AN EVALUATION OF THE EFFECTIVENESS OF THE CURRENT MINIMUM SIZE FOR ATLANTIC SWORDFISH

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SUMMARY

The benefits of the current ICCAT minimum size regulations for Atlantic swordfish (125 cm LJFL or 25 kg round weight, with 15% tolerance by number) were examined in terms of the gains in yield per recruit (YPR) and spawning per recruit (SPR), and the risks of recruitment over-fishing. Sensitivity analyses showed that smaller minimum sizes combined with zero tolerance could result in comparable levels of YPR and SPR. However, in all cases the SPR based on recent (1991) fishing mortality rates is small relative to the level required for population replacement. Reduced risk of recruitment over-fishing will require either a much larger minimum size, much improved survival of undersized returns, or lower fishing mortalities overall.

RESUME

Les résultats de la réglementation actuelle de l'ICCAT sur la taille minimale pour l'espadon (125 cm LJFL ou 25 kg poids vif, avec 15% de tolérance en nombre) ont été examinés en termes de gains dans le rendement par recrue (YPR) et de frai par recrue (SPR) et les risques de surpêche des recrues ont également été étudiés. Les analyses de sensibilité ont montré que des tailles minimales plus petites combinées à une tolérance égale à zéro pourraient donner des niveaux comparables de YPR et de SPR. Toutefois, dans tous les cas, le SPR basé sur les taux récents (1991) de mortalité par pêche est faible par rapport au niveau nécessaire au remplacement de la population. La réduction du risque de surpêche des recrues demanderait une taille minimale plus grande, que les poissons sous-taille remis à l'eau survivent mieux ou une réduction globale de la mortalité par pêche.

RESUMEN

Se examinaron los beneficios de la regulación actual de ICCAT de talla mínima para el pez espada atlántico (125 cm LJFL ó 25 kg peso vivo, con un 15% de tolerancia en número), en términos de ganancias en rendimiento por recluta (YPR) y reproductor por recluta (SPR), y los riesgos de sobrepesca del reclutamiento. Los análisis de sensibilidad mostraron que las tallas mínimas más pequeñas combinadas con una tolerancia cero podrían traducirse en niveles comparables de YPR y SPR. Sin embargo, en todos los casos el SPR basado en tasas de mortalidad recientes (1991) es pequeño en relación con el nivel que se requiere para reemplazo de la población. Reducir el riesgo de sobrepesca del reclutamiento requeriría una talla mínima mucho mayor, una gran mejora de la supervivencia de los descartes de peces inmaduros devueltos o bien una reducción global de la mortalidad por pesca.

INTRODUCTION

Current ICCAT recommendations for swordfish specify a minimum size of 25 kg round weight (approximately 41 lbs dressed weight) with a tolerance of 15% by numbers per landing. The U.S. implemented a regulation to this effect in mid-1991. In order to fully evaluate the effectiveness of the minimum size, it would be necessary to compare selectivities (partial recruitments) that apply to capture rates on the fishing grounds (rather than selectivities derived from length frequencies of landings) from before and after implementation of the minimum size. Since this and related information on changes in the distribution of fishing, changes in discard rates, and survival of discards is limited, the approach taken here was to use various assumptions about selectivities in a modified yield per recruit (YPR) and spawning per recruit (SPR) analysis to address the questions: (i) does imposition of the minimum size have appreciable benefits in terms of YPR and SPR, (ii) what is the equivalent minimum size with zero tolerance, and (iii) does the use of a minimum size in the vicinity of 25 kg reduce the risk of overfishing?

METHODS

Calculations of YPR were essentially based on the Thompson and Bell (1934) method and calculations of SPR followed the procedure detailed in Gabriel et al. (1989), with one main exception. Since some of the discards survive and are therefore potentially available to be caught again or to contribute to the spawning stock, the algorithms for YPR and SPR had to be solved iteratively (Fig. 1). There are then two outputs related to YPR: removals (fishing deaths) per recruit and landings per recruit.

