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Simulating the effect of fishing on squid (*Loligo* and *Illex*) populations off the Northeastern United States

by

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Abstract

Models designed to simulate the effect of fishing on squid (*Loligo* and *Illex*) were developed. The instantaneous growth, fishing and natural mortality rates were varied on a monthly basis. Spawning was simulated over an extended period. Recruitment was described by the Beverton and Holt (1957) stock-recruitment function.

Based on these models, the exploitation rate (over the lifespan of the species) that will result in the maximum sustainable yield (E_{msy}) is 0.75 and 0.63 for *Loligo* and *Illex*, respectively, if recruitment is independent of spawning stock size. If recruitment is moderately dependent on spawning stock size, then E_{msy} is probably about 0.40 and 0.37 for *Loligo* and *Illex*. E_{msy} is further reduced to about 0.15 for both species for a population with a stronger stock-recruitment relationship.

Introduction

Since the late 1960's, the fishery for squid (*Loligo pealei* and *Illex illecebrosus*) in ICNAF Subarea 5 and Statistical Area 6 (SA 5+6) has developed rapidly. In SA 5+6, only herring, mackerel, and silver hake, menhaden and sea scallop (including shell weight) fisheries produced more yield than the squid fishery during 1974. ICNAF established a Total Allowable Catch (TAC) of both species of 71,000 MT for 1974 and 1975 and 74,000 MT for 1976.

Unfortunately, our understanding of the population dynamics of *Loligo* and *Illex* has not kept pace with the growth of the fisheries. Little is known about the natural mortality of either species, particularly about the extent of post spawning mortality. The accuracy of estimates of stock size (Tibbetts, 1975; Efanov and Puzhakov, 1975; Ikeda and Nagasaki, 1975) is unknown. Part of the difficulty in understanding squid stocks results from the lack of a method for determining the age of individuals of either species.

Au (1975) estimated natural mortality based on the life expectancy of each species and applied Beverton and Holt's (1957) yield per recruit equation to both stocks. He also considered the long-term effect of exploitation by incorporating the Beverton and Holt (1957) stock-recruitment equation into his analysis. While this work filled an important gap, the Beverton and Holt constant parameter yield-per-recruit equation does not adequately describe fisheries for *Loligo* and *Illex*. Both fisheries are highly seasonal and thus fishing mortality is not constant through the exploited phase of the life cycle. If there is significant post spawning mortality the assumption of constant natural mortality is not valid. For *Loligo*, weight is not proportional to the cube of length (Tibbetts, 1975; Ikeda and Nagasaki, 1973) as assumed in the Beverton and Holt equation.

Therefore, a model specifically designed to simulate the effect of fishing on squid was developed. It accepts monthly values of the instantaneous growth rate and fishing and natural mortality rates. Spawning mortality is simulated and the long-term effect of fishing is assessed by using the Beverton and Holt (1957) stock-recruitment relationship to calculate the number of recruits in successive generations. The model is run for several hypothetical descriptions of the fisheries allowing consideration of the validity of the conclusions under various assumptions about the system.

In order to describe the seasonal nature of fisheries for *Loligo* and *Illex*, it was necessary to estimate the catch of each species on a monthly basis. This was done for 1974-1975.

Monthly Estimates of Squid Catch by Country and Species

Squid were traditionally landed in ICNAF SA 5+6 as by-catch to other major fisheries, and not reported separately as *Loligo* and *Illex*. In recent years with the development of directed fisheries for squid some countries have reported catches by species, but others have not. Table 1 shows the estimated catch of *Loligo* and *Illex* for 1974 and 1975, using the following criteria to allocate the catch by species applied in the order listed:

1. If reported by species, reported values were used (Japan, Spain and Italy in 1974 and Poland in 1975);
2. If any catch in the squid fishery of a country was sampled (by the country or by international inspection) then the species composition of the sample was applied to all squid landings of the country during the month of the sample;
3. The species composition obtained by 1 or 2 was applied to other vessels operating in a similar area during the month reported or sampled.
4. For catches not covered by 1, 2 or 3, the U.S.A. bottom trawl species composition by area, season and depth zone (<60 fathoms or >60 fathoms) was applied.

