COHORT ANALYSIS OF THE EASTERN ATLANTIC FISHERY FOR YELLOWFIN TUNA ☆

by

Alain Fonteneau[1] and William H. Lenarz[2]

SUMMARY

Estimates of age specific fishing mortality were made for the 1964-71 year classes of yellowfin tuna in the eastern Atlantic ocean. The estimates of fishing mortality were then used to calculate year class strength, biomass of the population, fecundity of the population and yield per recruit. With the exception of a weak 1968 year class, no reduction in strength of recruitment was apparent during the period, even though there was a significant drop in the fecundity of the population. No clear-cut change in the biomass of the population has occurred since 1969. Yield per recruit appeared to be lower in 1970 and 1971 than in 1969 and 1972. This may have been caused in part by the fleet tending to fish more for skipjack in 1970 and 1971 than during the other two years. At current levels of fishing effort, there appears to be little to be gained from manipulating age at recruitment. However, if fishing effort is doubled, the yield per recruit calculations indicated that about a 50% gain in yield per recruit could be achieved, if it is possible to increase age at recruitment.

☆ Data partially reproduced in Data Record, Vol. 3

[1] ORSTOM CRO, Abidjan

[2] National Marine Fisheries Service

RESUME

On a estimé la mortalité spécifique par âge due à la pêche pour la classe d'âge de 1964-71 de l'albacore dans l'Atlantique Oriental. Ces estimations ont ensuite servi à calculer l'importance de la classe annuelle, la biomasse de la population, sa fécondité, et le rendement par recrue. A l'exception d'une classe faible en 1968, aucune diminution de l'importance du recrutement n'a été observée au cours de cette période, bien qu'il y ait eu une baisse sensible de la fécondité de la population. Aucun changement net ne s'est produit depuis 1969 dans la biomasse de la population. Le rendement par recrue semble avoir été moindre en 1970 et 1971 qu'en 1969 et 1972. Ceci peut avoir été dû en partie au fait que la flotte a eu tendance à se porter plus sur le listao en 1970 et 1971 qu'au cours des deux autres années. Aux niveaux actuels de l'effort de pêche, il ne semble pas qu'il y ait beaucoup à tirer de manipulations de l'âge au recrutement. Néanmoins, si l'importance de l'effort de pêche est doublée, les calculs du rendement par recrue indiquent qu'un bénéfice d'environ 50% pourrait porter sur le rendement par recrue, si l'on pouvait augmenter l'âge au recrutement.

☆ Données partiellement reproduites dans le Vol. 3 du Recueil de Données

[1] ORSTOM CRO, Abidjan

[2] National Marine Fisheries Service

RESUMEN

Se hicieron estimaciones de la edad específica de mortalidad de pesca para las clases anuales de rabil durante el periodo 1964-71, en el Atlántico Oriental. Después, se utilizaron estimaciones de mortalidad de pesca para calcular la importancia de la clase anual, biomasa de la población, fecundidad de la población y rendimiento por recluta. Con excepción de 1968, que tuvo una clase anual reducida, no se apreció durante este periodo ninguna reducción en la importancia del reclutamiento, aún teniendo en cuenta que se produjo un descenso apreciable en la fecundidad de la población. No se ha producido ningún cambio evidente en la biomasa de la población desde 1969. El rendimiento por recluta pareció ser más bajo en 1970 y 1971 que en 1969 y 1972. El motivo puede ser en parte que la flota concentró sus esfuerzos sobre el listado más en 1970 y 1971 que durante los otros dos años. En los niveles actuales de esfuerzo pesquero, no parece existir mucha ventaja en utilizar datos de edad en el reclutamiento. Sin embargo, al duplicar el esfuerzo pesquero, los cálculos de rendimiento por recluta indicaron que se podía conseguir aproximadamente un 50% de ganancia en el rendimiento por recluta si se puede aumentar la edad de reclutamiento.

[*] Datos parcialmente reproducidos en el Vol. Nº 3 de la Colección de Datos Estadísticos

1/ ORSTOM CRO , Abidjan

2/ National Marine Fisheries Service

INTRODUCTION

The fishery for yellowfin tuna in the Atlantic Ocean has shown signs of reaching or nearing the level of maximum sustainable yield (ICCAT, 1973a). Because of this stock assessment, efforts on yellowfin have been intensified by members of the SCRS. The SCRS recommended at its 1972 meeting (ICCAT, 1973a) that estimates be made of the strength of year classes and spawning stock size and that updates be made of the previous work (Hayasi, 1972; Joseph and Tomlinson, 1972; Lenarz et al., in press; Pianet and LeHir, 1972) on size (age) specific F and yield-per-recruit isopleths. This study followed the above recommendations by using estimates of age specific F for yellowfin tuna available to the fisheries in the eastern Atlantic (Guinea area as defined by Honma, 1972) for the 1967-72 period to obtain the other desired parameters. We chose to treat the eastern Atlantic fishery as an entity because it appears to be more heavily exploited than the western Atlantic. Also, many of the recorded catches from the western Atlantic actually occurred in the Caribbean Sea and Gulf of Mexico, which are somewhat geographically isolated from the eastern Atlantic fishery.

METHODS AND MATERIALS

The data were compiled by quarter which is the finest time strata feasible. Catch information was obtained from ICCAT (1973b). We used the areal distribution of the Japanese longline catches (ICCAT, 1973c) to divide the total longline catch into eastern and western components. It was necessary to assume that the area distributions of the 1971 and 1972 longline catches were the same as the 1970 Japanese catch. Length composition data were available in either fork length or pre-dorsal length depending on the source. We chose to convert fork length data to pre-dorsal length and did so with a computer program (LFLD1) which employs the logarithmic equation of Poinsard (1969). Length composition data were obtained from ICCAT (1973c) and members of the SCRS.

Because data on the size composition of the catch is not available from all parts of the fishery it was necessary to make several assumptions.

The only available length composition data from the longline fisheries is from the 1967-70 Japanese catches. Consequently, it was necessary to assume that 1) the 1971 and 1972 Japanese catches had the same size distribution as the 1970 catch, and 2) for each year all other longline catches had the same size composition as the Japanese.

The best available data for the surface catches are from the 1969-72 catches by the FIS fleet, American purse seine fleet, and Japanese purse seine fleet for which we have data stratified by quarter, gear, and area. During the

1967-68 period the sampling intensity was lower and the data only stratified by quarter and gear. Because of incomplete coverage of the surface fleet it was necessary to assume that 1) catches by the Spanish fleet had the same size composition as the FIS fleet in the Dakar and Abidjan areas, and 2) catches made by Japanese and Angolan baitboats had the same size composition as FIS baitboats (with freezers).

We used the production model approach to obtain a feeling for the status of the stocks in the eastern Atlantic in order to increase our objectivity in choosing initial values of F for the cohort analysis. We recognize that others (e.g., ICCAT, 1972; Fox and Lenarz, 1972) have estimated the parameters of the production model for the entire Atlantic, but we felt that it was necessary to do so for the eastern Atlantic. We used the index of catch per effort that was compiled by Fonteneau and Caveriviere (1973) from the average of catch per day at sea of FIS baitboats (standardized to FIS average seiners) and FIS average seiners. The results indicate the maximum sustainable yield is at about 65,000 tons (Figure 1) which is approximately the present position of the fishery.

The computer program COHORT (written by W. W. Fox, Jr.) was used to calculate age specific F and population size in numbers using the Murphy-Gulland method for each year class born between 1963 and 1971. The program allows use of either the forward or reverse solution given F for the first or last age in the fishery. Upon checking we were relieved to find that the two procedures gave the same results. That is, if an initial F is used to calculate an F vector using the forward procedure and then the resulting final value of F is used as input for the reverse procedure, the resulting F vector is identical to that obtained from the forward procedure. We used the reverse procedure for the remainder of the study because the age structure of the catch generally caused F values to converge at young ages.

A major problem with the Murphy-Gulland method is choosing the proper initial value of F when little information is available. We used the results of the production model analysis to do this. Following Gulland (1970) we assumed that the mean value of F is equal to the coefficient of natural mortality when a fishery is at the MSY level as indicated in Figure 1. Being unsure of the exact position of the fishery we chose to use both a high and low level of F. We set the average value of F equal to M as the high level because higher levels gave unreasonably high values of F for the older fish of a cohort. We arbitrarily chose our low level of F to be equal to on the average to $\frac{M}{2}$. We did not use the first two quarters that a year class was available to the fishery in our calculations because the preliminary results indicated they were far from being fully recruited. Also, values of F for 1972 were not used in calculation of the averages, because inclusion would have caused unrealistic results.

The choice of M is also difficult. We assumed that M is constant as is usual and tried the usual value of 0.8 and also the value of 0.6. We believe that these two values encompass the true value, if M is constant.

Fish were aged using the growth curve of Le Guen and Sakagawa (1973) with a few exceptions when the position of modes suggested minor changes.

We used a relation previously calculated by Fonteneau to convert pre-dorsal length to weight ($W = 0.0003272LD1^{3.276762}$). With the exception of age 1 fish we used the weight predicted by the Le Guen and Sakagawa growth curve for our work. The age 1 mode progressed more slowly than predicted by the growth curve. Consequently, we used the 1967-72 mean weight of age 1 fish for our yield per recruit work (Table 1). However we used the growth curve predictions for estimates of biomass.

We examined the fecundity of the fished cohorts by using the age specific fecundity indices of Hayasi (1972) to convert biomass to fecundity. The two indices differ considerably in the fecundity of older fish relative to young fish. We also estimated fecundity of unfished cohorts, through age 8, and divided the results into the fecundity of the fished stock to arrive at an index of total fecundity.

We used the computer program MGEAR (written by Lenarz) to calculate yield per recruit isopleths. The program uses the Ricker (1958) yield equation.