Yield per recruit was expressed in terms of annual landings by weight. Spawning per recruit was expressed in terms of spawning biomass, projected through from 1 January to the time of peak spawning (0.75 years), as recommended by Gabriel et al. (1989).

The following assumptions were used in the calculations:

- The partial recruitment (PR) vector for capture on the fishing grounds was assumed equivalent to the 1988 PR, as estimated from the fishing mortality estimates in the 1992 SCRS assessment. The 1988 PR was used in preference to the 1991 PR to represent capture, since the latter apparently does not include discards that have been made since minimum size regulations were implemented. For comparative purposes, a PR vector equal to the maturity vector (see below) was also used in one run. The 1988 and 1991 PR vectors are given below:

Age	1	2	3	4	5+
1988 PR	0.257	0.596	0.782	0.933	1.0
1991 PR	0.044	0.349	0.567	0.856	1.0

- A maturity ogive (Arocha and Lee 1992) was used in preference to the usual assumption of knife-edge maturity at age 5:

Age	1	2	3	4	5	6	7	8	9+
P(mature)	0	0	0	0.29	0.71	0.89	0.96	0.99	1.0

- Weights at age (kg, round) in the catch were based on the 1992 SCRS assessment:

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
Weight	14.4	25.8	41.2	59.6	79.9	98.3	115.1	129.5	140.5	149.1	156.3	160.8	162.8	169.7	173.5	180.7	187.9	195.1	202.3	209.5

- The same weights were used to represent weights at age in the spawning stock.

- Natural mortality was assumed equal to 0.2.

- Dressed weight was assumed to be 75% of round weight.

- Survival of discards was assumed constant at 30%, unless otherwise specified.

Replacement levels of SPR and associated fishing mortality rates were calculated using the methods presented in Sissenwine and Shepherd (1987). The 1992 SCRS estimates of population numbers by age and year were used to compute the median ratio of spawning biomass to recruits (S/R), where S is the spawning biomass calculated by projecting 5+ population numbers foward 0.75 years and multiplying by a weighted average weight appropriate for that age group and year, and R is the beginning of year number of recruits at age 1. The median S/R ratio was then used as an estimate of the replacement SPR. Corresponding estimates of replacement fishing mortality rates (F_{rep}) were calculated from the spawning per recruit analyses and compared with recent levels of fishing mortality.

RESULTS

If small swordfish could be avoided rather than discarded, and the current fully-recruited F of about 0.5 is maintained, the benefits of moving from the 1988 PR to the 1991 PR would be substantial (Fig. 2a). Even greater benefits could be realized if the PR vector was similar to the maturity vector. Corresponding benefits for SPR are less notable for the 1991 PR compared to the 1988 PR, but are substantial when the PR vector is the same as the maturity vector (Fig. 3a).

However, if the selectivity on the fishing grounds has not actually changed since 1988, and if the survival rate of discards is only 30%, the benefits to YPR are likely to be much smaller (Fig. 3a), and the benefits to SPR may be virtually zero (Fig 3b).

Table 1 summarizes the results for several other combinations of PR, minimum size, tolerance, and survival, assuming a fully-recruited fishing mortality (F) fixed at 0.5 for all runs (i.e. $F \approx F_{91}$, as estimated in the 1992 SCRS assessment).

Part A of Table 1 gives the results for the baseline runs, which used a minimum size of 25 kg round (≈ 41.3 lbs dressed). The most obvious result is that it makes relatively little difference whether all, none, or some percentage of the undersized catch is retained. If all undersized fish are kept, the landed YPR will be 5.6% higher and the deaths in weight will be 3.1% lower than in the zero tolerance case. Thus, even in the long term, there may be a net decrease in YPR when small fish are returned to the sea. The gains from releasing small fish show up in higher SPR, which increases by 8.1% between the extremes of 100% and 0% tolerance. Note, however, that the %SPR levels (SPR expressed as as percentage of the maximum achieved at zero fishing) are all extremely low (5-6%) compared to the levels observed for most other exploited finfish stocks (usually greater than 10%, with the optimum usually believed to be somewhere in the range 20-40%).