Details of how these criteria were applied for each month and country are given in an appendix to this paper. The estimated monthly catches of *Loligo* and *Illex* by the German Democratic Republic (GDR) given in Table 1b conflicts with those reported as provisional landings for 1975. GDR reported 14, 9, 370, 60, 162, 4 and 1 MT of *Loligo* for April, May, June, July, August, November and December of 1975 and 278 MT of *Illex* for August 1975. The accuracy of this preliminary report of the species composition is questionable, since international inspections reported 249 MT of *Illex* and no *Loligo* on a GDR vessel on 27 June 1975.

Method

Let N_1 equal the number of squid from a single cohort that have not yet spawned, N_2 the number that have already spawned, P the cumulative weight that has spawned, YN the cumulative catch in numbers, Y the cumulative catch in weight and w the average weight of an individual at time t. Then

$$\frac{dN_1}{dt} = -\ (F+M+s)\ N_1 \qquad (1)$$

$$\frac{dN_2}{dt} = rsN_1 - (F+M)\ N_2 \qquad (2)$$

$$\frac{dw}{dt} = gw \qquad (3)$$

$$\frac{dYN}{dt} = F(N_1+N_2) \qquad (4)$$

$$\frac{dY}{dt} = Fw(N_1+N_2) \quad (5)$$

$$\frac{dP}{dt} = s\ N_1 \quad (6)$$

where F, M, s and g are the instantaneous fishing mortality, natural mortality, spawning and growth rates and r is the proportion surviving spawning. The solution of each equation is given below:

$$N_1 = N_{10}\ e^{-(F+M+s)t} \quad (7)$$

$$N_2 = (N_{10} + N_{20})e^{-(F+M)t} - N_{10}e^{-(F+M+rs)t} \quad (8)$$

$$w = wo\ e^{gt} \quad (9)$$

$$YN = \frac{FN_{10}}{F+M+s}(1-e^{-(F+M+s)t}) + \frac{F}{F+M}(N_{10} + N_{20})(1-e^{-(F+M)t}) - \frac{FN_{10}}{F+M+rs}(1-e^{-(F+M+rs)t}) \quad (10)$$

$$Y = \frac{FN_{10}\ wo}{F+M+s-g}(1-e^{-(F+M+s-g)t}) + \frac{Fwo}{F+M-g}(N_{10} + N_{20})(1-e^{-(F+M-g)t}) - \frac{FN_{10}\ wo}{F+M+rs-g}(1-e^{-(F+M+rs-g)t}) \quad (11)$$

$$P = \frac{s\ wo N_{10}}{M+F+s-g}(1-e^{-(M+F+s-g)t}) \quad (12)$$

N_{10}, N_{20}, and wo are initial conditions. Following Au (1975), the relationship between stock and recruitment is assumed to be according to Beverton and Holt (1957):

$$R = \frac{P'}{1 + A\ (P'-1)} \quad (13)$$

R is the size of a cohort when it enters the exploited phase of its life cycle relative to the number of recruits to the unexploited fishery. P' is the weight that spawn relative to weight spawning in the virgin fishery. A is a parameter ranging from 0 to 1. For A=1.0, recruitment is independent of spawning stock and for A=0, recruitment is linearly related to spawning stock. For a graphic representation of Equation (13) at several levels of A, the reader is referred to Au (1975).

Let t=0 at the time (in months) when the stock first becomes vulnerable to fishing. Vulnerability may result from migration onto the fishing ground and/or from growth to the minimum size retained by the fishing gear. The number of individuals at t=0 was assumed to be 1000 for the virgin stock. Equations (7)-(12) were then applied to the stock on a monthly basis (assuming F, M, s and g constant within months) through the hypothetical lifespan of the species. Recruitment to the next generation relative to the 1000 individuals assumed for the virgin stock, is then calculated by Equation (13) and the survival and spawning of this cohort is simulated. Each generation of the stock was simulated until the recruitment to successive generations differed by less than 1%. The yield from the last generations simulated is assumed to approximate the equilibrium yield per 1000 individuals recruited to the virgin stock for a specific exploitation rate (proportion of recruits eventually captured, E). This procedure was repeated for each species and several combinations of hypothetical representations of growth, mortality and spawning on a monthly basis. The equilibrium yield and the average weight of the catch is determined for several levels of exploitation rate.

