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COHORT ANALYSIS OF ATLANTIC BLUEFIN TUNA AND ESTIMATES OF ESCAPEMENT THROUGH THE JUVENILE FISHERIES UNDER TWO HYPOTHESES OF CATCH AGE STRUCTURE

J. F. Caddy
Biological Station
St. Andrews, N. B.

SUMMARY

1) Cohort analysis on pooled estimates of surface bluefin tuna catches for the North Atlantic were combined separately with each of 2 hypothesised age structures for Atlantic longline catch, to give two estimates of the recent Atlantic catch by all gears. Initial estimates of F and M used in the analysis encompassed those values found in the literature.

2) The 2 longline hypotheses were not critical to the estimated mortality rates, which peaked at age 3, remained low, and rose again after age 10. The initial guesses of age-specific mortality were most critical for the older fish, and the last few years in the data series.

3) Mortalities of young tunas peaked in the mid 1960's, and rose again in 1969-70. Escapement through the juvenile fisheries (age 1-5) into the potential spawning stock ranged from 3-9% and into the giant fish category, from <0.1-0.2%.

4) Spawning stock size dropped to one third of its initial level from 1960-70, while recruitment was very irregular, with highs in the early and mid 1960's and possibly the early 1970's.

5) The age structure of giant tuna caught off Prince Edward Island in 1974 (age 16-22) confirms that this group of fish predates the period of peak juvenile exploitation in 1962-65, and suggests the need for revision of growth estimates for older fish.

RESUME

1) Les analyses de cohortes portant sur des estimations groupées des prises de thon rouge en surface dans l'Atlantique Nord ont été combinées séparément avec deux hypothèses concernant la structure démographique de la prise palangrière atlantique, afin de donner deux estimations des récentes prises effectuées dans l'Atlantique par l'ensemble des engins. Les estimations initiales de F et de M utilisées dans l'analyse comprenaient les valeurs citées dans les travaux de référence.

2) Les deux hypothèses sur la palangre n'affectaient pas sensiblement les taux estimés de mortalité, qui montraient un maximum à 3 ans, demeuraient médiocres, puis s'élevaient de nouveau après 10 ans. Les appréciations initiales de la mortalité en fonction de l'âge intervenaient surtout dans le cas des poissons plus âgés, et les quelques dernières années dans la série des données.

3) La mortalité des jeunes thonidés a montré un maximum vers le milieu des années 60, et une nouvelle augmentation en 1969-70. La survie à la pêche des juvéniles (1 à 5 ans) vers le stock reproducteur potentiel allait de 3 à 5%, et vers la catégorie des très grands poissons de <0,1 à 0,2%.

4) L'importance du stock reproducteur a baissé à un tiers de son niveau initial de 1960 à 1970, alors que le recrutement s'est montré très irrégulier, avec des niveaux élevés au début et vers le milieu des années 60, et peut-être également au début des années 70.

5) La structure démographique du thon de très grande taille pris au large de l'Ile du Prince-Edouard en 1974 (16 à 22 ans) confirme le fait que ce groupe de poisson est plus vieux que la période d'exploitation maximum des juvéniles, et suggère la necessité de réviser les estimations de croissance des poissons les plus âgés.

RESUMEN

1) Se han efectuado análisis de cohortes sobre estimaciones agrupadas de capturas de atún de superficie para el Atlántico Norte y se han combinado por separado con cada una de las dos estructuras hipotéticas de la edad para la captura Atlántica de palangre, a fin de obtener dos estimaciones de la captura reciente Atlántica, efectuada por todos los artes de pesca. Las estimaciones iniciales de F y M utilizadas en el análisis se circunscribieron a aquellos valores que figuran en la documentación.

2) Las dos hipótesis de palangre no influyeron sensiblemente sobre las tasas de mortalidad estimadas, que alcanzaron el punto culminante a los 3 años, permanecieron bajas y ascendieron nuevamente después de los 10 años. Las conjeturas iniciales sobre la mortalidad específica de la edad influyeron especialmente en los peces más viejos y los últimos años en las series de datos.

3) La mortalidad de atunes jóvenes alcanzó su punto máximo a mediados de 1960 y ascendió de nuevo en 1969-70. La supervivencia de los peces jóvenes (de 1 a 5 años) de estas pesquerías para formar parte del stock reproductor potencial osciló del 3 al 9%, y de la categoría de peces gigantes, de <0,1 a 0,2%.

4) El volumen del stock reproductor descendió a un tercio de su nivel inicial durante el periodo 1960-70, mientras que el reclutamiento fue muy irregular, con periodos elevados a principios y mediados de 1960 y posiblemente a principios de 1970.