The current situation is assumed to be approximated by an effective tolerance of 10% (third row), to account for individual variability between trips which will result in less than the legal 15% tolerance limit being retained overall. Other than satisfying the requirement that the effective tolerance must be less than 15%, the 10% figure is arbitrary. The remaining results will be compared to this row.

Part B of the table shows the effects of smaller minimum size (approximately 39, 37, 35 & 33 lbs dressed weight) and zero tolerance. The smaller the minimum size, the higher the landed yield per recruit, the smaller the total deaths in weight per recruit and the smaller the SPR. Thus, for a constant fully-recruited F (0.5 in these examples), the smaller the minimum size the better in terms of yield and total deaths, but the worse in terms of SPR. The minimum size that gives the closest equivalent SPR to the baseline case (*) is 21.2 kg round weight (35 lbs dressed weight). However, the differences between all of the cases presented are trivial.

If survival of returned fish could be increased towards 100% then both YPR and SPR would increase noticeably (Part C of Table 1); for example, the SPR for a minimum size of 25 kg with an effective 10% tolerance would increase 11.6% over the base case. The trend in landed YPR would also be reversed, with YPR decreasing with decreasing minimum size.

If the minimum size was closer to the median size at recruitment (about 60 kg round or 100 lbs dressed), there would be an appreciable loss in long-term YPR and a moderate gain in SPR (Part D of Table 1).

The only way to improve SPR substantially is to shift the PR towards older ages (Part E of Table 1). If there were no discards, the 1991 PR would give greater increases in SPR than any of the other combinations in Table 1 (see Fig. 3a). A PR approximating the maturity ogive is required to achieve a %SPR level near 20% (a level commonly used as a basis for defining overfishing thresholds in the U.S.).

Risks of recruitment overfishing

Based on the 1992 SCRS assessment, the spawning biomass of Atlantic swordfish has exhibited an almost continuous decline since 1978, while at the same time recruitment appears to have been gradually increasing (Fig. 4). Thus, over most of the time period, it appears that the survival (R/S) of pre-recruit stages has been increasing (Fig. 5). The median survival ratio based on these stock-recruitment data is 0.0454 recruits per kg of spawners, and the median SPR (S/R) is 22.04 kg per recruit. The median SPR is about 8.1% of the maximum SPR (the maximum being attained when $F=0$). The effect of the trend in the S-R data is that when the time series is split in half, the median SPR is 14.0% of the maximum SPR for the first half of the series, and 6.6% for the second half.

Compared to other species for which the median SPR has been calculated (Mace and Sissenwine 1993), a median %SPR of 8.1% is relatively low. It falls near the 22nd percentile in Mace and Sissenwine's compilation of estimates covering 83 exploited stocks (Fig. 6). This suggests that Atlantic swordfish has relatively high resilience to fishing.

The corresponding estimate of the median age 5+ fishing mortality (F_{med}, here assumed to be an estimate of F_{rep}) is 0.41 if the 1988 PR is assumed and 0.49 if the 1991 PR is assumed. The estimated age 5+ fishing mortality rates have exceeded both of these values since about 1984, although fishing mortality rates appear to have declined towards replacement levels in the last few years, in conjunction with declines in landings (Fig. 7).

DISCUSSION

These results suggest that unless small fish can be avoided rather than discarded, and/or unless survival rates of returned fish can be improved, the benefits of minimum sizes that are well below the size at maturity may be negligible (Figs. 2 & 3 and Table 1). If a low minimum size nevertheless continues to be included as a conservation measure, there may be little loss in terms of YPR and SPR if a somewhat smaller minimum size was used in conjunction with zero tolerance. There are two reasons for considering this option. First, many U.S. fishermen contend that it is impossible to avoid capturing small swordfish and therefore the only effect of the minimum size is to decrease landings and increase discards, not to decrease fishing mortality rates on small fish. Second, adoption of a zero tolerance may make enforceability of the minimum size easier. Use of a non-zero tolerance implies that landings need to be sampled, which raises questions about the adequacy of the sample size, whether the sample was representative of the entire trip, and other concerns.