Hypothetical Representation of Fisheries

Loligo

A lifespan of approximately 2 years was assumed for *Loligo*. Some may survive for 3 years, but a lifespan of 2 years is more frequent (Summers, 1971). Monthly values of g, and several sets of values of s and F_r (fishing mortality relative to the highest monthly value) are given in Table 2. For each set of values of s, a single constant value of r and M is also given.

Values of g are based on bimonthly average lengths of *Loligo* (of a July brood) reported by Summers (1971) and the length-weight equation reported by Ikeda and Nagasaki (1975). The instantaneous growth rate is calculated by taking the natural log of the ratio of weight at successive points in time. An initial weight of 22.6 g corresponding to a length of 8.5 cm is assumed for December 1, which is about the size at recruitment (Au, 1975).

Reduced landings of *Loligo* during the warmer months (Table 1) probably reflects a decrease in vulnerability (except to the inshore U.S.A. fishermen) and in fishing mortality. Therefore, fishing mortality is assumed to be primarily concentrated during December-April. For 1974-1975, 77% of the estimated catch of *Loligo* was during December-April and 90% during November-May. Three sets of values of monthly relative fishing mortality were considered. These were based on trends in the commercial catch. Various levels of E are generated by multiplying each value of F_r by a constant. Set 1 of F_r assumes all fishing mortality during December-April, while sets 2 and 3 assume substantial F during November and May and some throughout the year.

There is evidence of an extended summer spawning period for *Loligo* (Summer, 1971 and Tibbetts, 1975). Spawning was assumed to occur during May-September, although the results are not sensitive to this assumption since there is little question that spawning occurs during a period of reduced fishing mortality. The instantaneous monthly spawning rates were established such that the ratio of N_1 to N_2 at the end of May, June, July and August would be 20%, 40%, 60% and 80% (respectively) of the ratio at the end of the spawning season if r = 1. The result is that the number spawning in each month is nearly uniform. It is not known if *Loligo* spawn more than once. For set 1 of s, all individuals are assumed to survive spawning and are assumed to spawn each season. Thus for this set of s, some *Loligo* spawn more than once. Tibbetts (1975) noted that in some years, the number reaching the second spawning season of their life may be 25% of the number at the first spawning season. Therefore M was selected so that the annual survival rate for the unexploited stock would be 20%. The stock represented by N_2 is transferred to N_1 during the winter following the first spawning season to permit simulation of a second spawning season. All individuals are assumed to have perished by the end of the second spawning season.

For set 2 of s, all non-fishing mortality is assumed to result from spawning (M = 0.0, r = 0.0). Values of s are selected so that the number spawning during the second spawning season will be 20% of the number spawning during the first spawning season for the unexploited fishery. Set 3 of s represents a compromise between set 1 and set 2. Here, M = 0.05, r = 0.0 and monthly values of s are again set so the ratio of second season to first season spawners is 20%. Since r = 0.0 for set 2 and 3 of s, for these cases, *Loligo* are assumed to spawn only once.

Illex

According to Squire (1967), spawning and subsequent mortality (r=0) of *Illex* most probably occurs at about 1 year of age. Spawning is believed to occur at great depth during winter although ripe individuals have been captured on Georges Bank during this time of year (Tibbetts, 1975). The growth equation of Efanov and Puzhakov (1975) and Mercer's (1973) length-weight equations (averaged for both sexes) were used to calculate monthly values of g in a similar manner as was described for *Loligo*. An initial length of 7.8 cm (6.5 g) was assumed for t=0. Monthly values of g, s and F_r and constant values of M are reported in Table 3. Efanov and Puzhakov estimated M = 0.1 (actually 0.6 for 6 months) and M=0 and .2 were considered here to indicate the sensitivity of the results to M. Values of s were set so that the number spawning during each month of the hypothetical spawning season would be nearly uniform for a low mortality rate. Two sets of values of F_r were again selected to parallel monthly estimates of the nominal catch of *Illex* for 1974-1975 (Table 1).