Table 1. Age specific weight and fecundity used in study

Age		Theoretical weight (kg)	Modal Weight (kg)	Fecundity index 1	Fecundity index 2
Year	Quarter				
1	1	0.5	3.5	0	0
	2	1.5	4.0	0	0
	3	3.5	4.5	0	0
	4	6.3	4.9	0.04	0
2	1	10.5	10.5	0.10	0.10
	2	16.2	16.2	0.20	0.20
	3	20.0	20.0	0.35	0.35
	4	25.0	25.0	0.50	0.50
3	1	30.0	30.0	0.60	0.60
	2	35.0	35.0	0.75	0.75
	3	40.0	40.0	0.90	0.90
	4	45.0	45.0	1.10	1.00
4	1	51.0	51.0	1.35	1.10
	2	58.0	58.0	2.00	1.25
	3	65.0	65.0	2.30	1.35
	4	70.0	70.0	2.60	1.45
5	1	76.0	76.0	2.75	1.60
	2	82.0	82.0	3.50	1.75
	3	88.0	88.0	3.80	1.85
	4	94.0	94.0	4.20	1.95
6	1	100.0	100.0	4.70	2.10
	2	106.0	106.0	5.00	2.20
	3	112.0	112.0	5.00	2.30
	4	118.0	118.0	5.00	2.60

RESULTS

Age composition of the catch

Examination of the length composition of the catch (Figure 2) shows that it was often quite difficult to separate year classes using modal analysis alone. Because of this difficulty we usually resorted to the growth curve of Le Guen and Sakagawa (1973), as previously mentioned, to determine the boundaries between adjacent year classes. It was particularly difficult to distinguish between the 1966 and 1967 year classes. This suggests that there may have not been a marked cessation in recruitment between the 1966 and 1967 year classes. Also the position of the mode of the 1967 year class in quarters 3 and 4 of 1968 suggests that recruitment of the 1967 year class ceased earlier in the year than is normal. Examination of Figures 4 and 6 of Le Guen and Sakagawa (1973) indicates that a year class appears later in the Dakar region than in the Pointe Noire region (as mentioned previously by Champagnat and Lhomme, 1970) and that the modes appear to be consistently several months apart. Whether or not these data represent the extremes of a common distribution or separate stocks needs to be examined. The age composition of the catch is compiled by quarter and year in Table 2).

Table 2. Age composition, in hundreds of fish, of the catch of yellowfin tuna from the eastern Atlantic

		Age (years)						
		1	2	3	4	5	6	Total
Year Class		1966	1965	1964	1963			
Year Caught	Quarter							
1967	1	401	2,906	534	1,387			5,228
1967	2	1,038	1,550	712	592			3,892
1967	3	2,819	2,664	891	133			6,507
1967	4	631	1,638	1,722	365			4,356
Total		4,889	8,758	3,859	2,477			19,983
		1967	1966	1965	1964	1963		
1968	1	894	2,781	1,733	1,108	293		6,809
1968	2	4,968	1,368	873	419	119		7,747
1968	3	5,911	1,997	1,014	700	481		10,103
1968	4	6,443	1,834	822	184	17		9,300
Total		18,216	7,980	4,442	2,411	910		33,959
		1968	1967	1966	1965	1964	1963	
1969	1	264	4,333	2,455	707	157	12	7,928
1969	2	825	2,394	2,303	492	239	18	6,271
1969	3	4,349	2,162	2,787	822	434	33	10,587
1969	4	3,190	850	1,539	704	78	19	6,380
Total		8,628	9,739	9,084	2,725	908	82	31,166
		1969	1968	1967	1966	1965	1964	
1970	1	756	816	2,963	1,492	247	17	6,291
1970	2	4,452	986	697	578	185	18	6,916
1970	3	17,812	1,051	587	597	306	14	20,367
1970	4	7,997	699	344	243	22	2	9,307
Total		31,017	3,552	4,591	2,910	760	51	42,881
		1970	1969	1968	1967	1966	1965	
1971	1	4,219	2,201	1,078	847	265	15	8,625
1971	2	4,216	4,439	468	320	97	6	9,546
1971	3	9,207	3,937	409	704	115	2	14,374
1971	4	6,219	1,622	174	210	43	2	8,270
Total		23,861	12,199	2,129	2,081	520	25	40,815
		1971	1970	1969	1968	1967	1966	
1972	1	5,231	3,875	2,100	502	479	54	12,241
1972	2	5,059	3,839	1,275	224	79	7	10,483
1972	3	7,859	6,259	1,376	178	136	4	15,812
1972	4	5,644	2,193	952	375	87	4	9,255
Total		23,793	16,166	5,703	1,279	781	69	47,791

Estimate of age specific F

Estimates of age specific F are shown by year class in Figure 3 and age of capture in Figure 4. The results indicate that 1-year-old fish are not heavily exploited until the third quarter of the year of recruitment to the fishery. Estimates of F for the first quarter are generally 15% of the estimates for the third quarter and estimates for the second quarter are about 25% of the estimates for the third quarter (Figure 5). Estimates for the other age groups are also generally higher in the third quarter but the difference between the first and third quarters are not nearly so great. This suggests that the slow progression of the mode of an incoming year class is caused by the year class becoming increasingly vulnerable as the year progresses. This could be caused by fish not becoming vulnerable until obtaining a given size. The mode of the incoming year class tends to become less peaked with time suggesting that the above hypothesis is reasonable.

Regardless of the chosen value of initial F or M the estimations of F are higher for ages 3 through 5 years than for ages 1, 2, and 6. However, there is less of a difference between estimations of F for 1 through 2 year fish and 3 through 5 year old fish for M = 0.6 than for M = 0.8 (Figure 5). It seems reasonable that F would be higher for the middle-aged fish than for the younger fish because longliners do not fish for young fish and as previously mentioned the young fish do not appear to be heavily exploited to the fishery until the third quarter of the first year in the fishery.

Estimates of F for younger fish have increased since 1967, while estimates for the older fish have remained about the same. Since we forced the mean value of F to be the same for each year class, the trends probably do not have much meaning, except that the increased F for young fish is probably due to increased effort by the surface fleet.

Estimates of year class size

We estimated recruitment in terms of numbers of fish at the beginning of the first quarter of the first year in the fishery. We noted that estimates of recruitment corresponding to high F converged to an asymptote as F increased and for the year classes examined our lower estimates of recruitment are close to the asymptotic value (Figure 6). However, for a given cohort the asymptote increased as we increased the number of age groups included in the analysis (Figure 7). This means that we are probably underestimating, for the lower range, recruitment of the most recent year classes because of the few age groups included in the analysis. Our estimates of recruitment are shown in Figure 8. There is no obvious trend in recruitment and the 1968 year class appears to be about half the size of adjacent year classes while the other year classes are quite similar in size. However, because of the difficulties in ageing older fish from length frequency distributions (particularly when pre-dorsal lengths with only 1 cm accuracy) and the necessity of assuming that the longline catches for 1971 and 1972 had the same distributions as the longline catches for 1970, we probably have underestimated the differences among adjacent year classes.

We also noted that the estimates for the 1969 and 1970 year classes are relatively higher for M = 0.6 than for M = 0.8. The estimates may converge to their asymptotic values faster for M = 0.6 than for M = 0.8 because there is a smaller difference between F for ages 1 through 2 fish and F for ages 3 through 5 fish when M = 0.6. It is probably too early to say much concerning the strength of the 1969 and 1970 year classes other than they appear to be as strong or stronger than the 1965-68 year classes.

Estimates of fecundity

Estimates of age specific fecundity for an unfished population are shown in Figure 9. Fecundity is highest for 4 through 7 year old fish for index I, and 3 through 6 year old fish for index II. This shows that fishing for young fish can have a great effect on fecundity. Our estimates of fecundity of the fished stocks divided by fecundity of a virgin stock are shown in Figure 10. Most of the estimates show a drop since 1969 with the biggest drop between 1969 and 1970. Our estimates of the ratio for 1972 is as low as 0.1. This suggests that the spawning stock has been considerably effected by fishing and strength of recruitment should be closely monitored in the coming years.

Estimates of biomass

Estimates of biomass by age are shown in Figure 11. The stock is dominated by the biomass of ages 2 and 3 fish. Estimates of total biomass and biomass of the fished stocks divided by biomass of a virgin stock with the same recruitment are shown in Figure 12. Estimates for high values of F indicate that the biomass has decreased since 1969 while estimates for low values of F indicate that there has been no decrease or an increase. These conflicting results are not too surprising because Figure 1 indicates there has not been a drastic change in fishing effort since 1969. Thus, one would expect minor changes in biomass during the period which could be masked by the imprecision of our data and methods.

Estimates of yield per recruit

Figure 13 indicates that yield per recruit was slightly lower in 1970 and 1971 than in 1969 and 1972. The cause of this is not known but at least some of the fleet concentrated their effort more on skipjack in 1970 and 1971 than in 1969 and 1972. Also, we may have overestimated F for 1972 which could have effected yield per recruit. Plots of yield per recruit (Figure 14) as a function of fishing effort for 1971 indicate that the fishery has reached or nearly reached the MSY level in a yield per recruit sense which is in agreement with the production model approach. It is interesting to note in this respect that our estimates of the ratio of fished biomass to unfished biomass for high F (0.25-0.30) is about what Table 1 of Gulland (1970) predicts when M/K is 2 (0.8/0.4), the ratio of size at recruitment to L_∞ is 0.4 (20/50) and maximum sustainable yield per recruit is obtained. Plots of yield per recruit as a function of age at recruitment indicate that there is not much to be gained by manipulating age at recruitment if effort remains at the 1971 level (Figure 15). The maximum gain in yield per recruit (about 20%) would be obtained if M = 0.6, fishing on the incoming year class is eliminated for the first 5 quarters that it is available to the fishery and effort remains at the 1971 level. Effort has been increasing in the fishery and we expect the increase will continue. If effort doubles the composition of the fleet remains the same, and if M = 0.6,eumetric fishing would result in as much as a 50% increase in yield per recruit over that obtained at the present age at recruitment. The feasibility of being able to do this is not known, but thought to be unlikely (ICCAT, 1972; Lenarz et al., in press).