Regardless of which combination of minimum size, tolerance and survival is selected from Table 1, parts A-C (for which it is assumed that the fully-recruited F is 0.5 and the 1988 PR applies for capture on the grounds), the %SPR is below the replacement level of 8.1% estimated from the median survival ratio of S-R observations (Fig. 5). This means that in the long term, unless either PR or F change substantially, recruits will be insufficient to maintain the stock at observed average levels, and the stock is likely to remain low, or to decline further. However, if the 1991 PR were to reflect relative fishing mortality rates, rather than relative landings, the 1991 fully-recruited fishing mortality rate could be close to the replacement fishing mortality rate (Fig. 7).

Sissenwine and Shepherd (1987) defined recruitment overfishing as a fishing mortality rate in excess of F_{rep} (or F_{med}). Since Atlantic swordfish appear to meet this criterion, further evaluations of the risks of recruitment overfishing under the current fishing mortality regime should be considered.

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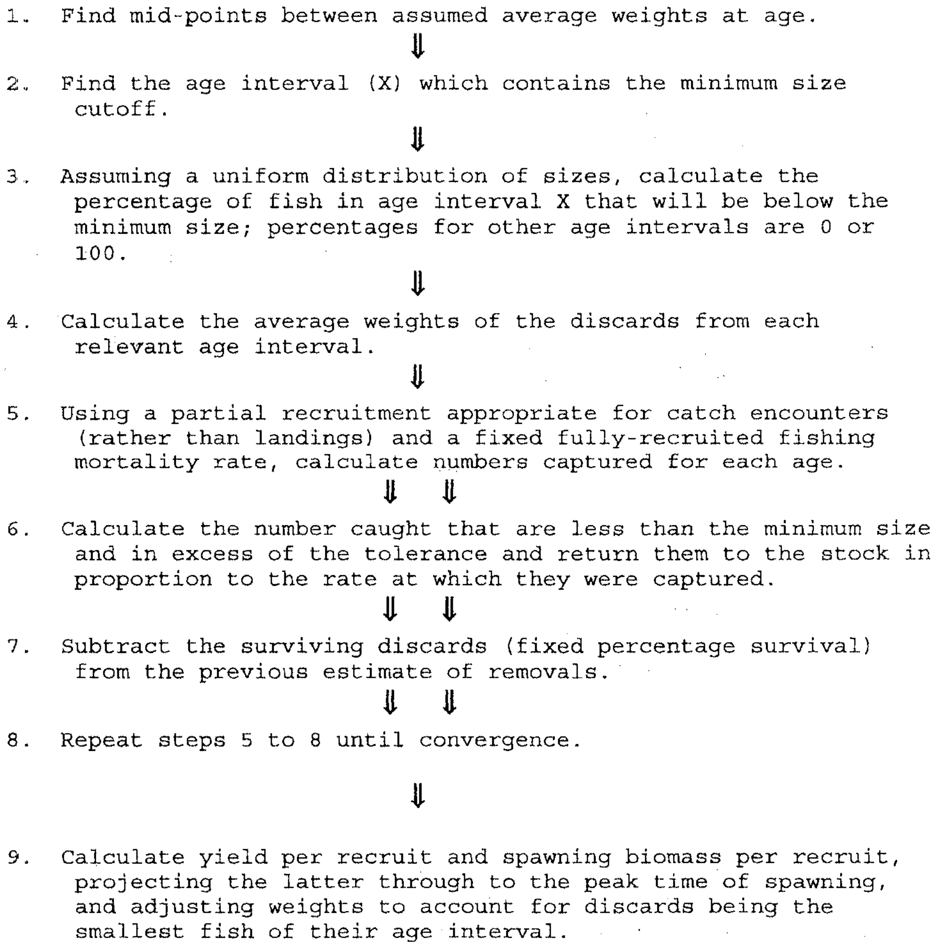
TABLE 1. Yield per recruit (YPR) and spawning per recruit (SPR) results for Atlantic swordfish using various combinations of levels of the input variables: partial recruitment (PR), minimum size, tolerance expressed as maximum allowable percentage (by numbers) of undersized fish in the landings (% kept), and percent survival. Landings, deaths and spawning biomass are all expressed on a per recruit basis.