Results

The simulated equilibrium yield of *Loligo* in weight per 1000 individuals recruited to the virgin fishery (Y) is plotted (Figure 1-3) against exploitation rate over the lifespan of the species (E) for M=0.13, 0.0 and 0.05 (and corresponding sets of s) A=1.0, 0.8 and 0.4 and set 2 of the monthly values of F_r. The results are quite similar for sets 1 and 3 of F_r. The maximum equilibrium yield in weight per 1000 individuals recruited to the virgin fishery (Y_{max}) for each combination of F_r, M and A are given in Tables 4-6 along with the corresponding yield in numbers (YN), exploitation rate (E_{msy}) and average weight of individuals in the catch (W_{msy}).

For *Illex*, the simulated equilibrium yield in weight per 1000 individuals recruited to the virgin fishery is plotted against exploitation rate (Figures 4-6) for M = 0.0, 0.1, 0.2; A = 1.0, 0.8, 0.4 and set 2 of F_r. The results are similar for set 1 of F_r although the yield curves are somewhat lower than those plotted in Figures 4-6. The maximum equilibrium yield in weight per 1000 individuals recruited to the virgin fishery for each combination of A, F_r and M with corresponding values of YN, E_{msy} and W_{msy} are given in Table 7.

Discussion

Loligo

Of the factors considered (over the range of values considered) the maximum equilibrium yield of the fishery for *Loligo* per 1000 virgin recruits appears to be most sensitive to A, then to M (and corresponding sets of s and values of r) and finally to the sets of monthly values of F_r. If A=1.0, Y_{max} is probably about 38 kg (E_{msy} = 0.74, W_{msy} = 51.5g). Y_{max} as low as 32 kg where M = 0.13 (no spawning mortality) or as high as 44 kg where M=0.0 (only spawning mortality) seems less likely.

Au (1975) argued that recruitment can be expected to be strongly dependent on spawning stock size for squid since because of their short lifespan there is little competition between generations. If this is the case, Y_{max} should be considerably less than when A=1.0. For A=0.4, Y_{max} is probably about 8 kg (E_{msy} = 0.15, W_{msy} = 72.4g) while for a more moderate degree of density dependence (A=0.8) Y_{max} is probably about 22 kg (E_{msy} = .40, W_{msy} = 84.6). The level of E yielding Y_{max} is considerably higher than was reported by Au (1975), but E_{msy} is more sensitive to A than Au's results indicated.

Tibbetts (1975) estimated the biomass of *Loligo* in SA 5Z+6 for 1967-1974 by areal expansion based on the U.S.A. autumn bottom trawl survey. The catch per tow for night samples was adjusted upward to correspond to day samples when the gear is more effective at catching squid and all tows were adjusted upward to correspond to a more efficient trawl. These estimates were recalculated for SA 5+6 (1968-1975) with updated day-night and trawl conversion factors. An estimate of stock size in numbers was obtained by dividing by mean weight (Table 8). The mean weight per individual in the survey catch indicates the age composition of the stock. For *Loligo* growth as described by Summers (1971) using Ikeda and Nagasaki's (1973) length-weight equation, at least 90% of the stock would be young of the year for a mean weight per individuals in the survey catch less than 40 g. Since stock size estimates based on the areal expansion method usually underestimate the true stock size, an annual recruitment of at least 1.5 billion *Loligo* for SA 5+6 seem likely. If recruitment were independent of spawning stock size (A=1.0), then a catch of at least 56,800 MT ($1.5X10^9 \cdot 0.74 \cdot 51.5X10^{-6}$ MT for M=0.05, set 2 of F_r) appears possible. It seems more likely that there is some relationship between recruitment and spawning stock size; therefore a catch of 43,400 MT ($1.5X10^9 \cdot 0.40 \cdot 72.4X10^{-6}$ MT for M=0.05, set 2 of F_r and A=0.8) may be more rational. This is approximately the 1976 TAC. If recruitment is strongly dependent on spawning stock size then a catch exceeding 19,000 MT ($1.5X10^9 \cdot 0.15 \cdot 84.6X10^{-6}$ MT for M=0.05, set 2 of F_r and A=0.4) may be dangerous. The simulated equilibrium recruitment relative to the virgin stock at E_{msy} (R_{EQ}) is given in Table 9. Recruitment and catch should (theoretically) decline by 28 and 39% for A=0.8 and 0.4 (respectively) at E_{msy}.