DISCUSSION AND RECOMMENDATIONS

The results of our study indicate that under present conditions the fishery for yellowfin tuna in the eastern Atlantic has reached or nearly reached the maximum sustainable yield in both the production model sense and yield per recruit sense. If effort remains constant, it appears that little can be gained by increasing age at recruitment. More gains would occur if age of recruitment could be increased and effort increases, but we did not examine the effects of changing the composition of the fleet and anticipate that the fleet will continue to be as dynamic as it has in the past. We believe that the recommendation of ICCAT to member countries to have a 3.2 kg minimum size limit is good, because even if it does not increase the size at recruitment from the present position, it should prevent a decrease in size at recruitment which would undoubtedly decrease yield per recruit.

Our estimates of strength of recruitment give no indication that recruitment has been effected by fishing. However, the fecundity of the stock has been considerably reduced by fishing. Thus, we believe the strength of recruitment should be closely monitored in the coming years and recommended that the SCRS assign this task at its 1973 meeting.

The available data may not be truely representative of the catch. Several components of the fishery are not sampled and some of the samples are 3 years out of date. There is also the possibility that the average size of purse seiner landings is being overestimated by the method of compiling the length composition statistics. Normally samples of fixed size are given equal weight in compilation of the length composition data regardless of the weight of the landing that they represent within a time-area stratum. This causes the importance of large fish to be overemphasized. A preliminary analysis indicates that the average size of yellowfin caught by the American fleet is overestimated by about 10%. The extent of the bias for the FIS fleet is unknown. Correction of the bias would tend to increase F for young fish relative to old fish and probably increase the gain in yield per recruit that would result from an increase in age at recruitment. We recommend that sampling procedures be changed so that proper weight can be assigned to length frequency samples and repeat the usual plea for increased coverage of the fishery.

Our assumption that the eastern Atlantic fishery is utilizing a single population that is separate from the western Atlantic population is open to question. If there is only one population in the entire Atlantic it is likely that we have overestimated F for young fish relative to old fish and probably overestimated the benefits of increased age at recruitment. If there is more than one population in the eastern Atlantic, the effect on our results is unknown.

LITERATURE CITED

Champagnat, C. and F. Lhomme. 1970. La Pêche Thoniere à Dakar de 1966 à 1969. ORSTOM-Dakar. DSP No. 27.

Fonteneau, A. et A. Caveriviere. 1973. Application des modeles de Schaeffer et derives aux populations d'albacore (*Thunnus albacares*) de l'Atlantique. Doc. pres. ICCAT meeting Paris, 1973.

Gulland, J. A. 1970. The fish resources of the ocean. FAO Fish. Tech. Pap. No. 97.

Hayasi, S. 1972. Biological views for conservation of yellowfin tuna in the Atlantic Ocean, based on information obtained up to October 1972. SCRS/72/21, 16 p.

Honma, M. 1972. Overall fishing intensity and catch by length class of yellowfin tuna in Japanese Atlantic longline fishery, 1956-1970. SCRS/72/14, 19 p.

IATTC. 1973. Annual report of the Inter-American Tropical Tuna Commission, 1972. 166 p.

ICCAT. 1972. Report of the meeting of the Special Working Group on Stock Assessment of Yellowfin Tuna. Abidjan, June 12-16, 1972.

__________. 1973a. Report for biennial period 1972-73. Part 1, 157 p.

__________. 1973b. Statistical bulletin. Vol. 3.

__________. 1973c. Data record. Vol. 1, 271 p.

Joseph, J. and P. K. Tomlinson. 1972. An evaluation of minimum size limits for Atlantic yellowfin. Paper presented at Abidjan meeting, June 1972, 15 p.

Le Guen, J. C. and G. T. Sakagawa. 1973. Apparent growth of yellowfin tuna from the eastern Atlantic Ocean. Fish. Bull., U.S. 71: 175-187.

Lenarz, W. H., W. W. Fox, Jr., G. T. Sakagawa and B. J. Rothschild. (In press). An examination of the yield per recruit basis for a minimum size regulation for Atlantic yellowfin tuna. Fish. Bull., U.S., 75 p.

Pianet, R. and Y. Le Hir. 1972. La campagne thorière 1971 à Pointe-Noire. ORSTOM Pointe Noire Document 20, 26 p.

Poinsard, F. 1969. Relations entre longueur predorsale, longueur a la fourche et poids des albacores, *Thunnus albacares* (Bonnaterre) peches dans le sud du Golfe de Guinee. Cah. ORSTOM, Ser Oceanogr. 7(2): 89-94.

Ricker, W. E. 1958. Handbook of computation for biological statistics of fish populations. J. Fish. Res. Bd. Canada, 119, 300 p.

FIGURES

Figure 1. Catch and effort of the eastern Atlantic fishery for yellowfin. The line represents equilibrium yield obtained using the general production model with M = 1.4. The computer program GENPROD was used to fit the model.

Figure 2. Length composition of the catch of yellowfin tuna in the eastern Atlantic by year and quarter. The vertical lines represent our estimates of the divisions between year classes.

Figure 3. Estimates of age specific F for yellowfin in the eastern Atlantic by year class. (a) M = 0.8, (b) M = 0.6.

Figure 4. Estimates of age specific F for yellowfin in the eastern Atlantic by year of capture. (a) M = 0.8, (b) M = 0.6.

Figure 5. Averages of age specific F for yellowfin in the eastern Atlantic, 1969-72. (a) M = 0.8, (b) M = 0.6.

Figure 6. Estimates of recruitment of 1966 and 1967 year classes as a function of initial value of F.

Figure 7. Estimates of recruitment of 1966-69 year classes as a function of number of year classes in the analysis.

Figure 8. Estimates of number of recruits (first quarter of first year in the fishery) of yellowfin in the eastern Atlantic (1963-70).

Figure 9. Estimates of age specific fecundity of an unfished population of yellowfin.

Figure 10. Estimates of total fecundity of yellowfin in the eastern Atlantic.

Figure 11. Estimates of age specific biomass of yellowfin in the eastern Atlantic by year of capture.

Figure 12. (a) Estimates of total biomass of yellowfin in eastern Atlantic by year of capture. (b) Estimates of ratio of fished biomass to biomass of an unfished stock of yellowfin in the eastern Atlantic by year of capture.

Figure 13. Estimates of yield per recruit of yellowfin in eastern Atlantic by year of capture.

Figure 14. Estimates of yield per recruitment of yellowfin in the eastern Atlantic as a function of fishing effort under the conditions that prevailed in 1971.

Figure 15. Estimates of yield per recruit of yellowfin in the eastern Atlantic as a function of age of recruitment under the conditions that prevailed in 1971.

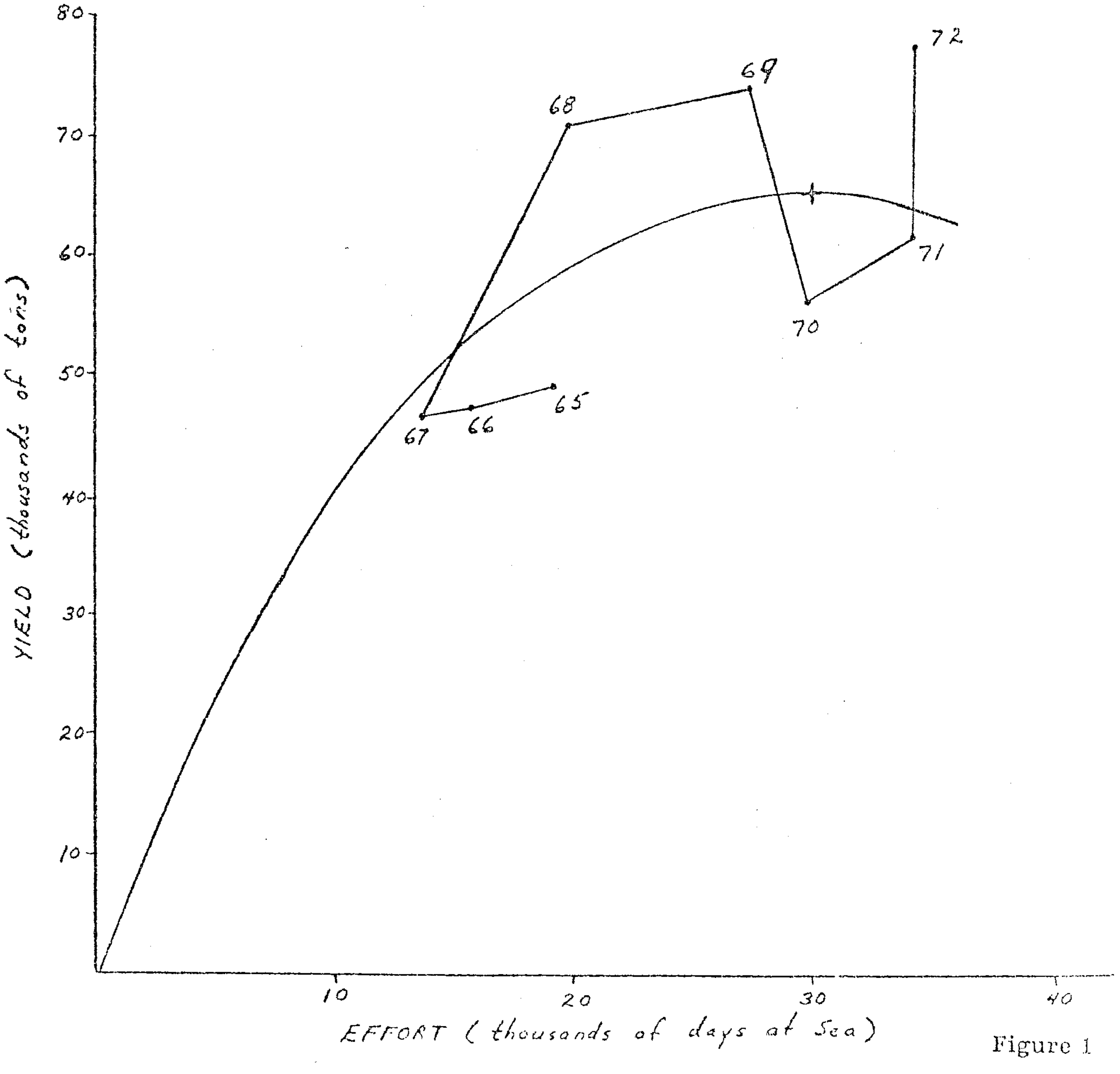

80
70
60
50
40
30
20
10
YIELD (thousands of tons)
10
20
30
40
EFFORT (thousands of days at Sea)
65
66
67
68
69
70
71
72