5) La estructura de edad de los atunes gigantes capturados frente a la Isla Prince-Edward en 1974 (edades: 16-22 años) confirma que este grupo de peces es anterior al periodo culminante de explotación de peces jóvenes en 1962-65 y sugiere la necesidad de revisar las estimaciones de crecimiento de peces de más edad.

INTRODUCTION

Concern has been expressed over the last few years regarding the status of Atlantic bluefin stocks, largely based on dramatic events in a number of fisheries, documented in the comprehensive papers of Mather, Mason and Jones (1973) and Sakagawa and Coan (1973). No overall assessment of Atlantic bluefin as a whole has come to the author's attention, apparently for three main reasons:

1) Uncertainties of stock structure and migration pattern.
2) Major gaps in the data, particularly on size and age composition of the catches.
3) The highly age-specific nature of bluefin tuna fisheries, which (together with the first reason) violates the basic assumptions of the Generalized Production approach widely used for other tuna species (Pella and Tomlinson (1969)).

The 'gauntlet' model developed for West Coast salmon stocks seems potentially applicable here, where the fish runs sequential risks of capture during the course of its life history as it migrates through a number of different age-specific fisheries, and this concept is touched on by Fox and Beardsley (1974) in a paper presented to the ICES-ICCAT bluefin tuna working group this year. The first approach to such a model (which would hopefully be able to incorporate both tagging and catch data), is to consider how overall mortalities change with age under a) a reasonable set of input parameters, and b) the best guesses of catch age structure. For this purpose, cohort analysis appears to offer the best chance of incorporating data from a number of age-specific fisheries.

Problems of application of cohort analysis to bluefin tuna populations

Migration

Evidence from tag returns supports the idea that interchanges between East and West Atlantic (and between Atlantic and Mediterranean) stocks can occur, although their frequency, extent and direction is not yet predictable (ICES-ICCAT Report 1974).

It seems worthwhile considering the repercussions of the first of these hypotheses, namely that all Atlantic fisheries operate on one stock. (The second hypothesis is not explored here, and for reasons of time rather than validity, Atlantic catches alone are considered in this study: - Table 1.)

Validity of the data base

In 1974, emphasis was placed by the U.S. and Canada on the collection of improved statistics on sizes and numbers of bluefin taken in the West Atlantic. Evidently, however, the data already at hand must be used in any assessment of current stocks, and it is to be hoped that international agreement will be reached on the 'best estimates' of historical catches and their age structures which can be used to repeat this type of study with more precision in both the data base and the parameter estimates. It is believed, however, that these results may still have some relevance in assessing the recent state of the stocks. The data base used in this study is that given in the two major references above, supplemented by ICCAT statistical bulletin, Vol. 3. From comments by Sakagawa and Coan (1973), the data they tabulate for years 1960-62 must be regarded as speculative for both the French-Moroccan-Spanish bait boat and troll fisheries, and the U.S. sports fishery; in all of which the size frequency of the U.S.-Canadian purse seine fishery, particularly for 1961, was the sole basis for postulated age compositions in these other fisheries. This is unrealistic, since no fish less than age IV are recorded for 1960 and 1961 in the W. Atlantic purse seine fishery. Although there is evidence that this fishery did concentrate its efforts mostly on older fish in these early years, there is a good indication from more recent observations that young fish are available to a surface trolled bait, so that unless there was poor recruitment at that time, we must assume that catches of young fish were underestimated in the U.S. sport catch and Moroccan catches in these early years. At the risk of overestimating juvenile catches in the early 1960's, the catches of bluefin 7+ years of age in 1960-62 were assumed to be accurate in Tables 9 and 17 of Sakagawa and Coan (1973), and to bear the same ratio to the numbers of 1 to 6 year old fish as in the long-term averages shown in the last column of each of their tables. East and West Atlantic surface catches are given in Tables 2 and 3.

The other major deficiency of existing statistics relates to the Atlantic longline fishery by several nations; in particular, Taiwan, Cuba, Japan and Korea. The lack of information on size composition of the catches has led to some controversy as to whether these fisheries are all exploiting similar age groups, although there seems to be general agreement that they concentrate particularly on medium-large fish. The assumption adopted here is that the Japanese size-frequency data in Mather et al. (1973) for 1957-60 and 1962-67, and that for 1971 in the ICCAT data record (p. 213) applies to the combined tonnage of Atlantic longline catches for the above countries recorded in the ICCAT statistical bulletin, after their conversion to estimated ages using the age-length key of Mather et al. (1973). No allowance was made for the undefined proportion of Southern Bluefin in the Japanese catches, and these are included in the total. In guessing at the age structure of these catches (Tables 4 and 5), two approaches were adopted.

Hypothesis 1: The average age structure of Japanese longline catches was calculated from the size frequencies after their conversion using the length-weight key, and the assumption made that this age composition was constant for all years. The numbers at age which correspond to the total recorded catch in each year were then calculated.

