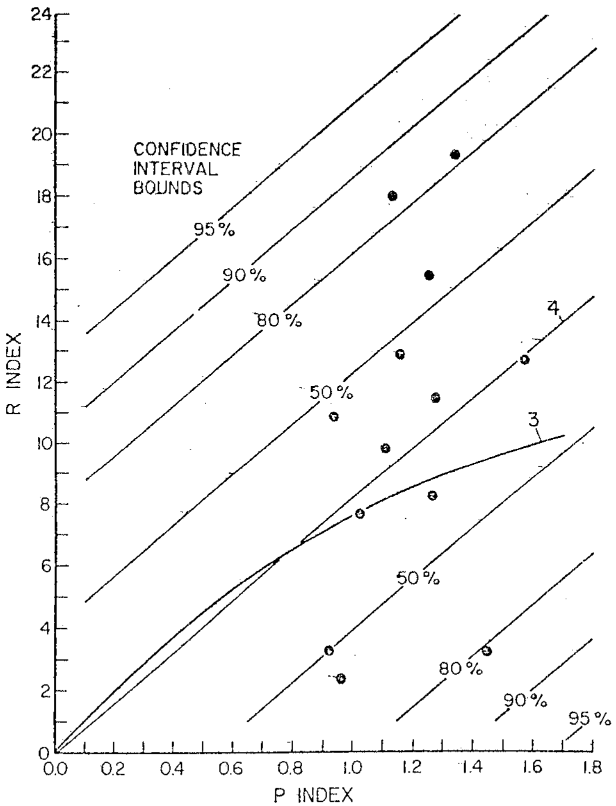

Fig. 5. The 50%, 80% 90%, and 95% confidence bands on the location of the next recruitment index value, R, given various parent stock index levels, and assuming the linear relationship, text equation 4 is the correct spawner-recruit relationship.

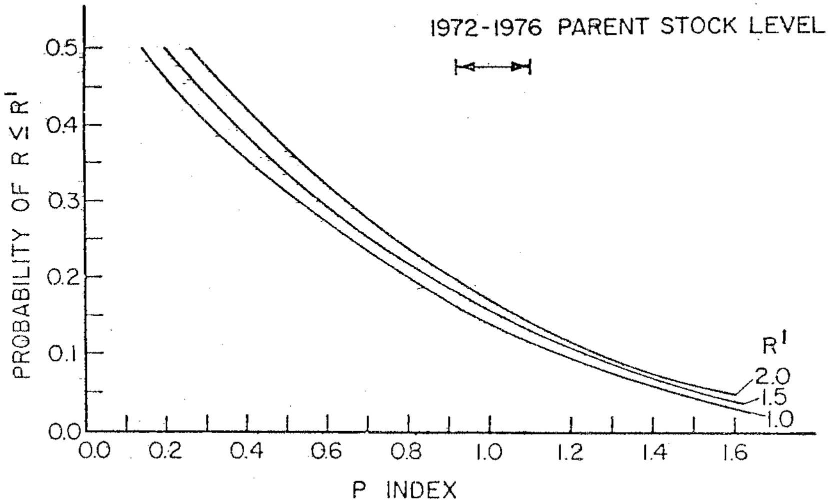

Fig. 6. Probability that the observed recruitment index value, R, will be smaller or equal to some recruitment index value R', at any given parent stock index level, P, given spawner-recruit equation (4) confidence bands (see text).