PR vector	MIN SIZE (kg, round)	% KEPT (TOL)	% SURVIVE	LANDED NOS.	LANDED YIELD (kg, round)	DEATHS NOS.	DEATHS WEIGHT (kg, round)	SPR WEIGHT (kg, round)	% SPR
A. Baseline cases									
1988	0	100.0	-	0.579	24.71	0.579	24.71	14.39	5.28
1988	25.0	15.0	30	0.511	24.09	0.569	25.09	14.94	5.49
1988*	25.0	10.0	30	0.486	23.86	0.565	25.23	15.14	5.56
1988	25.0	0.0	30	0.436	23.40	0.558	25.50	15.55	5.71
B. Smaller minimum sizes with zero tolerance									
1988	23.6	0.0	30	0.451	23.62	0.560	25.42	15.38	5.65
1988	22.4	0.0	30	0.464	23.80	0.562	25.35	15.25	5.60
1988	21.2	0.0	30	0.477	23.96	0.564	25.27	15.11	5.55
1988	20.0	0.0	30	0.490	24.10	0.566	25.19	14.97	5.50
C. Better survival									
1988	25.0	10.0	100	0.534	26.42	0.534	26.42	16.90	6.20
1988	25.0	0.0	100	0.507	27.45	0.507	27.45	18.43	6.77
1988	22.4	0.0	100	0.521	26.88	0.521	26.88	17.33	6.36
1988	20.0	0.0	100	0.534	26.30	0.534	26.30	16.34	6.00
D. Minimum size near median weight at recruitment									
1988	60.0	15.0	30	0.268	17.71	0.535	25.98	19.10	7.01
1988	60.0	0.0	30	0.182	15.70	0.523	26.33	20.46	7.51
E. Alternative PRs									
1991	0	100.0	-	0.498	27.26	0.498	27.26	20.92	7.68
=P(mature)	0	100.0	-	0.329	30.22	0.329	30.22	51.32	18.84
$4\times0, 5^{+}=1$	0	100.0	-	0.321	30.83	0.321	30.83	50.95	18.70

FIG. 1. Algorithm for incorporating discard survival into yield per recruit (YPR) and spawning per recruit (SPR) calculations.



1. Find mid-points between assumed average weights at age.
2. Find the age interval (X) which contains the minimum size cutoff.
3. Assuming a uniform distribution of sizes, calculate the percentage of fish in age interval X that will be below the minimum size; percentages for other age intervals are 0 or 100.
4. Calculate the average weights of the discards from each relevant age interval.
5. Using a partial recruitment appropriate for catch encounters (rather than landings) and a fixed fully-recruited fishing mortality rate, calculate numbers captured for each age.
6. Calculate the number caught that are less than the minimum size and in excess of the tolerance and return them to the stock in proportion to the rate at which they were captured.
7. Subtract the surviving discards (fixed percentage survival) from the previous estimate of removals.
8. Repeat steps 5 to 8 until convergence.
9. Calculate yield per recruit and spawning biomass per recruit, projecting the latter through to the peak time of spawning, and adjusting weights to account for discards being the smallest fish of their age interval.