Hypothesis 2: Despite the small numbers of fish in some samples, it was assumed a) that the estimated modal ages obtained after the length-age conversion had some individual validity, b) that the variance in age frequency around the modal age was constant, and given by the mean age frequency at different intervals from the modal age (Fig. 1) and c) that for years where no size frequency is available, (1961 and 1968-69) a modal age can be obtained by interpolation between adjacent modal ages. The 1970 and 1972 age compositions were assumed to be the same as for 1971. Realizing that this detailed set of assumptions is strictly speaking indefensible from existing data, it does nonetheless provide a hypothesised age structure that reflects the steady progression in increasing modal ages shown by the Japanese data for 1959-67, and that observed in other fisheries on mature bluefin in the period. The decrease in modal age from 1968-70 is probably spurious.

The third major deficiency of the data related to those fisheries not covered in this analysis, such as those off Brazil, Argentina and South America. These catches are fairly low.

The East and West Atlantic catches from those fisheries listed in Table 1 are summarized in Tables 2 and 3, and the estimated matrices of catch at age added together, and the sum added separately to Tables 4 and 5 which comprise the 2 hypothesised age structures for the longline catch; the resultants forming Tables 6 and 7, which are the basis for the following analysis.

Estimates of parameters and methods of cohort analysis

Sakagawa and Coan (1973) discuss the existing data on age, mortality and exploitation rate in bluefin tuna, and the general consensus is that M must be low for such a long-lived fish. To bracket the probable magnitude, two values, M = 0.1, and M = 0.4 were assumed in the first draft of the paper presented at SCRS in 1974. Discussion at that meeting suggested that M is unlikely to be as high as 0.4 for such a long-lived fish and is most probably in the range 0.1-0.2.

Published estimates of Z in the literature range from 0.5-1.8 (FAO 1972) based on tagging data in the West Atlantic, and a rather similar range of values was estimated from CPUE analysis for the West Atlantic purse seine fishery by Sakagawa and Coan (1973): these authors suggest a Z averaging 0.8 (giving corresponding guesses of F = 0.6 and 0.7 with the above values of M) for the Atlantic population as a whole. Another recent study of tagging data (Mather et al. 1974) suggests an instantaneous fishing mortality rate averaging F = 0.57, although the suggestion is made that on an annual basis F may be lower than this for young fish. In conclusion, the true mortality rate for the population is likely to be bracketed by a range of F's from 0.4-0.7 and M = 0.1-0.2. The approach adopted in the paper presented to SCRS is extended and 4 cohort analyses carried out for each stock hypothesis, with input values as follows:

	M	F	F
Hypothesis 1	0.1	0.4	0.7
Hypothesis 1	0.2	0.4	0.7
Hypothesis 2	0.1	0.4	0.7
Hypothesis 2	0.2	0.4	0.7

As noted by Schumacher (1970), the virtual population analysis (his method 2) is not well adapted for cohorts that have not completely passed through the fishery. Method 3 of Schumacher (1970) is used here to estimate age-specific F's, based on the ratio of catches from a cohort in successive years for each of the sets of input values above.

Age-specific mortality estimates and escapement through the juvenile fisheries

The mean values of F predicted for each age group by cohort analysis under hypotheses 1 and 2, with the range of input values considered are presented separately in Figure 2 for periods 1960-65 and 1966-70. Peak mortality occurs at age 2 and 3 with F values ranging from 0.5-1.0, dropping off at age 4, and rising at age 10 to F = 0.4-0.6. Hypothesis 1 shows a more smoothed transition in age-specific mortality rates with age than hypothesis 2 and a comparison of average mortality rates before and after 1965 suggests that mortality rates increased in the second pentade for young bluefin (age 1-5), and decreased somewhat for older fish (age 5+). The effect of the initial guess of age-specific F was most pronounced for the last few ages which show the widest divergence, but decreased with back-calculation from an initial 75% difference in the starting values of F (0.4-0.7), to an 18% difference by age 3 & peak mortality, suggesting as Schumacher (1970) pointed out, that the estimated mortality rates become less reliable for the older age groups.

These estimated mortalities allow calculation of the escapement of fish through each age group if recent fishing intensities were to be continued. In Table 8 escapement of 1,000 age 1 fish through each age group are given for the sets of age-specific mortalities estimated to be in effect for 1966-70. These estimates suggest an escapement into the first mature age group (here considered to be age 6) of between 3 and 9%, and into the 'giant' fish category (age 11+) from <0.1 to 0.2%.