Since it is difficult to estimate recruitment or exploitation rate for a squid population, it might be useful to assess the appropriateness of the recent level of catch by comparing the mean weight of individuals in the catch to the mean weight of the simulated catch reported in Tables 4-6. For A=1.0, a mean weight of the catch (W) of about 50 g (at most 60 g) seems appropriate. If A=0.8, W should be from 65 to 78 g while for A=0.4 W should be from 75 to 88 g. Graphs relating the mean weight of the catch to E (set 2 of F_r, M=0.05 for *Loligo* and set 2 of F_r, M=0.1 for *Illex*) are given in Figure 7.

Ikeda and Nagasaki (1975) estimated the mean weight per individual of the *Loligo* catch for the 1968-1969 to 1973-1974 seasons as 71, 70, 65, 77, 59, and 68 g, respectively. Japan has produced a larger catch of *Loligo* than any other country in recent years and in many years has produced more than 50% of the entire catch (Tibbetts, 1975), Therefore these estimates should be representative of the mean weight in the total catch. Since at least one length-frequency sample from the commercial catch was reported to ICNAF for SA 5+6 *Loligo* for each month during 1974 it was possible to crudely estimate the mean weight of the catch for that year. Using a length-weight equation (Ikeda and Nagasaki, 1973), the mean weight per individual of each sample was calculated and the overall mean weight for 1974 was calculated as 89 g based on these samples and the estimated catch of *Loligo* during each month (Table 1). The difference between this estimate and those reported by Ikeda and Nagasaki may in part reflect the fact that the Japanese catch during summer months (when the mean weight of individuals in the *Loligo* population is higher) is a smaller proportion of the total monthly catch than during winter months. The difference may also result from sampling error.

Based on the above discussion, it appears that the mean weight of *Loligo* in the catch during recent years was greater than 60 g. Thus, according to Figure 7 for a population where recruitment is independent of spawning stock size, E could be increased, but if recruitment is moderately dependent on spawning stock size (A=0.8), the exploitation rate during some recent years may have been too high. If the mean weight of the catch during 1974 were in fact greater than 85 g, then the rate of exploitation during 1974 would be below E_{msy} for even a population where recruitment is strongly dependent on spawning stock.

Illex

As for *Loligo*, the equilibrium yield per 1000 recruits to the virgin *Illex* fishery is less sensitive to the sets of F_r considered, than to M or A. Y is plotted against E for combinations of A and M and for set 2 of F_r. The maximum equilibrium yield per 1000 recruits to the virgin fishery for all combinations of F_r, A and M with the corresponding value of E_{msy}, YN and W_{msy} are reported in Table 7.

Unlike *Loligo*, Y_{max} for *Illex* is quite sensitive to M. Y_{max} at M=0.0 is from 2 to 3 times as large as for M=0.2. If only Efanov and Puzhakov's (1975) estimate of natural mortality (M=0.1) is considered and some catch is assumed during all months (set 2 of F_r), then Y_{max} = 45 kg (E_{msy} = .63, W_{msy} = 72 g) for A=1.0, Y_{max}= 25 kg (E_{msy} = .37, W_{msy} = 90 g) for A=0.8 and Y_{max} = 9 kg (E_{msy} = .15, W_{msy} = 100 g) for A=0.4.