Figure 1

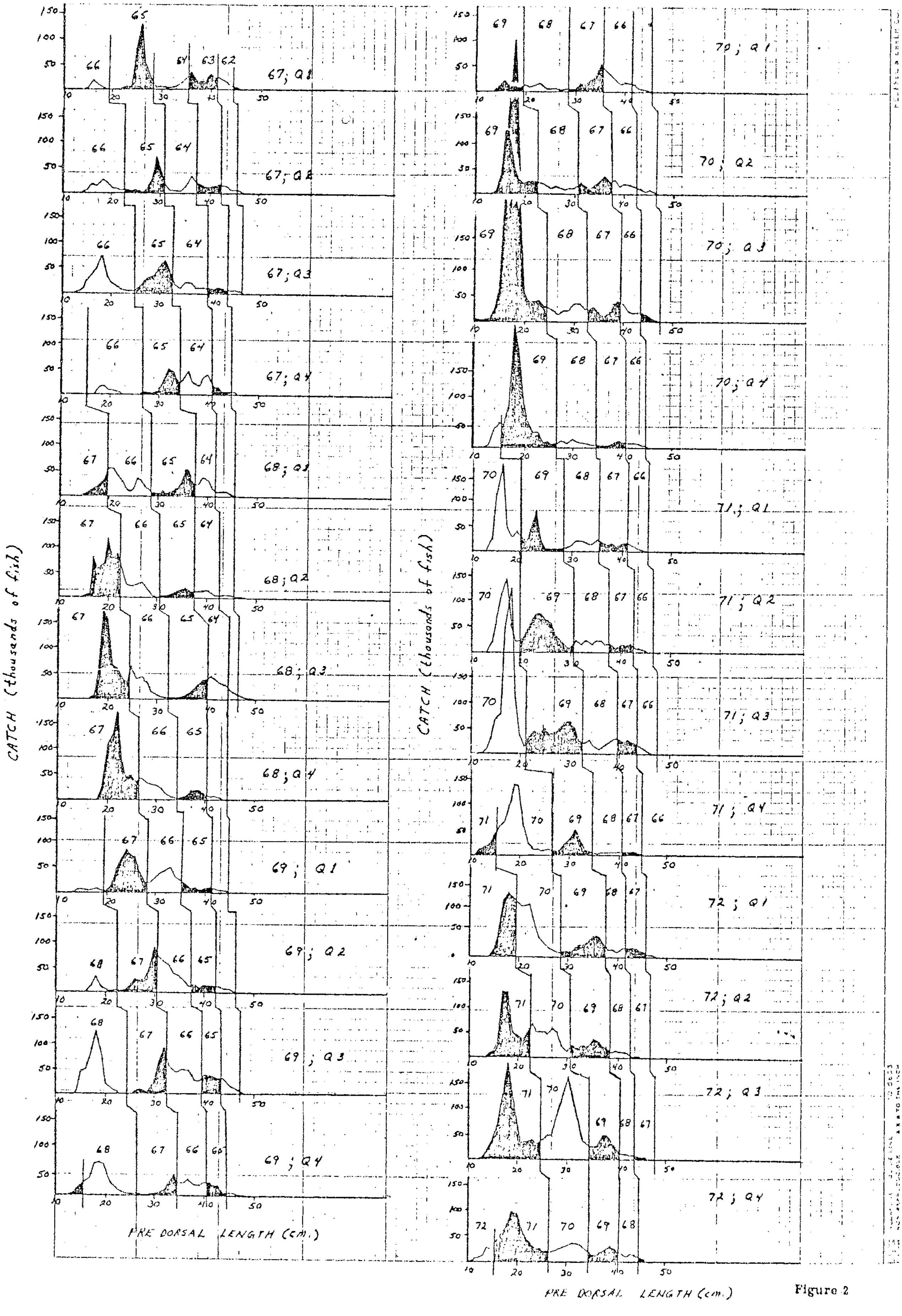

CATCH (thousands of fish)
150
100
50
10
20
30
40
50
67; Q1
67; Q2
67; Q3
67; Q4
68; Q1
68; Q2
68; Q3
68; Q4
69; Q1
69; Q2
69; Q3
69; Q4
62
63
64
65
66
67
68
PRE DORSAL LENGTH (cm.)
70; Q1
70; Q2
70; Q3
70; Q4
71; Q1
71; Q2
71; Q3
71; Q4
72; Q1
72; Q2
72; Q3
72; Q4
69
70
71
72
PRE DORSAL LENGTH (cm.)