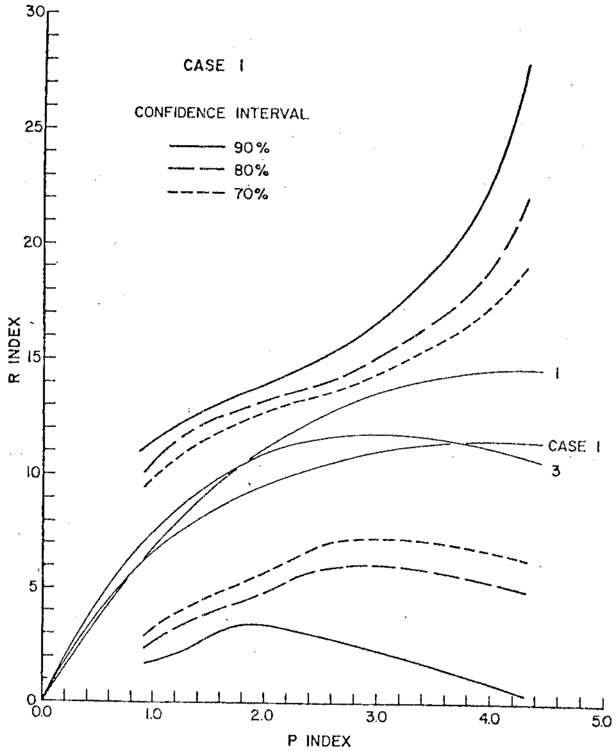

Fig. 7. Spawner-recruit relationship of Case 1 and equations 1 and 3 (see text) and 70%, 80% and 90% confidence bands on Case 1. P index is the parent stock index; R index is the recruitment index.

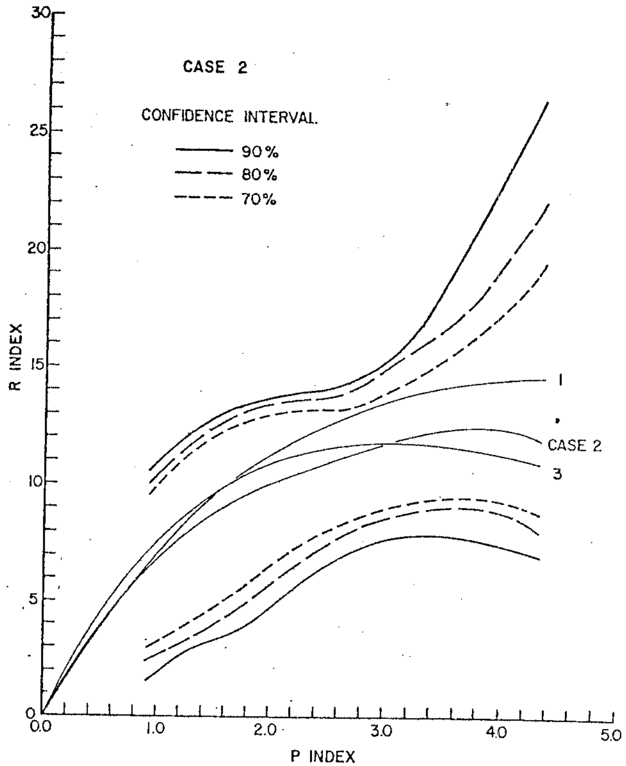

Fig. 8. Spawner-recruit relationship of Case 2 and equations 1 and 3 (see text)and 70%, 80%, and 90% confidence bands on Case 2. P index is the parent stock index; R index is the recruitment index.