Estimated trends in spawning stock size and level of recruitment since 1960

Using the exploitation rate estimated by cohort analysis, the numbers at age n at the start of each year t were calculated from ${}_nN_t = {}_nC_t/{}_n\mu_t$. This is a relatively non-rigorous approach, considering the uncertainties in parameter assumptions, but can be used to estimate both recruitment trends during the period, and also the population of potential spawners (age 6 and older). In Figure 3 'spawners' are moved forward 1 year with respect to the time-series plot of age 1 fish to allow comparison between age 1 fish and the population size of spawners which produced them the previous year. This analysis would suggest that the population of spawners has decreased from 400,000-600,000 fish in the early 1960's to 100,000-200,000 in 1970, with a temporary increase in the mid-1960's. The apparent increase in population size and recruitment in 1971 is likely to be more of an artifact of the method of cohort analysis, which assumes a uniform guess of F for all age groups in the last year of the series, and is of doubtful validity for the last 1-2 years of the analysis. Recruitment is evidently subject to wide fluctuations of from <0.5->1.0 x 10^6 age 1 fish p.a. and was high in the first few years and again in 1966. As noted earlier, the high recruitment in 1971 is probably largely a result of the initial assumptions of mortality for that year. A general relationship between peaks of spawner abundance and recruits in the following year is suggested by the data and would imply some degree of density dependent recruitment, although better estimates of recruitment will be needed to investigate this suggestion.

Changes in abundance of 'giant' tuna since 1960

This analysis which groups all fish of estimated ages 14+ evidently can say nothing about the stock size and depletion rate of giant tuna now being fished off eastern Canada. Changes in migration patterns may cause changes in availability, and the lack of a satisfactory method of ageing has hampered efforts to determine exploitation rates for these old fish, and rates of recruitment to this component of the stock. It is of interest to note however (M. J. A. Butler personal communication) that ageing of bluefin tuna caught off Prince Edward Island, Canada, in 1974 has been possible from vertebral rings and otoliths; both methods showing good agreement. From the 20+ fish aged so far, the ages range from 16-22 years (1952-58 cohorts). Evidently, unless the occurrence of giant bluefin off eastern Canada is regarded as an occasional phenomenon, the implication is that there has been little recruitment to this stock component from year classes 1959 onwards. It may not be a coincidence that the 1959-1962 cohorts passed through their age at peak vulnerability to the juvenile fisheries (age 3) in 1962-65; the period of peak mortality by the juvenile fisheries (Fig. 3). This would seem to confirm the hypothesis of Fox and Beardsley (1974) who in a paper submitted to the ICES-ICCAT working group in 1974 suggested that the timing of peak exploitation rates in the US-CAN purse seine fishery could account for the decline in Japanese longline catches in the 1960's. If this hypothesis is correct, a decline in catches of giant fish to a low level over the next 5 years seems inevitable as the present stock of old fish are depleted, which will only be reversed 8-12 years after escapement through the juvenile fisheries is improved.

Changes in exploitation rate since 1960

Averaging yearly mortality rates for ages 1-4, 5-9 and 10-12 (Fig. 4) shows similar pictures for both stock hypotheses: peak mortalities in the mid 1960's for young fish, probably due to peak effort by U.S. purse seine and French bait boat fleets in that period; a rise in mortality rates in 1970 for all sizes of fish may be an artifact of the method of analysis, or in the case of age 1-5 fish, a measure of the increased U.S.-Canadian purse-seine effort on bluefin beginning in 1970. Overall, there seems to have been a change in emphasis from peak mortality rates on old fish in the early sixties to peak mortalities on medium and small fish by the mid 1960's, with rising mortalities on small and medium sized fish in the early 1970's.

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Table 1. Data sources used to estimate age composition under different hypotheses for stock structure.

Fisheries	Period	Est. Size Comp.	Est. Comp.	Wt. Landed	Author
A) E. Atlantic					
French-Moroccan-Spanish bait boat and troll	60-71		X		Sakagawa & Coan (1973)
Moroccan-Portuguese-Spanish trap	60-71		X		"
Norwegian Purse Seine	60-71		X		"
German handline	60-62		X		"
Danish handline	60-71		X		"
B) W. Atlantic					
Canadian -U.S. purse seine fishery	60-72*		X		"
Canadian -U.S. handline, harpoon, & trap fishery	60-71				"
Canadian sport fishery	60-71		X		"
U.S.A. sport fishery	60-72*		X		"
C) Mid Atlantic & Long line					
Japanese longline	57-60	X			Mather & Mason SCRS/73
" "	62-67	X			Mather & Mason SCRS/73
" "	1971			X	- ICCAT DATA RECORD
" "	63-72			X	- Miyake & Tibbo,(1973)
Japan, Taiwan, Cuba, Korea longline	63-72			X	- Miyake & Tibbo,(1973)

(*) Earlier years adjusted for small fish.