Based on a 1971 cruise of the RV *ARGUS*, Efanov and Puzhakov (1975) estimated the minimum biomass of *Illex* on the Southern Nova Scotia shelf and Georges Bank as 110,000 MT. Since this cruise occurred during June (Noskov and Richter, 1972) the estimate of biomass was divided by the approximate mean weight of *Illex* for that month (reported by Efanov and Puzhakov for 1974 as about 88 g) to obtain a stock size estimate of 1.25 billion individuals. Since some mortality must occur prior to June, the number of recruits may substantially exceed this value. Therefore if recruitment is insensitive to spawning stock size, a yield of at least 56,700 MT ($1.25X10^9 \cdot 0.63 \cdot 72X10^{-6}$ MT) should be possible. Since recruitment is probably at least somewhat sensitive to spawning stock size, a catch of 41,630 MT ($1.25X10^9 \cdot 0.37 \cdot 90X10^{-6}$ MT) would be prudent unless there is reason to believe the stock exceeded 1.25 billion. If recruitment is strongly dependent on spawning stock size, a catch of 19,000 MT ($1.25X10^9 \cdot 0.15 \cdot 100X10^{-6}$ MT) would be proper. Recruitment and catch should (theoretically) decline by 26 and 39% for A=0.8 and 0.4 at E_{msy} (Table 9). Since Efanov and Puzhakov's stock size estimate includes parts of SA 4+5, the proper level of catch for SA 5+6 cannot be ascertained directly from the above discussion. According to Noskov and Rikhter (1972, their Figure 8) substantial numbers of *Illex* were taken in SA 5+6 other than on Georges Bank. From this data it should be possible to estimate minimum stock size within several areas separately.

The mean weight of individuals in the *Illex* catch was estimated (in the same manner as for *Loligo*) as 85 g during 1974. According to Figure 7 and this estimate of mean weight, E was about 20% above E_{msy} for A=0.8 where some *Illex* are taken during all months (set 2 of F_r) and M=0.1. If our estimate of the mean weight of the catch is realistic, then the rate of exploitation (and level of catch) in recent years may be too high for a stock with a moderately strong stock-recruitment relationship (A=0.8).

Conclusion

Two major obstacles to more rational management of squid in SA 5+6 are the lack of knowledge about the number of individuals recruited annually and about the nature of stock-recruitment relationships. In the absence of data adequate to determine the stock-recruitment relationships, it is prudent to assume that recruitment is at least moderately dependent on spawning stock (perhaps A=0.8) and manage accordingly. Where only a minimum estimate of annual recruitment is available, catch should only gradually be permitted to exceed the level indicated by applying E_{msy} and W_{msy} to that estimate.

The possibility of using the mean weight of the catch as a criterion for judging the approrlateness of a particular level of exploitation (based on Figure 7) is appealing although this approach may be premature considering the uncertainty of available estimates of growth and mean weight. Typically, growth and mean weight of the catch are among the easiest fisheries parameters to estimate.

Based on an annual recruitment of 1.5 billion *Loligo* to SA 5+6, a catch of about 44,000 MT (which is the 1976 TAC) would be reasonable for A=0.8, although according to stock size estimates from the U.S.A. autumn bottom trawl survey a higher catch may be possible during some years. Since exploiting the stock at a rate above E_{msy} will have a long term detrimental effect on the fishery, while exploiting at below E_{msy} only results in a lower catch than is possible during the years when E is too low, it is prudent to restrict the catch so that E will seldom exceed E_{msy}. The mean weight per individual of the catch estimated from 1974 length frequency samples indicates that E (and the catch) during that year could have been increased for even a population with a strong stock-recruitment relationship (A=0.4), but the mean weight per *Loligo* of the Japanese catch during recent fishing seasons indicates that for some years E may have been too high for A=0.8. A catch of 42,000 MT of *Illex* from Southern Nova Scotia and Georges Bank (for A=0.8) is indicated by Efanov and Puzhakov's (1975) estimate of stock size. A very crude estimate of the mean weight of the catch in SA 5+6 indicates that the exploitation rate (which produced an estimated catch of 20,500 MT) during that year was about 20% too high for A=0.8. The 1974 catch was below the 1976 TAC.