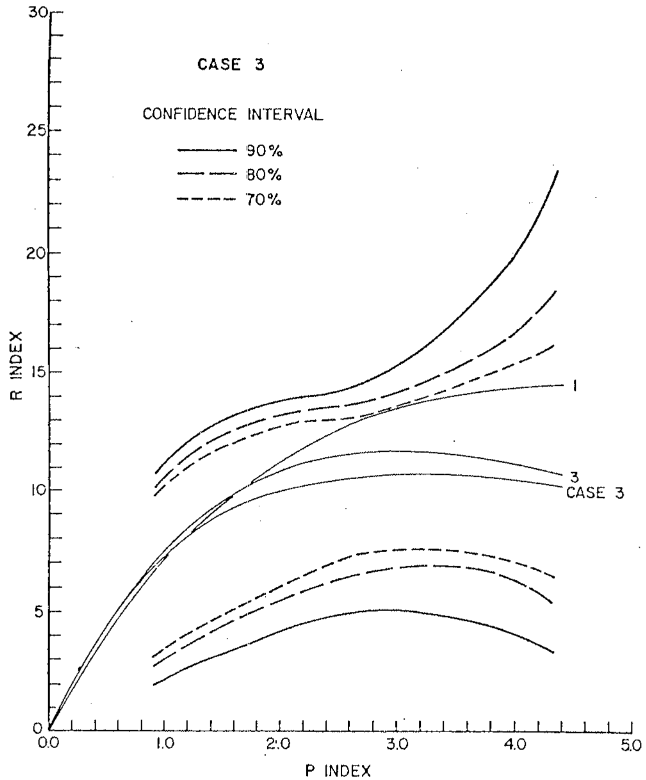

Fig. 9. Spawner-recruit relationship of Case 3 and equations 1 and 3 (see text) and 70%, 80%, and 90% confidence bands on Case 3. P index is the parent stock index; R index is the recruitment index.

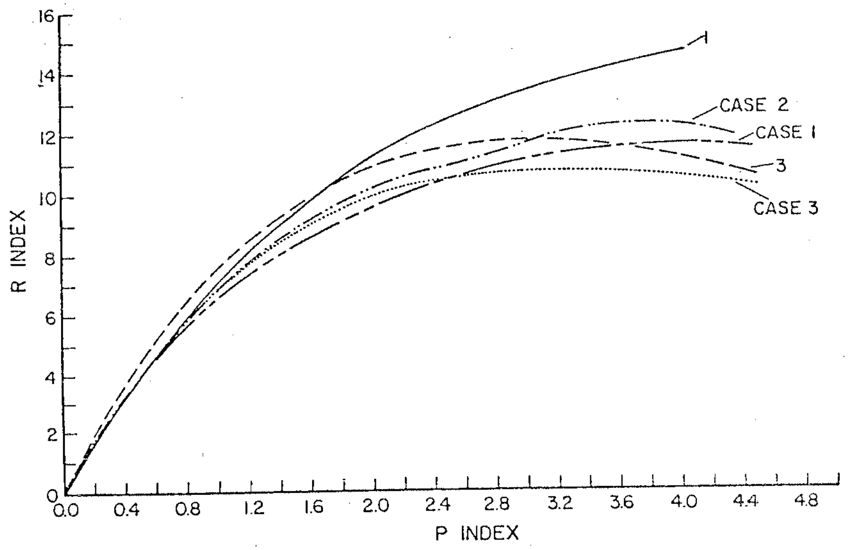

Fig. 10. Comparison of spawner-recruit relations of equations 1 and 3 and cases 1, 2, and 3 (see text). P index is the parent stock index; R index is the recruitment index.

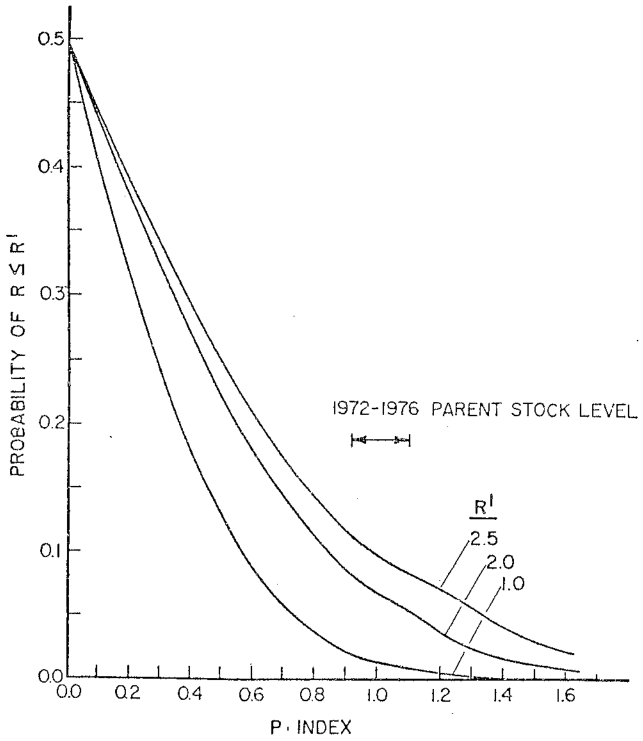

Fig. 11. Probability that the observed recruitment index value R, will be smaller or equal to some recruitment index value, R', at any given parent stock index level, P, given Case 1 simulation analysis confidence bands (see text).