Table 2. BLUEFIN TUNA - EAST ATLANTIC

AGE	Numbers of fish by age & year of capture											
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	689958	446634	130410	45150	25193	34944	700125	15034	12767	1432	16730	40906
2	666229	431274	125925	26755	34080	131480	163194	204742	105520	39257	57130	100455
3	334027	216228	63135	21924	53555	37043	36019	85102	46485	65468	69941	15747
4	51108	33084	27021	14644	18807	1030	111	3587	878	3299	5374	19548
5	45719	29595	9037	15332	13558	6575	324	5222	114	7175	8662	3982
6	29812	19272	5572	14042	4015	11100	1172	554	100	3089	1383	199
7	12090	7688	1305	894	6604	2133	1410	1617	417	153	588	205
8	17647	10347	1973	1126	897	2136	2758	1285	672	929	509	45
9	36750	24228	5093	3102	1713	1084	3019	3124	1001	1554	1844	238
10	23875	18110	13494	7647	4343	1455	1705	3390	1428	945	1967	312
11	17627	19750	25188	10811	12065	6370	3768	3487	3156	1967	1837	558
12	3356	12195	17950	3004	6262	8699	3873	3155	1661	1589	943	392
13	1732	6543	10946	1310	3683	8640	4272	4814	1591	1847	857	570
14+	1237	3016	5394	670	2750	5782	4014	7423	3125	3461	1475	2461

EAST ATLANTIC includes -

FMSB - French-Moroccan-Spanish Baitboat & Trolling Fleets
MPST - Moroccan-Portuguese-Spanish Trap Fishery
NPS - Norwegian Purse Seine Fishery
DHL - Danish Handline
GHL - German Handline

Table 3. BLUEFIN TUNA - WEST ATLANTIC

AGE	Numbers of fish by age and year of capture											
	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	529	469	1178	90616	50479	40626	190728	9015	4780	1170	28128	69869
2	479	426	2430	54399	68320	153652	43987	122770	39525	35676	96738	170808
3	936	662	25890	44861	107324	43299	9755	51028	17402	60616	117593	26965
4	3105	4813	43434	17149	37659	765	12	2135	325	3062	9059	33425
5	6063	7362	35759	32015	26761	7607	9	3063	38	6637	14569	6830
6	809	1052	4157	31149	7131	11756	71	-	-	2834	2506	367
7	3180	2719	1642	7897	12511	1527	129	6	-	26	443	298
8	1609	2168	3321	1540	678	1559	158	63	38	300	60	78
9	496	649	1139	1273	241	425	118	70	111	23	41	36
10	229	497	457	412	268	445	100	107	75	54	45	52
11	464	222	432	211	623	935	287	213	389	487	394	379
12	326	336	172	860	740	862	397	609	401	557	430	823
13	136	30	225	111	471	749	441	683	440	650	502	742
14+	265	91	282	180	445	684	1164	749	1088	1052	1017	1009

WEST ATLANTIC INCLUDES -

CUPS - Canadian - U.S.A. Purse Seine Fishery
CUHT - Canadian - U.S.A. Handline, Harpoon & Trap Fishery
CSF - Canadian Sport Fishery
USF - U.S.A. Sport Fishery

Table 4: Hypothesis 1: Estimated age composition Atlantic longline catch using average age composition of Japanese catch.

AGE	'57	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71
1			3	1	1	4	8	13	10	3	3	2	1	5	9
2	36	90	611	144	108	665	1401	2318	1743	611	593	323	234	826	1653
3	70	175	1188	280	210	1293	2726	4509	3390	1188	1153	629	454	1608	3215
4	81	202	1372	323	242	1493	3147	5205	3914	1372	1332	726	525	1856	3712
5	160	401	2727	642	481	2968	6256	10347	7780	2727	2647	1444	1043	3690	7379
6	235	588	3995	940	705	4348	9166	15160	11399	3995	3878	2115	1526	5406	10811
7	303	758	5154	1213	909	5609	11823	19554	14704	5154	5002	2728	1971	6973	13946
8	436	1089	7407	1743	1307	8061	16992	28103	21132	7407	7189	3921	2832	10021	20042
9	233	583	3965	933	700	4315	9097	15046	11313	3965	3849	2099	1516	5365	10730
10	175	439	2984	702	527	3247	6846	11322	8514	2984	2896	1580	1141	4037	8075
11	155	388	2640	621	466	2873	6057	10018	7533	2640	2563	1398	1010	3572	7144
12	45	113	771	181	136	839	1769	2926	2200	771	748	408	295	1043	2086
13			3	1	1	4	8	13	10	3	3	2	1	5	9
14+															

Table 5. Hypothesis 2: Estimated age composition; Atlantic longline catch using available Japanese size data.