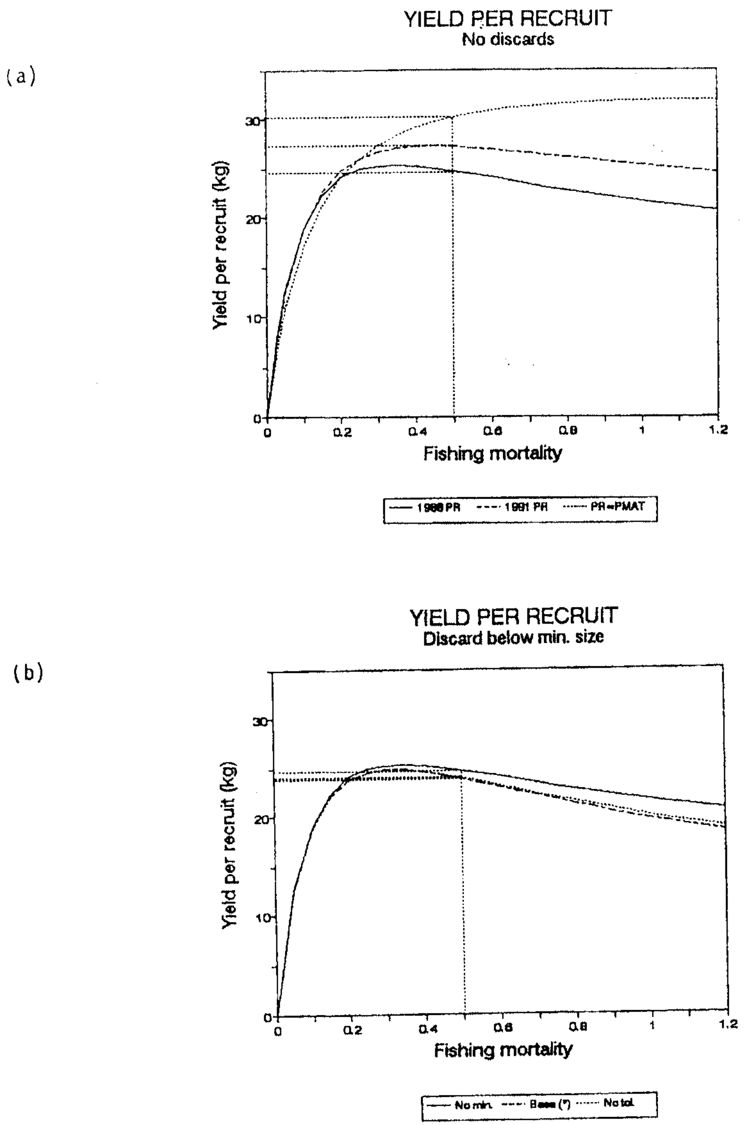


FIG. 2. Yield per recruit results for (a) alternative partial recruitment (PR) vectors (1988, 1991, and same as proportion mature) and (b) different combinations of minimum size and tolerance (No. min. is the result from the first line of Table 1; Base is the third line; and No tol. is the seventh line).