Figure 2

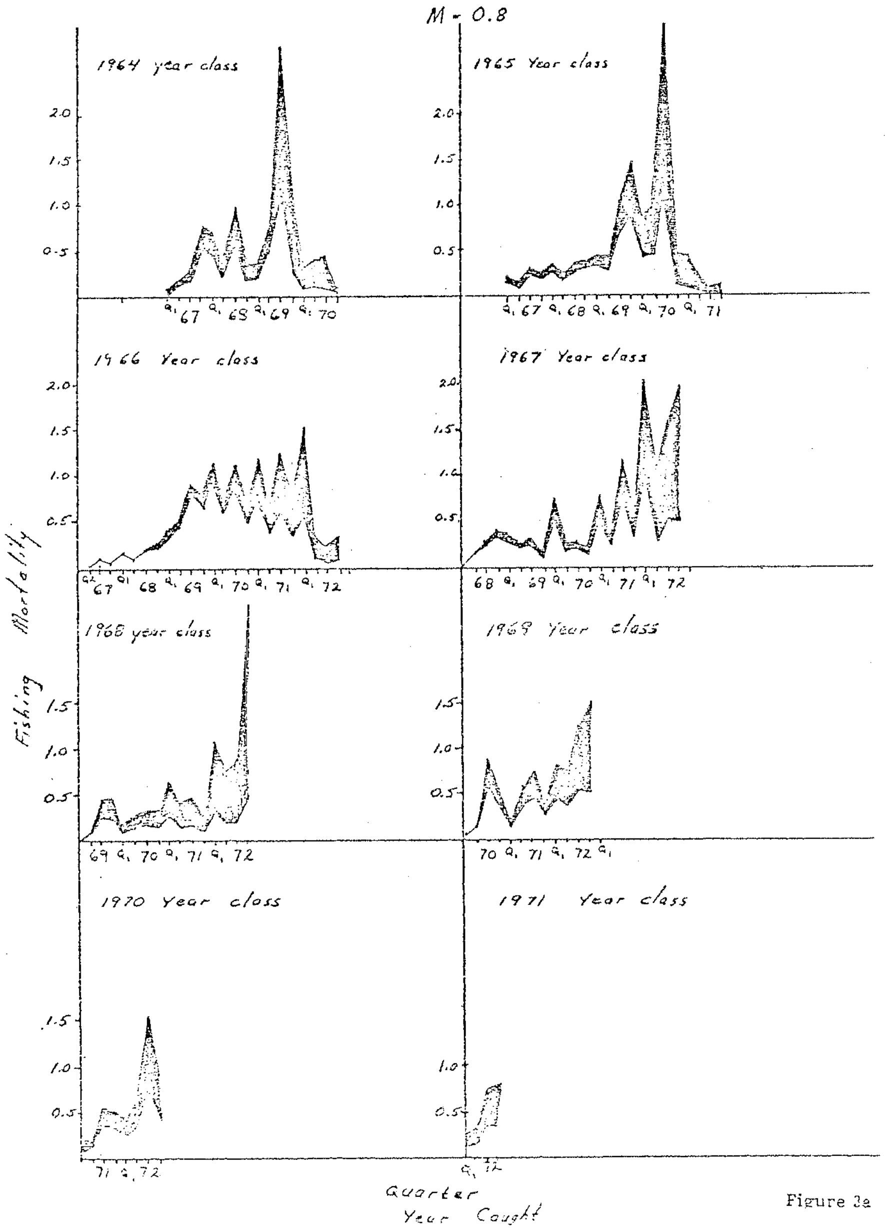


Figure 3a

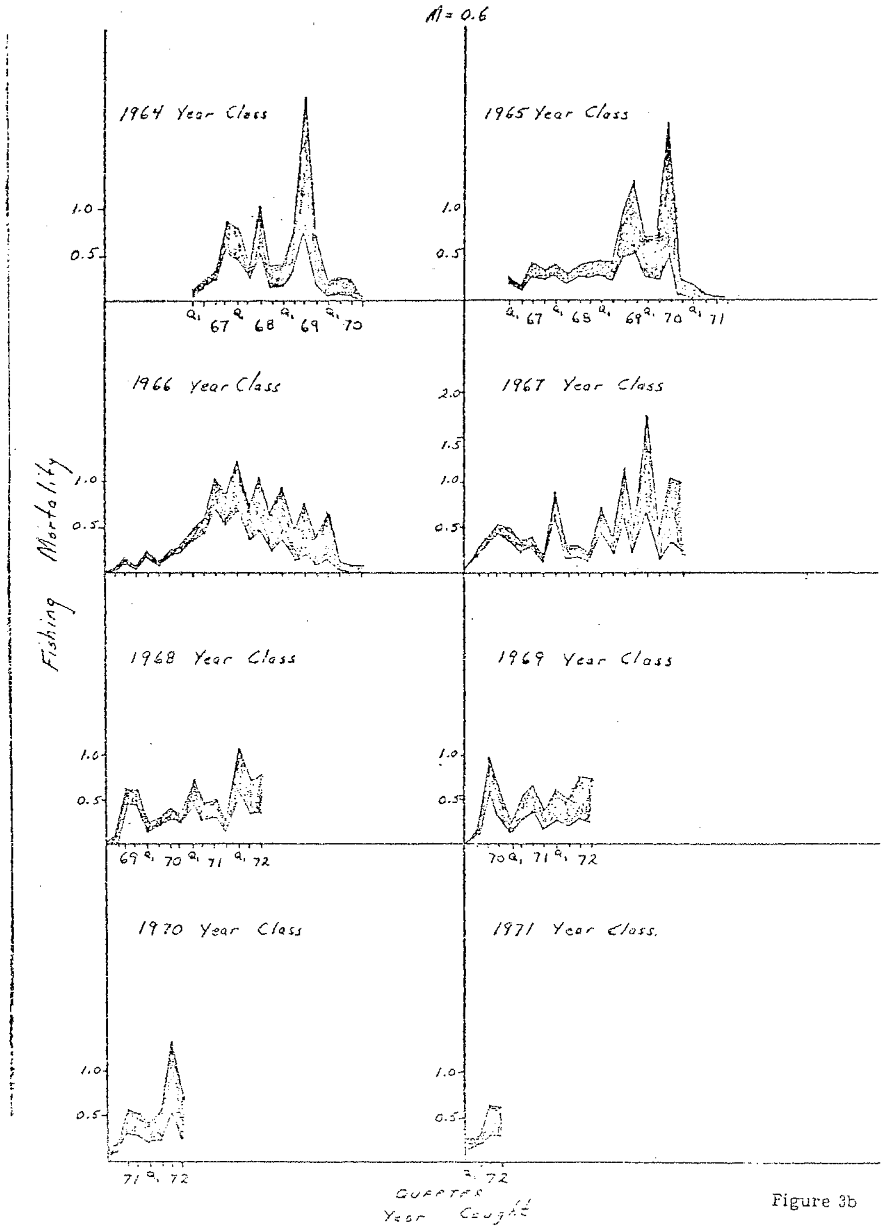
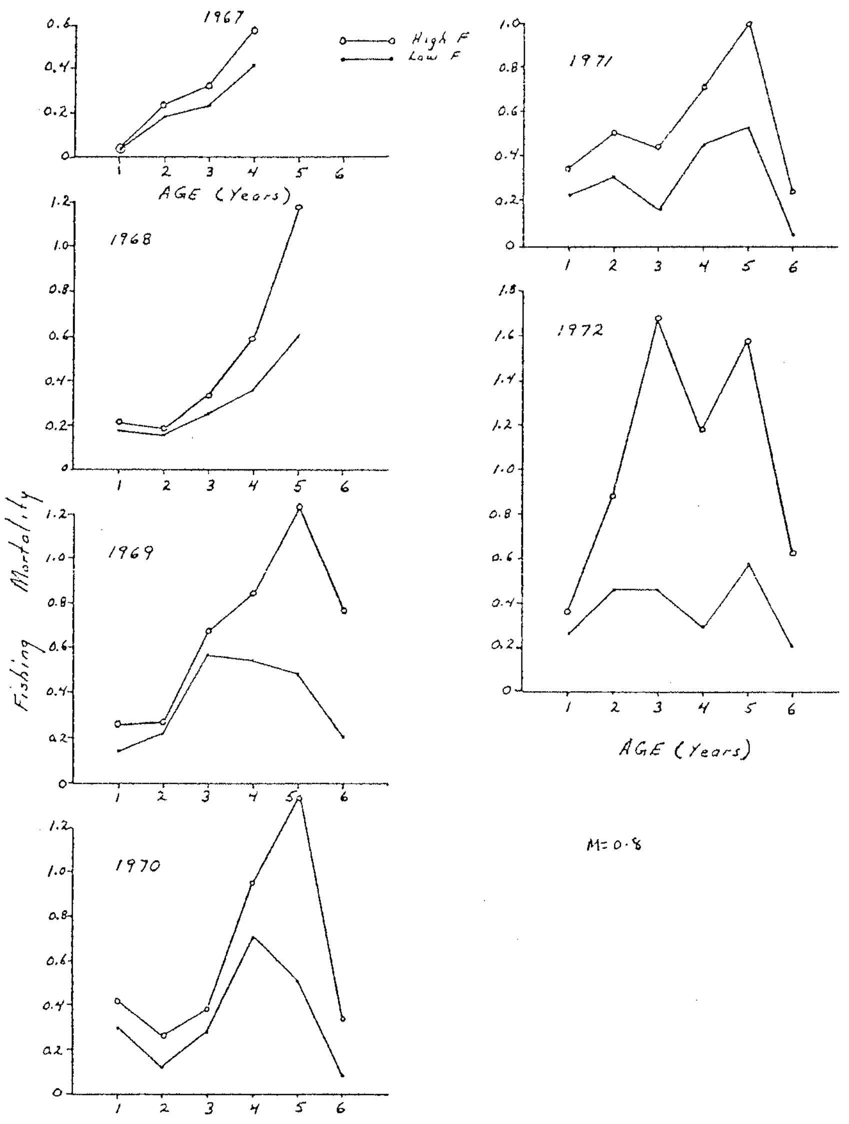
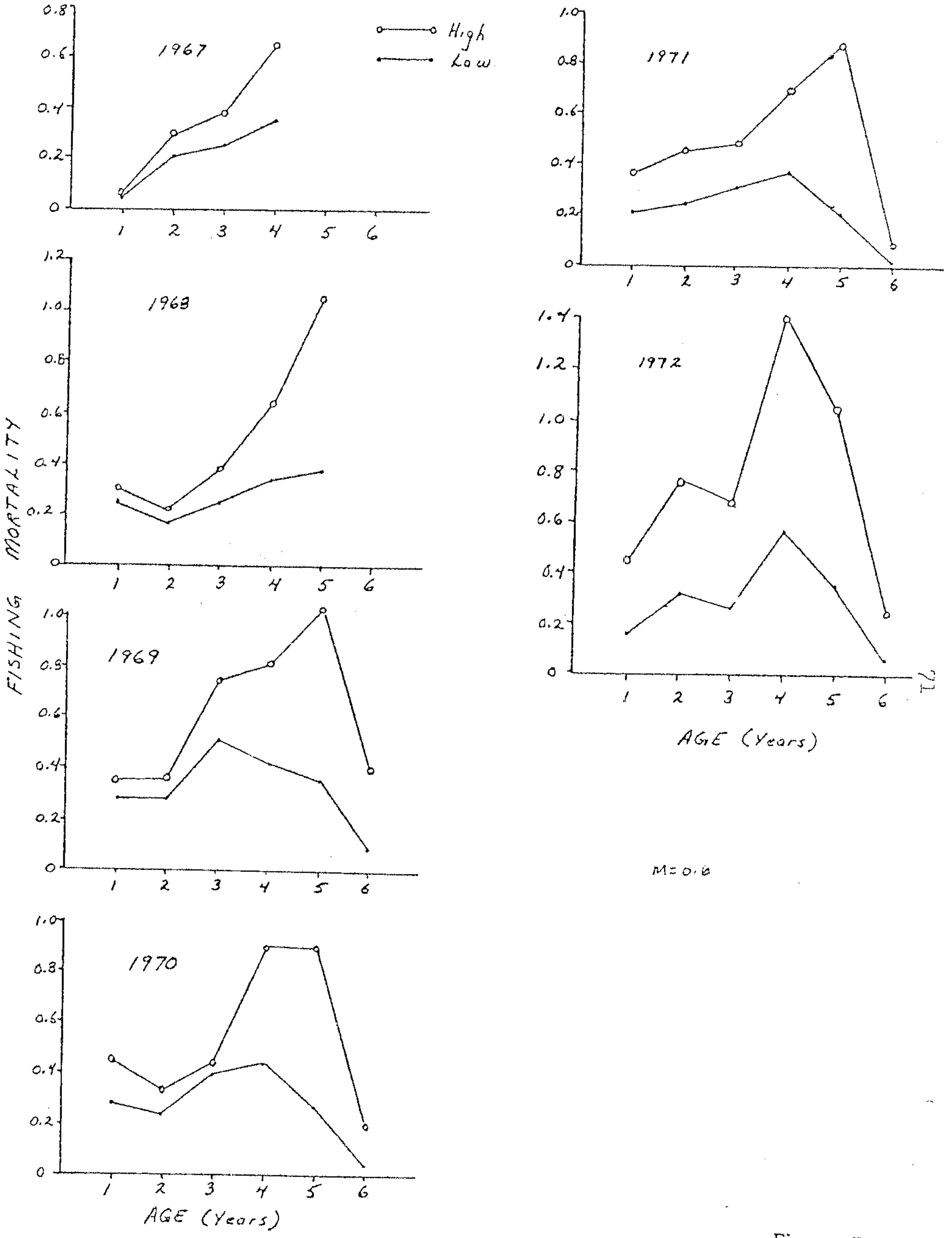