Age	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	-	22	520	-	-	1,176	2,479	-	-	-	-	-	-	-	-
2	7	59	803	27	21	3,182	6,707	441	-	-	-	-	-	128	315
3	19	91	2,172	75	57	3,804	8,019	1,214	272	95	-	-	17	598	866
4	29	247	2,597	116	87	8,991	18,955	1,876	748	262	-	31	58	982	1,338
5	79	295	6,139	315	236	28,496	60,072	5,076	1,156	405	67	112	117	1,963	3,620
6	94	697	19,457	376	282	11,412	24,058	6,069	3,129	1,097	184	163	258	3,030	4,328
7	222	2,210	7,792	890	667	4,150	8,748	14,346	3,741	1,311	285	479	416	8,151	10,231
8	705	885	2,834	2,819	2,115	2,421	5,103	45,494	8,842	3,099	770	540	766	14,254	32,424
9	282	322	1,653	1,129	847	2,559	5,395	18,208	28,023	9,823	921	1,132	2,257	5,676	12,985
10	103	188	1,747	411	308	1,176	2,479	6,621	11,223	3,934	2,177	3,477	2,407	2,134	4,722
11	60	199	803	240	180	553	1,166	3,862	4,081	1,431	6,899	2,294	941	3,201	2,755
12	63	91	378	253	190	69	146	4,083	2,381	834	2,763	857	391	1,323	2,912
13	29	43	47	116	87	138	292	1,876	2,517	882	1,005	418	300	-	1,338
14+	19	16	94	75	57	-	-	1,214	1,905	868	1,675	755	391	-	866

Table 6. ATLANTIC (WEST AND EAST) LONGLINE CATCH (HYPOTHESIS 1)

AGE	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	690488	447104	131592	135774	75685	75580	890856	240052	17549	2603	44863	110784
2	666852	431808	130020	82555	104718	286875	207792	328105	145368	75167	154694	272916
3	335243	217200	90318	69511	165388	83732	46962	137283	64516	126538	189142	45927
4	54536	38139	71948	34940	61671	5709	1495	7054	1929	6886	16289	56685
5	52424	37438	47764	53603	50666	21962	3060	10932	1596	14855	26921	18191
6	31561	21029	14077	54357	26306	34255	5238	4432	2215	7451	9295	11377
7	16483	11316	8556	20614	38669	18364	6693	6625	3145	2150	8004	14449
8	20999	13822	15430	19658	29678	24827	10323	8537	4631	4061	10590	20165
9	38166	25536	13010	13472	17000	12822	7102	7043	3211	3093	7250	11004
10	24796	19109	20557	15005	15927	10414	4789	6393	3083	2140	6049	8439
11	18644	20351	25056	17079	22692	14836	6695	6263	4943	3464	5803	8081
12	3535	12342	5900	5630	9885	11739	5041	4509	2470	2441	2416	3301
13	1253	5912	2386	1423	4111	9380	4716	5487	2029	2496	1364	1321
14+	716	2562	1178	849	3146	6424	5178	8153	4194	4501	2491	3461

Table 7. ATLANTIC (WEST AND EAST) LONGLINE CATCH (HYPOTHESIS 2)

AGE	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
1	690487	447103	132764	138245	75672	75570	890853	24049	17547	2602	44858	110775
2	666735	431721	132537	87861	102841	285132	207181	327512	145045	74933	153996	271578
3	335038	217047	92829	74804	162093	80614	45869	136130	63887	126101	188132	43578
4	54329	37984	79446	50748	58342	2543	385	5722	1234	6419	15415	54311
5	52097	37193	73292	107419	45395	15338	738	8352	264	13929	25194	14432
6	30997	20606	21141	69249	17215	25985	2340	738	263	6181	6919	4894
7	16160	11074	7097	17539	33461	7401	2850	1908	896	595	9182	10734
8	22075	14630	7715	7769	47039	12537	6015	2118	1250	1995	14823	32547
9	38375	25724	8791	9770	20162	29532	12960	4115	2244	3834	7561	13259
10	24515	18915	15127	10538	11226	13123	5739	5674	4980	3406	4146	5086
11	18331	20152	26173	12188	16550	11386	5486	10599	5839	3395	5432	3692
12	3935	12721	18191	4010	11085	11942	5104	6527	2919	2537	2696	4127
13	1984	6660	11309	1713	6030	11906	5595	6502	2449	2797	1359	2650
14	1577	3164	5676	850	4409	8371	5846	9847	4978	4904	2492	4336

Table 8. Estimated escapements of an initial population of 1,000 age 1 bluefin tuna through each age group using values of F averaged for 1966-70 and the 4 sets of initial assumptions considered in this study.