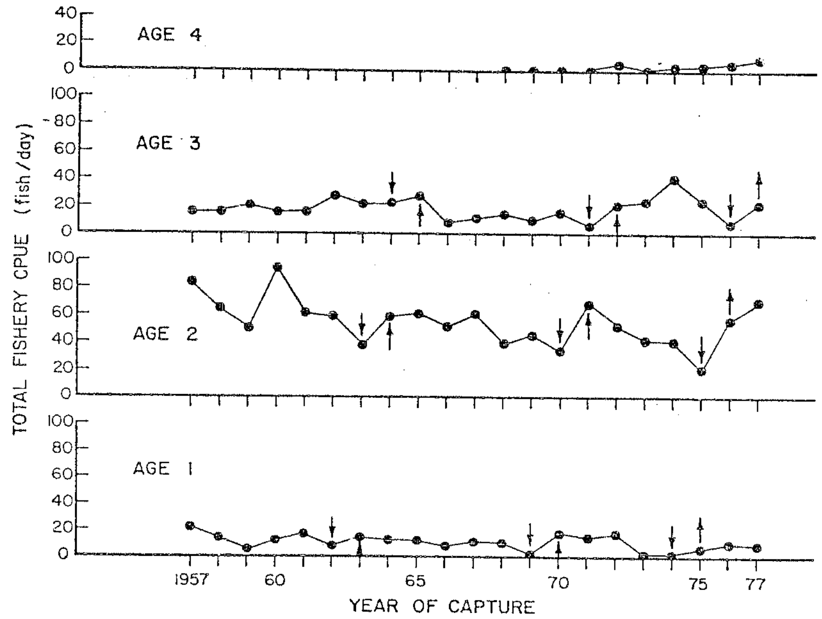

Fig. 12. Catch-Per-Effort (CPUE) by age of fish (Bartoo, 1979) versus year of capture, for French-Spanish troll caught North Atlantic albacore. Arrows note data from relatively weak or strong cohorts at ages 1 to 3 moving through the fishery.

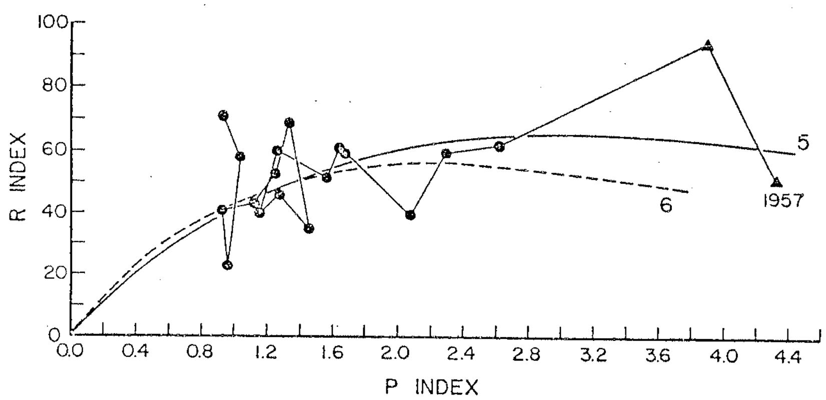

Fig. 13. Comparison of spawner-recruit relationship equations 5 and 5 (see text). P index is the parent stock index; R index is the recruitment index. Data points shown as triangles were not used in fitting equation 6.