Figure 3b



M=0·8

Figure 4a



M=0·6

Figure 4b

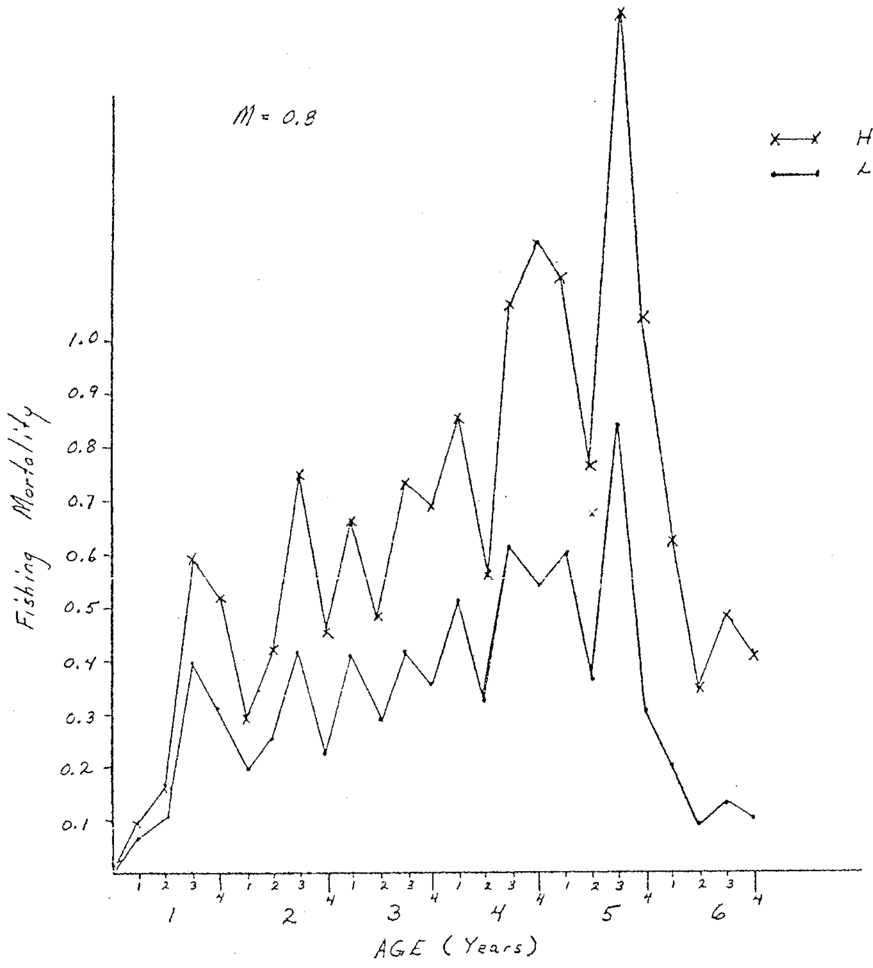


Figure 5a

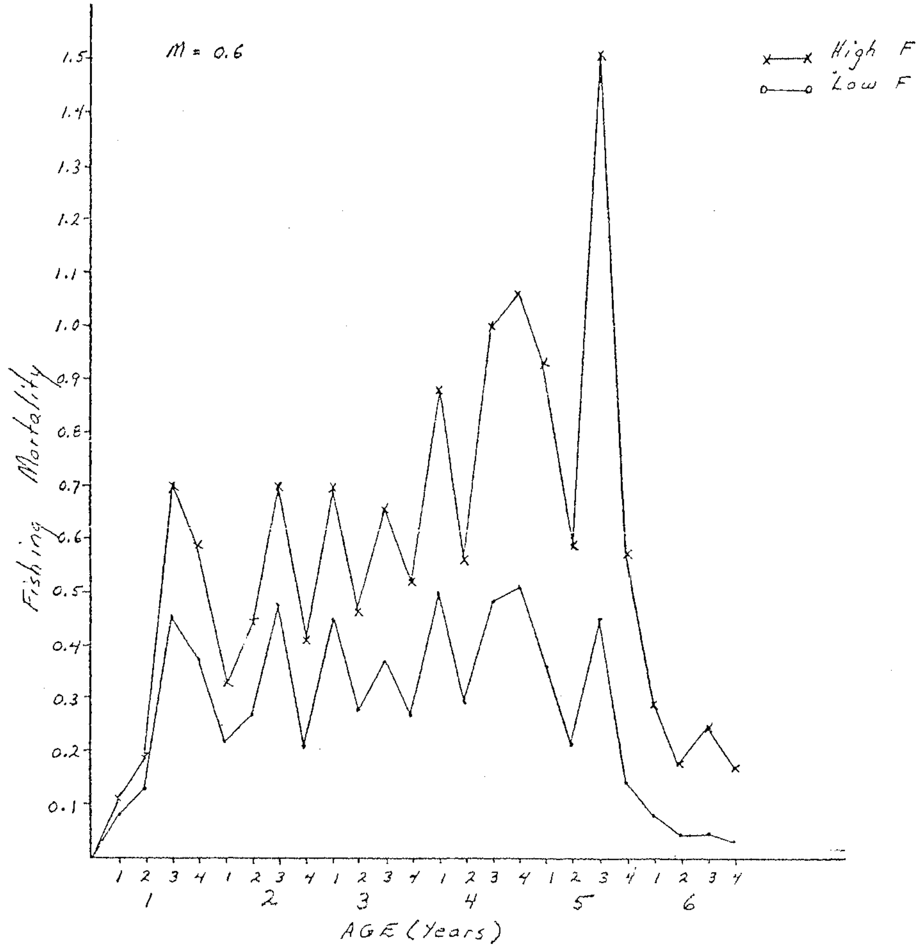


Figure 5b

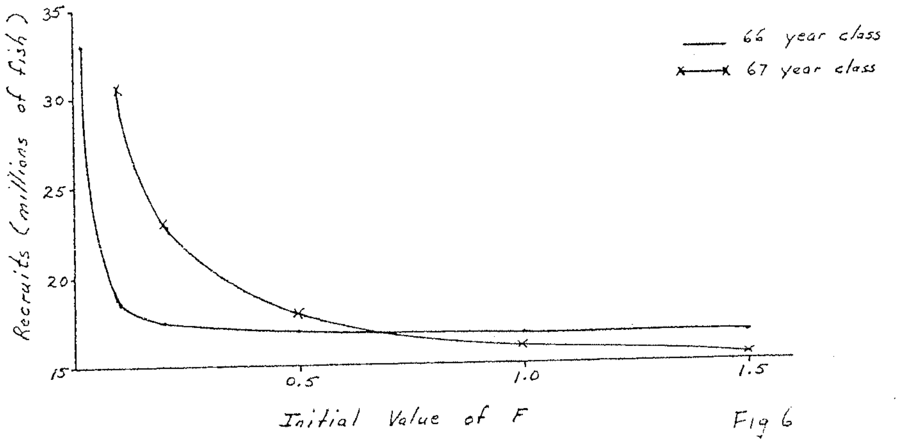


Fig 6

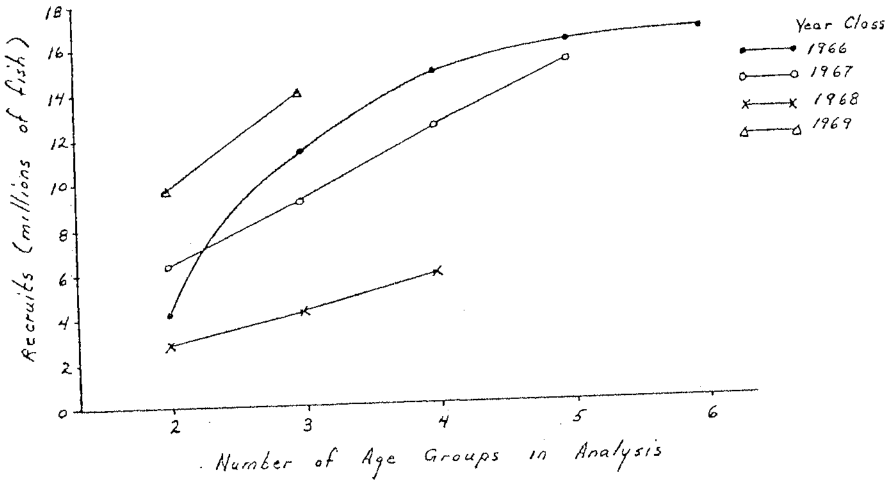


Figure 7

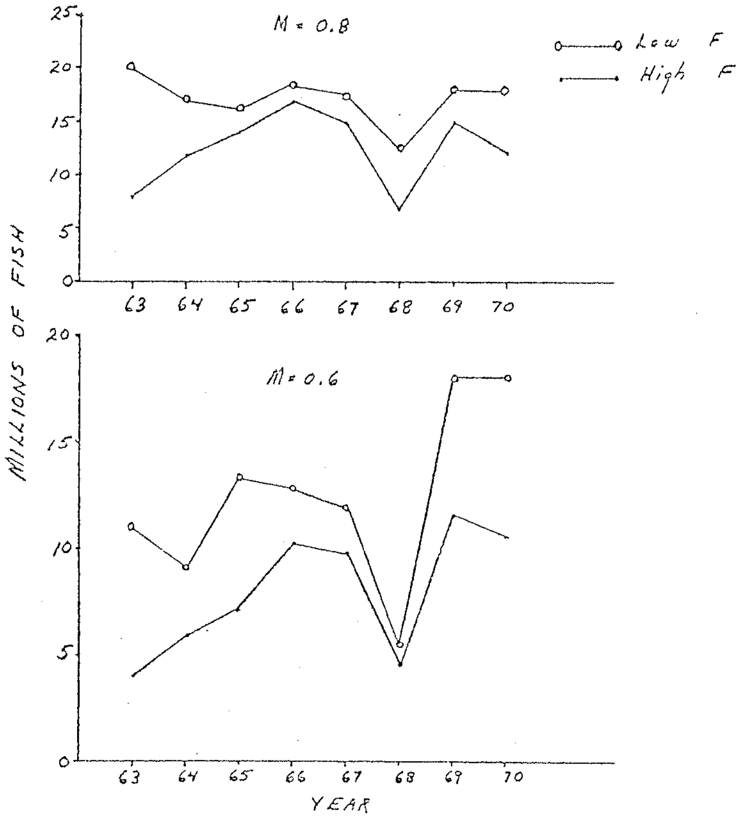


Figure 8

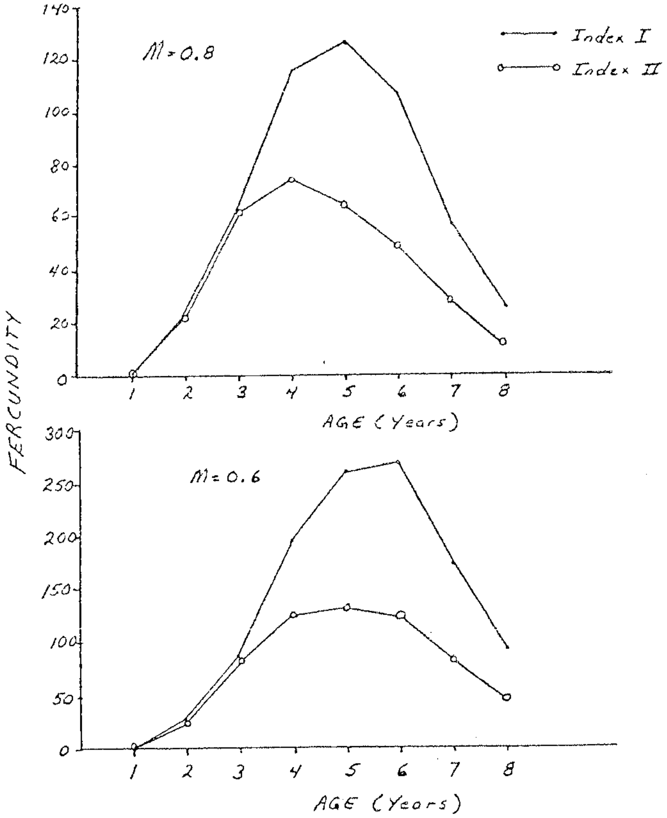