If it is assumed that A=0.8, recruitment should gradually decline even at E_{msy} (Table 9). Therefore the catch (and TAC), in theory, must also decline in order to maintain the proper exploitation rate. If the relative abundance of the stock is reduced by more than is expected (about 28% and 26% for *Loligo* and *Illex*, respectively, for A=0.8) as a result of fishing, then E should be reduced since this would indicate that A is smaller than was assumed. If relative abundance remains constant or increases, then E should be increased since this would indicate that A is larger than was assumed or that annual recruitment is higher than was estimated. Unfortunately, changes in relative abundance of the magnitude expected as a result of fishing at E_{msy} probably cannot be distinguished from natural fluctuations or sampling error. Therefore the philosophy described above could only be applied on a long term basis.

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Table 1.a. Estimated monthly nominal catch of *Loligo* and *Illex* in SA 5+6 by country for 1974. The total catch of both species for each month and country equals the catch reported to ICNAF (1975a and 1975b) as squid (nonspecified), *Loligo* and *Illex*. For those countries reporting their catch by species (Japan, Italy and Spain), the report values are used directly in this table. When catch was reported as squid (nonspecified) the species composition was estimated as described in the appendix.

							1974						
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Loligo													
Bulg		56	74	126	23	8	1					12	300
Can	27												27
Ita	700	800	1000								450	330	3280
Jap	2393	701	2083	546	200	46	56	168	246	455	2810	3789	13493
Pol			10		197					126	521	800	1653
Spa	3657	2250	1410	588	424	433	329	160	99	21			9371
USSR	146		908	1027	105	115	96	72	712	673	479	267	4485
USA	137	67	58	328	533	278	139	95	105	141	128	130	2141
Total	7060	3874	5543	2615	1482	880	621	495	1162	1416	4388	5328	34750
Illex													
Bulg		12	8	164	60	13	35					1	293
Ita	250	200	250								180	100	980
Jap	1		111	368	390	160	320	258	924	250	105	430	3314
Pol			79	2544	1596	628	87			68	22	28	5052
Rom		1		1	2	4	1						9
Spa	229	398	972	1397	938	1243	937	581	64	10			6769
USSR	8		48	54	942	1032	862	653	126	119	84	17	3945
USA						32	14	15	29	36	21	1	148
Total	488	607	1468	4528	3928	3112	2256	1507	1143	483	412	577	20510

Table 1.b. Estimated monthly nominal catch of *Loligo* and *Illex* in SA 5+6 by country for 1975. The total catch of both species for each month and country equals the catch reported as squid (nonspecified), *Loligo* and *Illex* in 30-day submissions of provisional catch statistics or as provisional catch reported on form IC-01 (for U.S.A. and Poland). This table only reflects 30-day submissions or provisional catch statistics received in Woods Hole prior to March 15, 1976. For countries reporting their catch by species (Poland), the reported values are used directly in this table. When catch was reported as squid (nonspecified) the species composition was estimated as described in the appendix.

	1975												
	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Loligo													
Bulg				29	24	25							78
FRG												2	2
GDR				12	3						3	1	19
Ita	680	710	620	158		390			17	203	380	432	3598
Jap	3053	689	790	1033						27	947	3381	9920
Pol	940	756	179	122	23		3	147	9	3	417	1191	3785
Spa	914	2502	1880	973		595			22				6886
USSR	415		593	2983	258				24	14		8	4295
USA	86	113	134	109	314	136	75	11	62	125	238	190	1593
Total	10858		4196	5419	622	1146	78	158	134	372	1980	5205	30176
Illex													
Bulg		15	6	4	48	47							120
FRG										20			20
GDR				2	6	387	60	440			1		896
Ita				36			6		89	109	205	38	483
Jap	31	177	86	8	45			4	9	14	510	294	1178
Pol				40	1032	1524	416	37	2				3051
Rom								8					8
Spa	45	117	84	108			852	306	106				1618
USSR		131	6	124	774	300	1418	832	118	2	1		3706
USA						20	7	69	5	3	3		107
Total		516	182	322	1905	2278	2759	1696	329	148	720	332	11187

Table 2. Hypothetical monthly values of the instantaneous growth rate (g), relative fishing mortality rate (F_r), and spawning rate(s) with associated constant values of natural mortality rate (M) and the proportions surviving spawning (r).