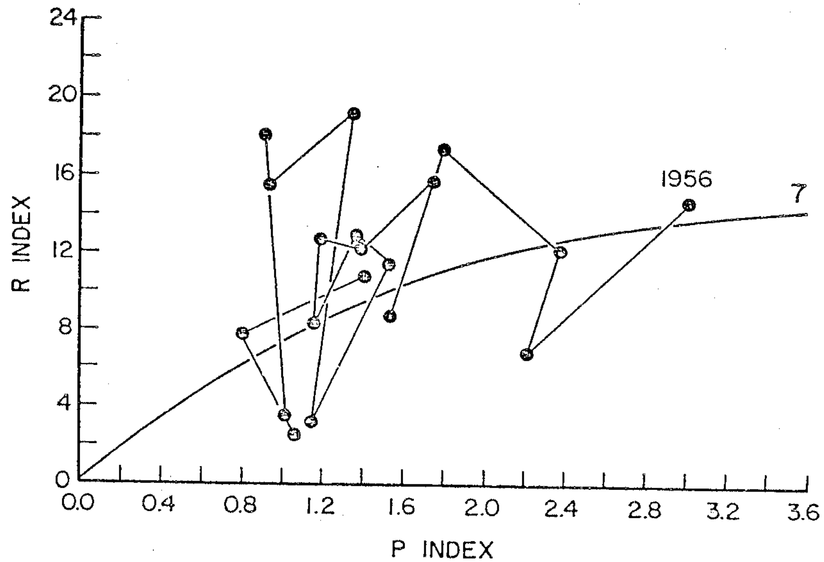

Fig. 14. Spawner-recruit relationship equation 6 and Case 4 (see text) and 70%, 80%, and 90% confidence bands on Case 4. P index is the parent stock index; R index is the recruitment index.

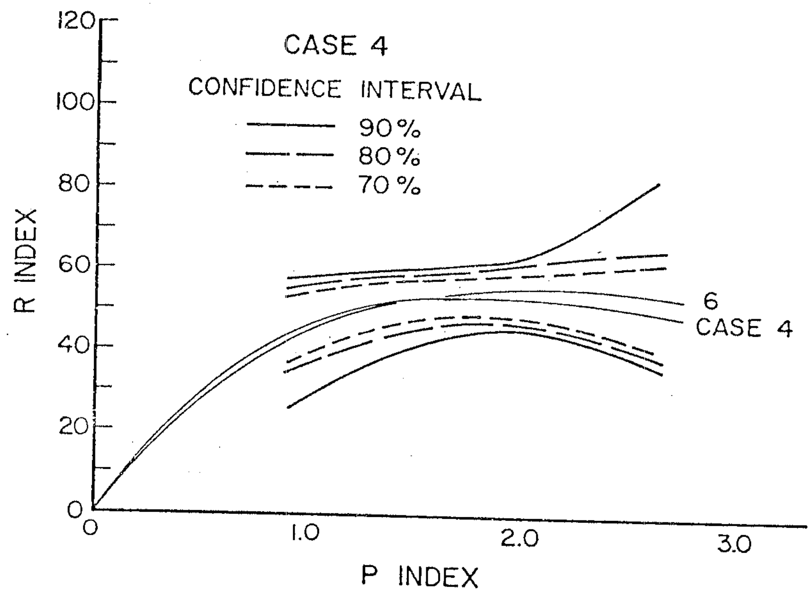

Fig. 15. Spawner-recruit relationship of text equation 7. P index is the parent stock index; R index is the recruitment index.

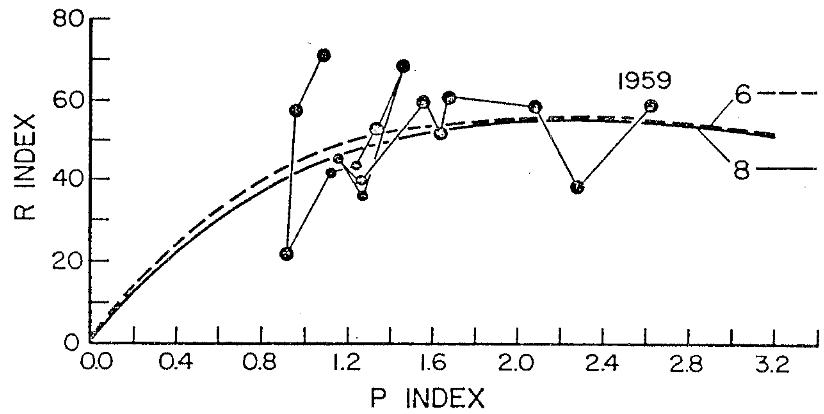

Fig. 16. Comparison of spawner-recruit relationship equations 6 and 8 (see text). P index is the parent stock index; R index is the recruitment index.