Figure 9

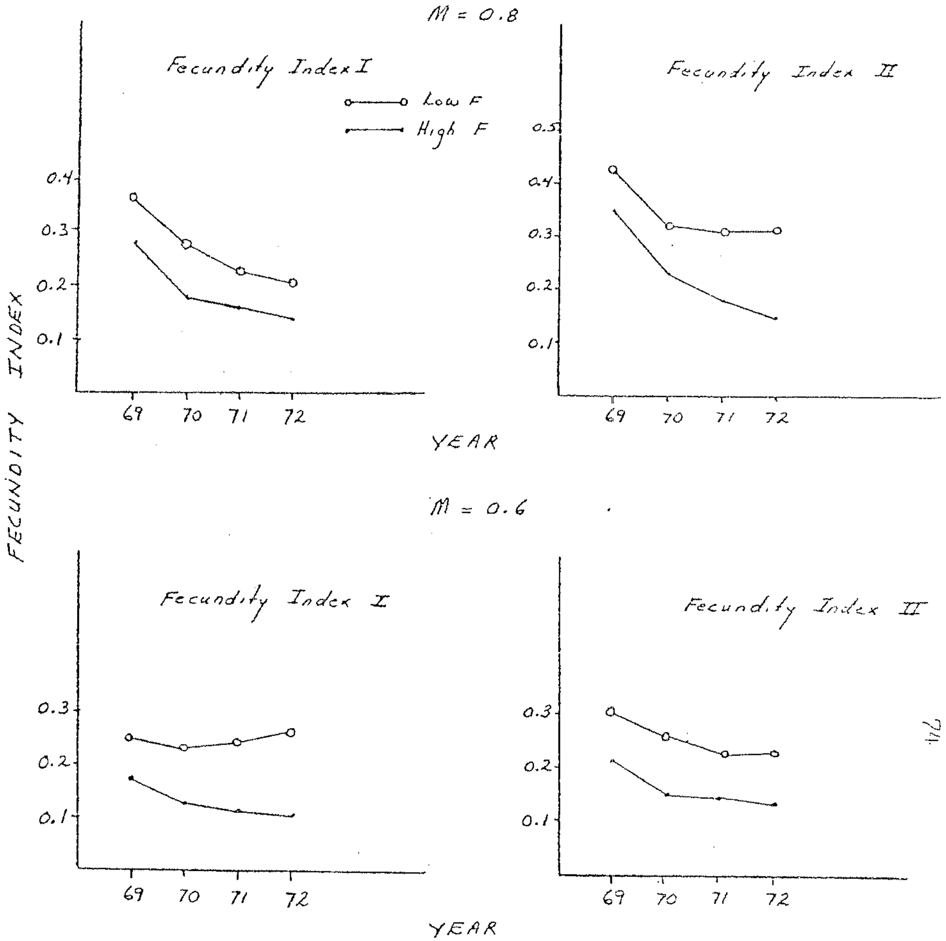


Figure 10

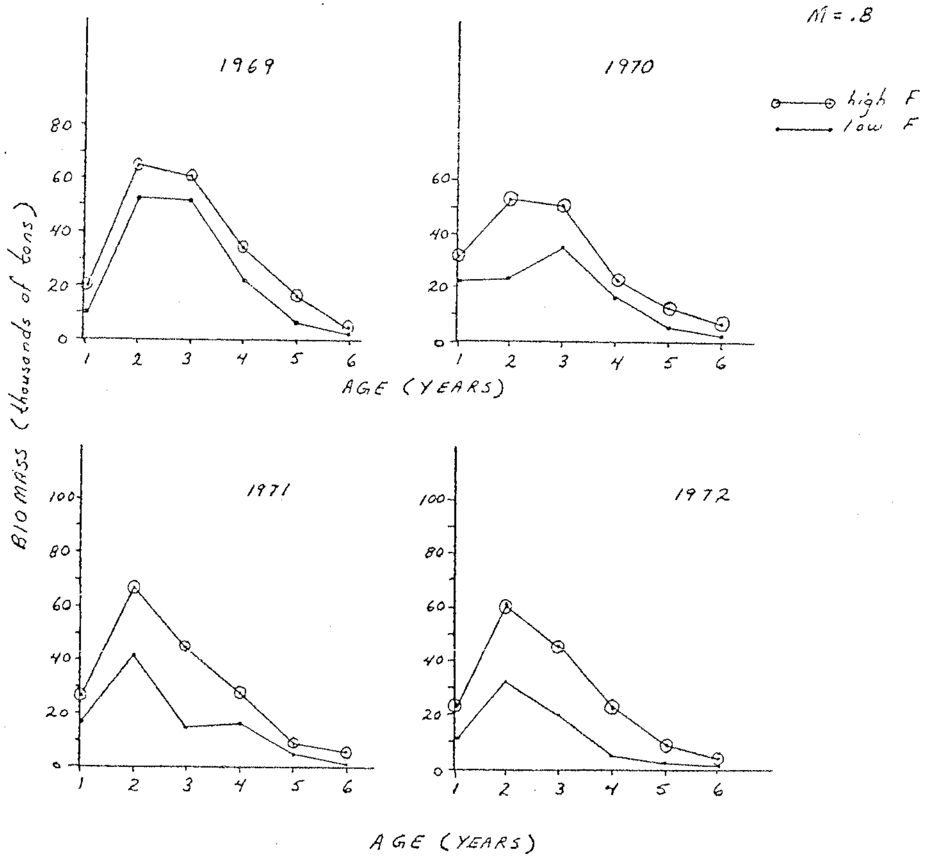


Figure 11

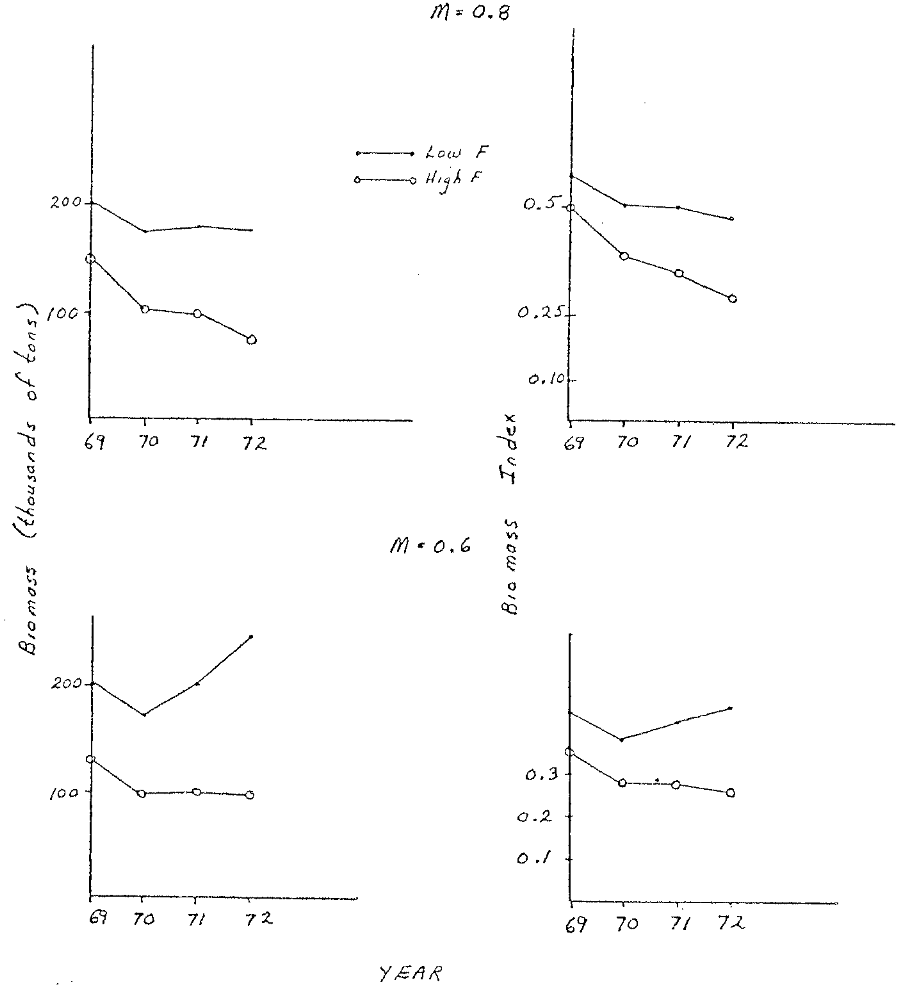


Figure 12

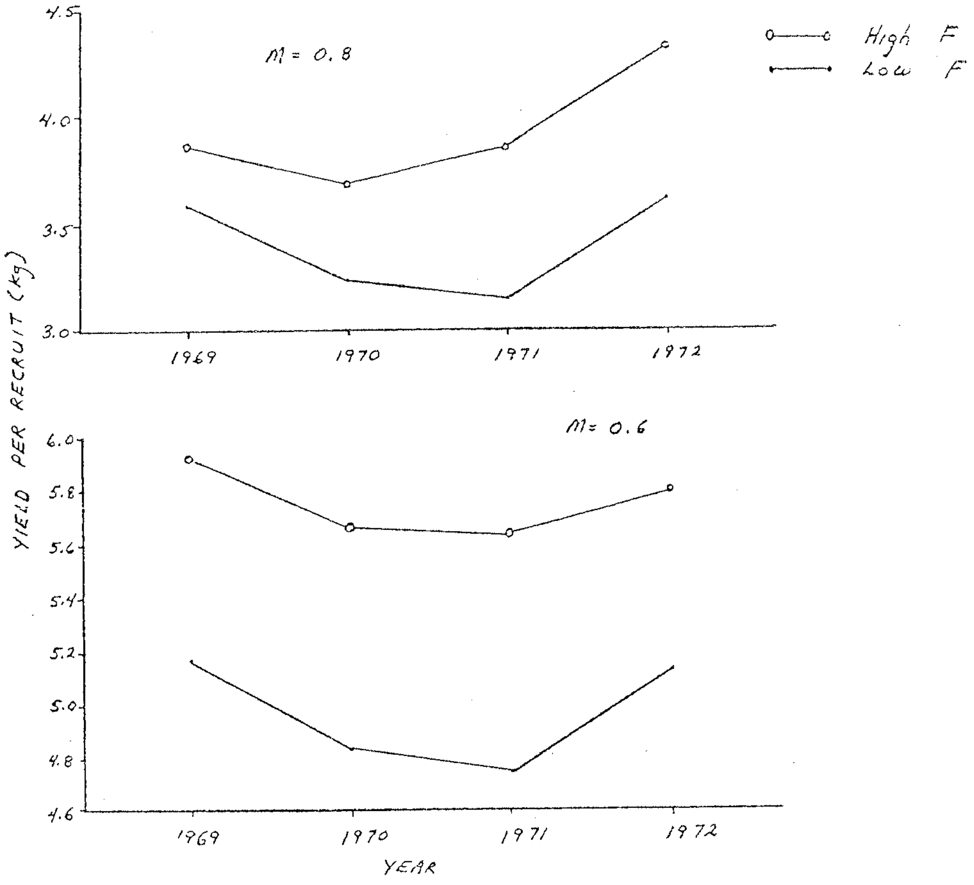


Figure 13

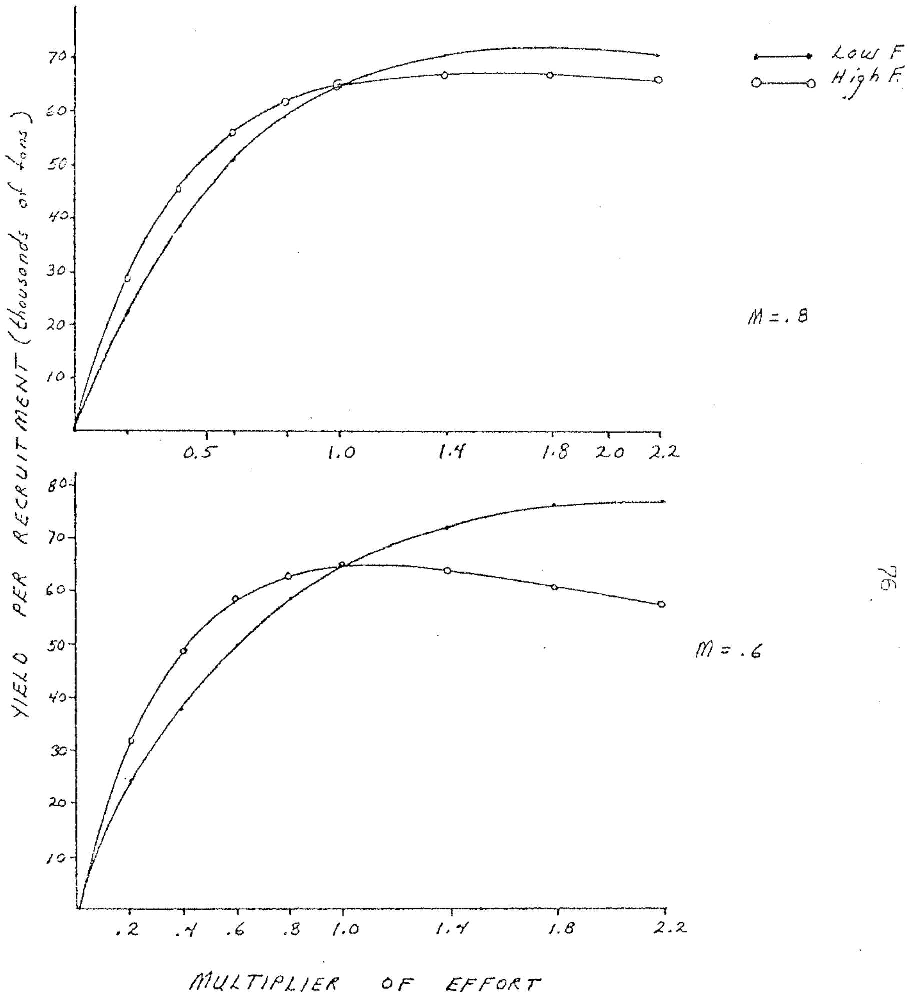


Figure 14

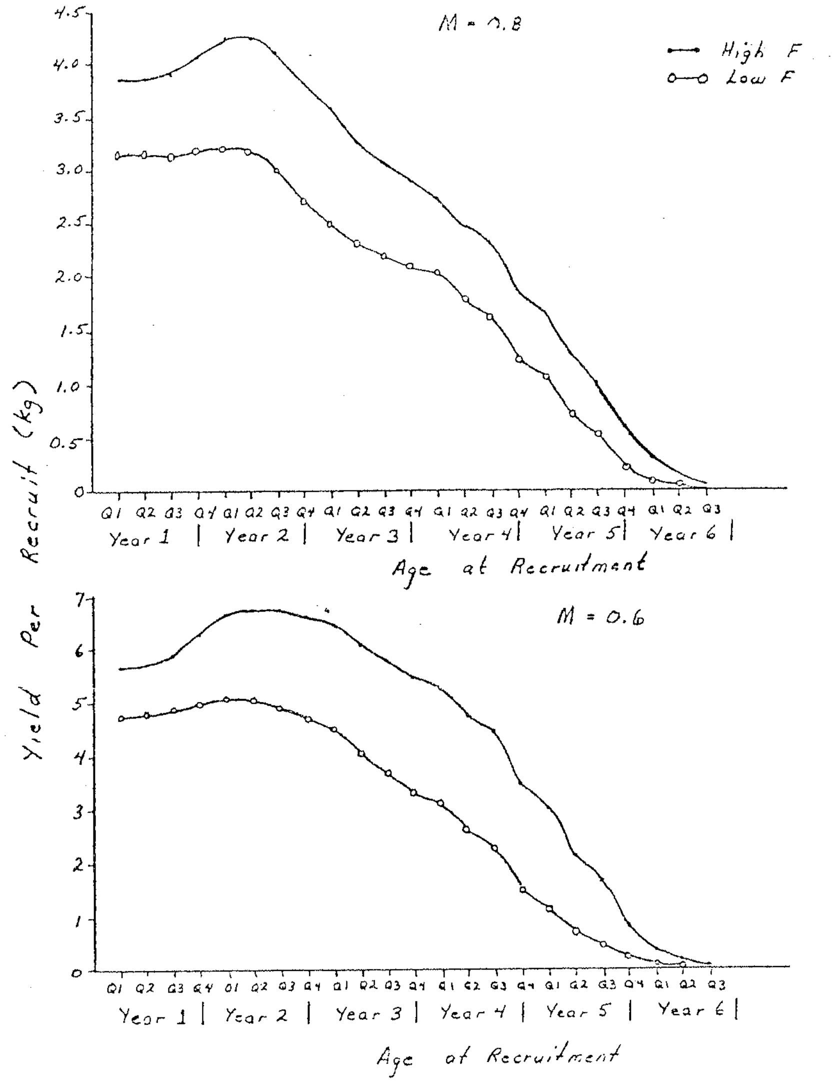

M = 0.8
High F
Low F
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3
Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 |
Age at Recruitment
Yield Per Recruit (kg)
M = 0.6
7
6
5
4
3
2
1
0
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3
Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 |
Age of Recruitment

Figure 15