Age	M=0.1	F=0.4	M=0.2	F=0.4	M 0.1	F=0.7	M=0.2	F=0.7
	H1	H2	H1	H2	H1	H2	H1	H2
1	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
2	666	715	627	663	655	708	614	663
3	322	333	300	300	325	304	267	279
4	141	125	134	111	124	97	101	94
5	116	100	101	81	99	75	74	67
6	85	67	69	51	68	47	48	39
7	70	56	52	39	54	39	35	29
8	57	48	39	30	42	32	26	22
9	41	38	27	22	29	25	17	16
10	30	26	18	15	20	16	11	10
11	22	19	12	10	14	11	7	6
12	13	11	7	6	7	6	3	3
13	8	7	4	3	4	3	2	2
14	7	6	3	3	3	3	1	1

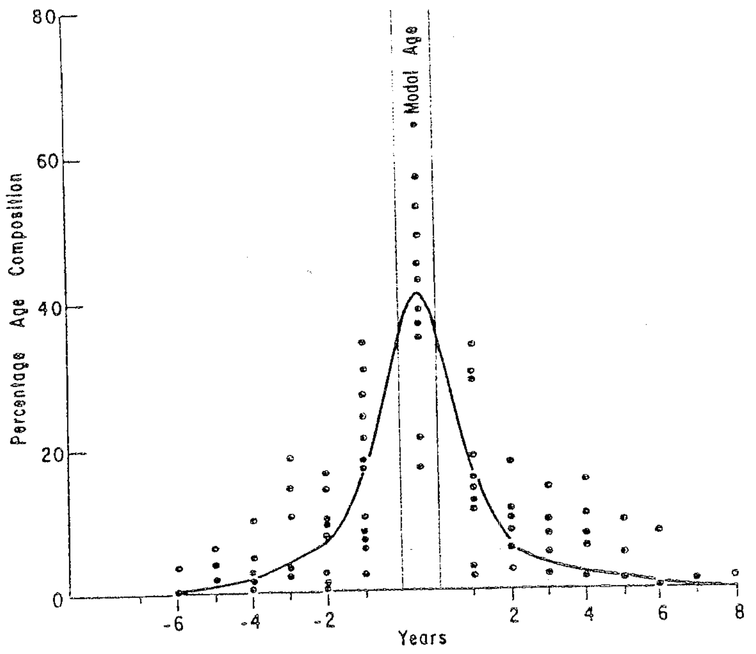

Fig. 1. Range of percentage-age compositions around the modal age (Japanese longline data).

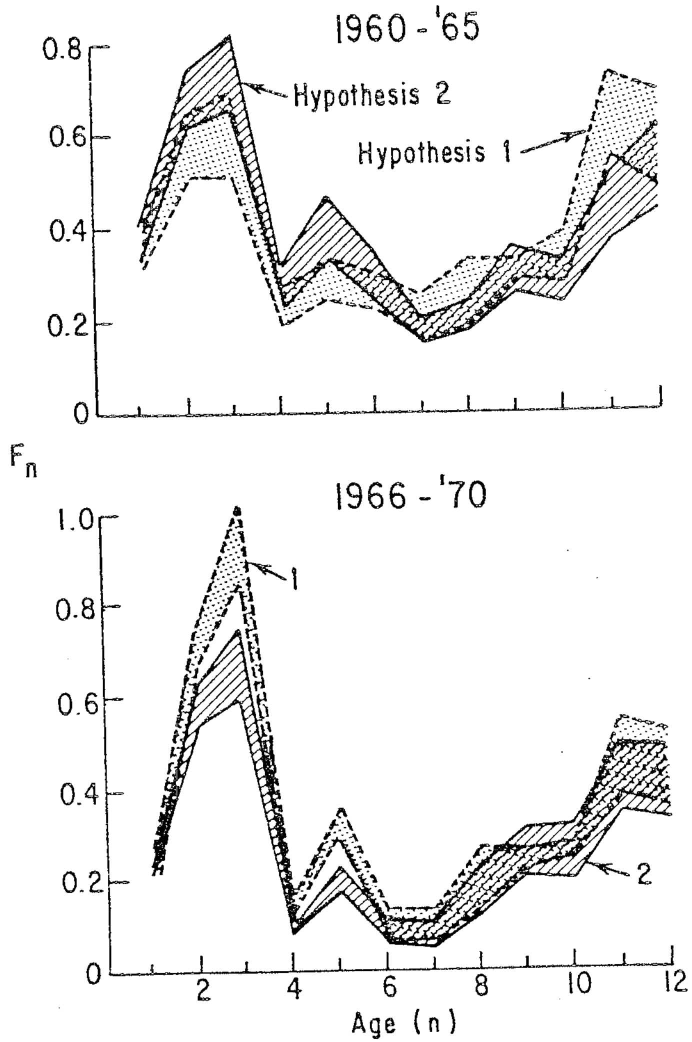

Fig. 2. Envelopes enclosing calculated averages for age-specific mortalities over 2 time periods under 2 stock hypotheses and the initial mortality estimates assumed in the text.