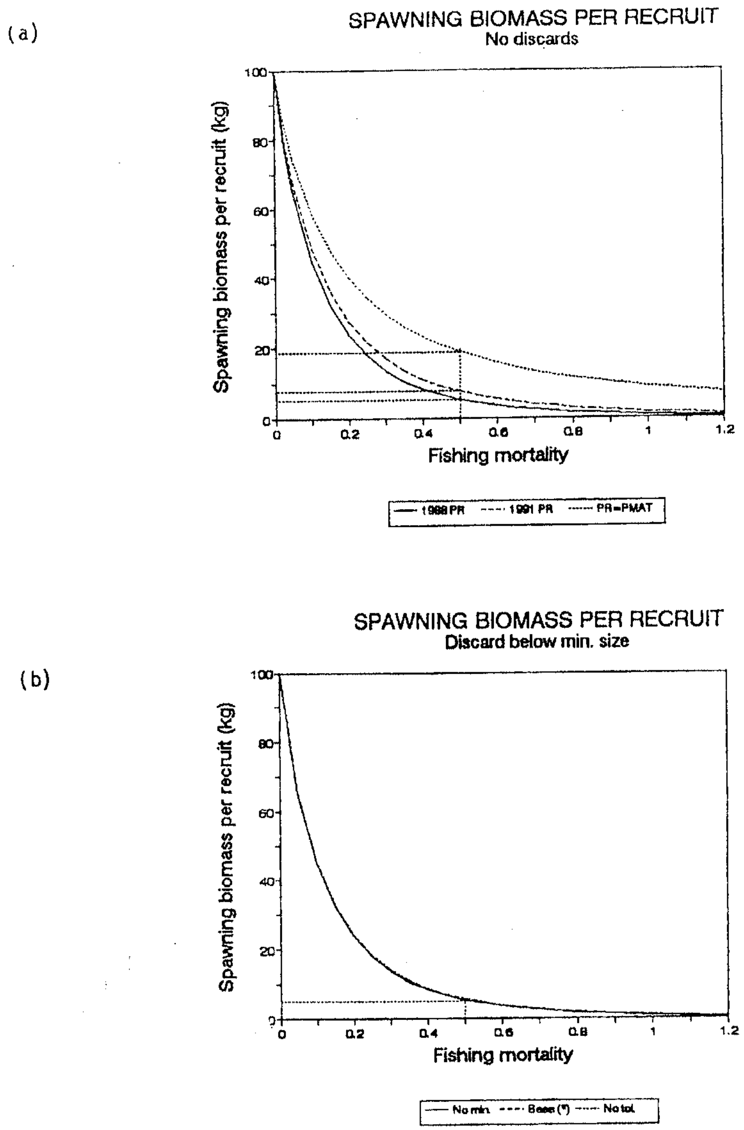


FIG. 3. Spawning biomass per recruit results for (a) alternative partial recruitment (PR) vectors (1988, 1991, and same as proportion mature and (b) different combinations of minimum size and tolerance (No min. is the result from the first line of Table 1; Base is the third line; and No tol. is the seventh line).

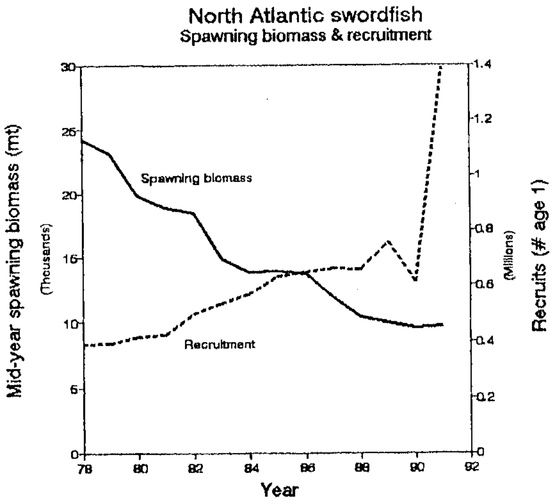


FIG. 4. Spawning biomass and recruitment estimates from the 1992 SCRS swordfish stock assessment.

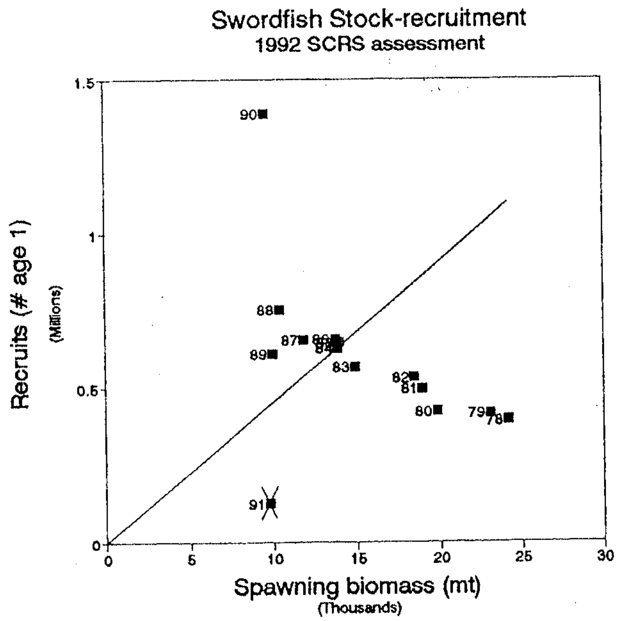


FIG. 5. Stock and recruitment plot using spawning biomass and recruitment estimates from the 1992 SCRS assessment. The straight line is the median of the R/S ratios, excluding the 1991 point (since recruitment is likely to have been poorly estimated).