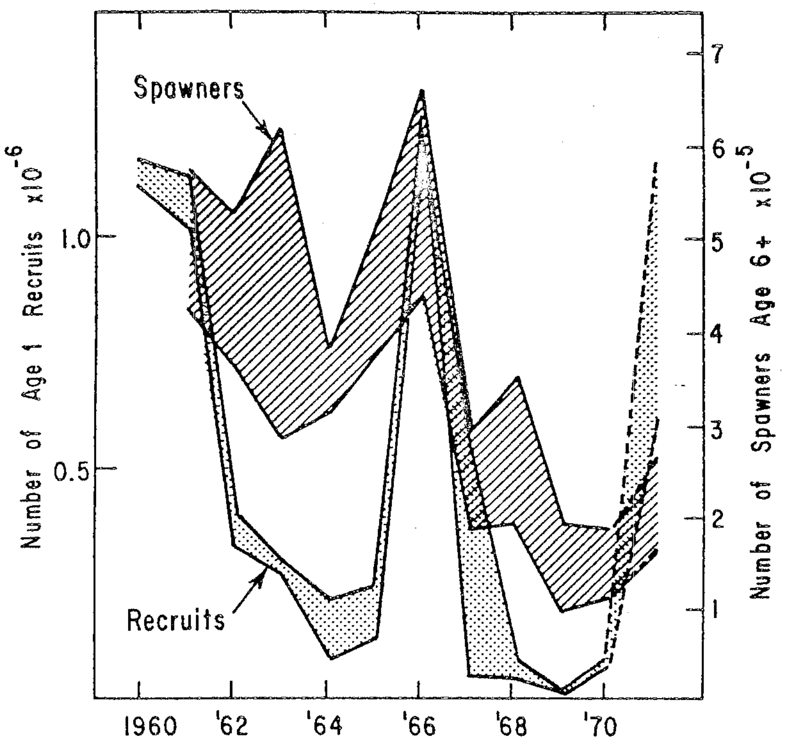

Fig. 3. Range of calculated recruitment (age 1 fish) and population size of age 6+ ("mature") fish in the preceding year, calculated assuming both stock hypotheses and the estimates of F and M specified in the text.

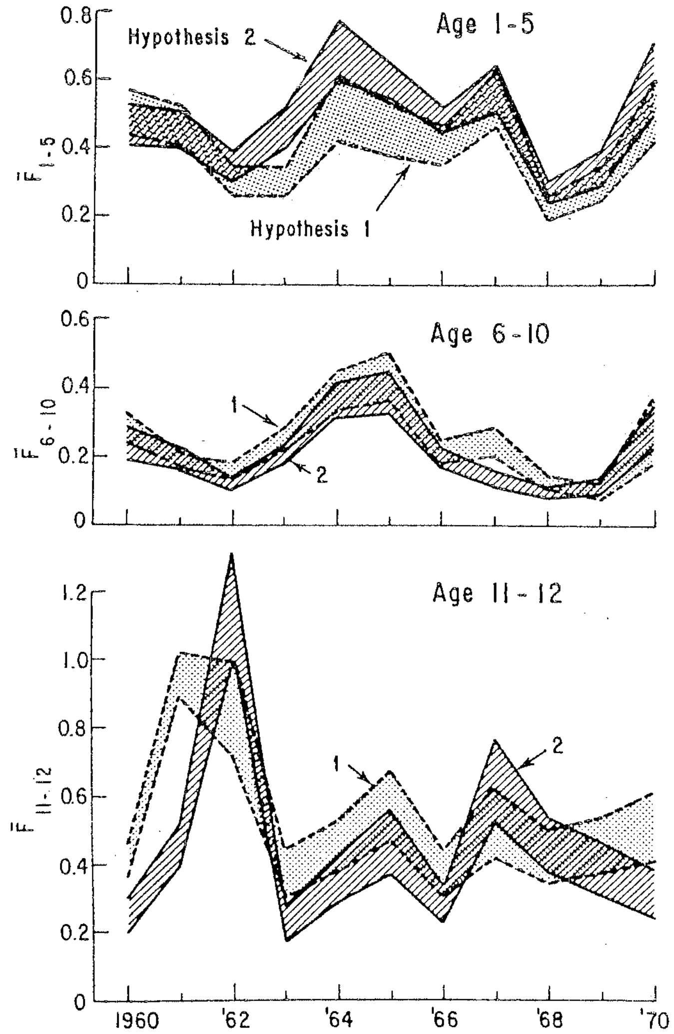

Fig. 4. Range of mean age-specific mortalities for 3 age groups of bluefin tuna each year, calculated for the 2 stock hypotheses and input values considered in the text.