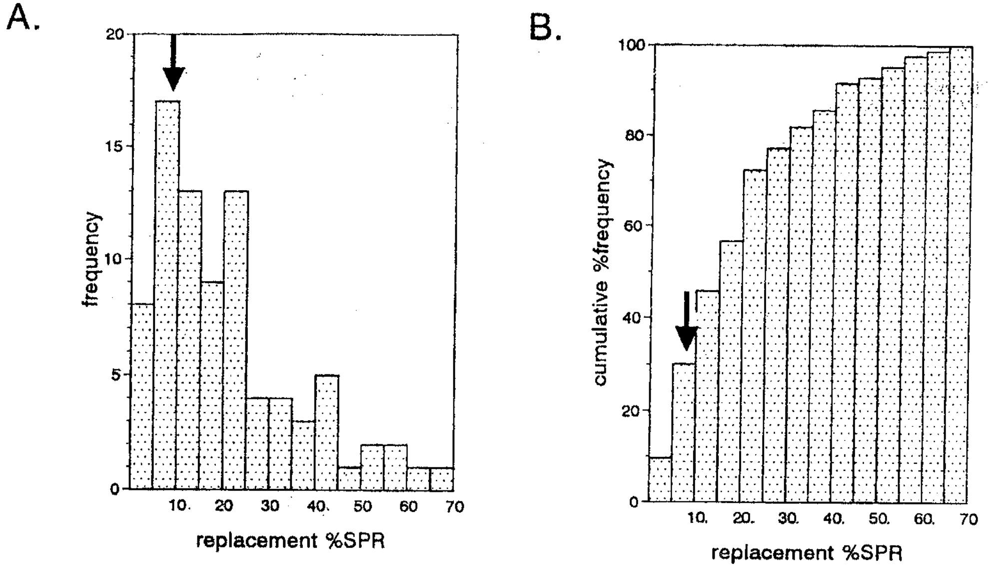


FIG. 6. Estimated replacement %SPR for swordfish relative to other estimates compiled by Mace and Sissenwine (1993). Low replacement %SPR is assumed to indicate high resilience.

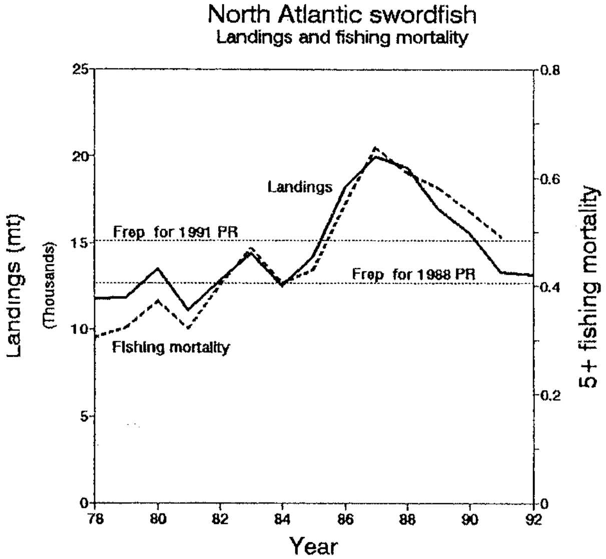


FIG. 7. Landings and 5+ fishing mortality rates from the 1992 SCRS swordfish stock assessment. Horizontal lines are the fishing mortality rates that would have resulted in stock replacement if the 1988 or 1991 PR's had applied at each time step.