Month	F_r			s			g
Set :	1	2	3	1	2	3	
Dec	1.	.8	.9	0	0	0	.38
Jan	1.	1.	1.	0	0	0	.21
Feb	1.	1.	1.	0	0	0	.21
Mar	1.	1.	1.	0	0	0	.22
Apr	1.	.8	.9	0	0	0	.22
May	0	.4	.6	.22	.17	.13	.18
Jun	0	.1	.2	.29	.21	.16	.18
Jul	0	.1	.2	.41	.27	.19	.16
Aug	0	.1	.2	.69	.37	.23	.16
Sep	0	.1	.2	∞	.59	.29	.11
Oct	0	.1	.2	0	0	0	.11
Nov	0	.4	.6	0	0	0	.08
Dec	1.	.8	.9	0	0	0	.08
Jan	1.	1.	1.	0	0	0	.12
Feb	1.	1.	1.	0	0	0	.12
Mar	1.	1.	1.	0	0	0	.09
Apr	1.	.8	.9	0	0	0	.09
May	0	.4	.6	.22	.22	.22	.08
Jun	0	.1	.2	.29	.29	.29	.08
Jul	0	.1	.2	.41	.41	.41	.08
Aug	0	.1	.2	.69	.69	.69	.07
Sep	0	.1	.2	∞	∞	∞	.07
M				.13	0	.05	
r				1.0	0	0	

Table 3. Hypothetical monthly values of the instantaneous growth rate (g), relative fishing mortality rate (F_r) and spawning rate (s) and constant (over lifespan) values of instantaneous natural mortality rate (M) and the proportion surviving spawning (r) for *Illex*.

Month	F_r		s	g
Set :	1	2		
Apr	.3	.3	0	1.17
May	1.	1.	0	.78
Jun	1.	1.	0	.55
Jul	1.	1.	0	.41
Aug	1.	1.	0	.32
Sep	.3	.6	0	.25
Oct	0	.2	0	.22
Nov	0	.2	0	.17
Dec	0	.2	0	.14
Jan	0	.2	.41	.13
Feb	0	.2	.69	.10
Mar	0	.2	∞	.08
		M		r
Set :	1	2	3	
Constant	0	.1	.2	0

Table 4. Maximum equilibrium values of Y and corresponding values A, E_{msy}, YN, and W_{msy} for set 1 of s (M = .13, r = 1.0) for *Loligo*.

F_r	A	E_{msy}	YN	Y(kg)	W_{msy}(g)
Set 1	1	.65	645.3	31.0	48.0
	.8	.34	256.8	17.1	66.7
	.4	.16	84.6	6.4	75.5
Set 2	1	.64	639.3	32.3	50.6
	.8	.34	251.4	18.2	72.3
	.4	.13	81.9	6.9	85.1
Set 3	1	.66	661.1	32.8	49.6
	.8	.36	254.8	18.7	73.5
	.4	.14	81.9	7.3	88.6

Table 5. Maximum equilibrium values of Y and corresponding values of A, E_{msy}, YN, and W_{msy} for set 2 of s (M = 0.0, r = 0.0) for *Loligo*.

F_r	A	E_{msy}	YN	Y(kg)	W_{msy}(g)
Set 1	1	.81	811.5	40.6	50.1
	.8	.44	335.1	23.1	68.8
	.4	.21	110.5	8.6	77.6
Set 2	1	.82	820.0	43.0	52.5
	.8	.45	331.5	24.4	73.5
	.4	.17	107.0	9.2	85.8
Set 3	1	.72	725.2	43.9	60.5
	.8	.42	322.0	25.1	78.1
	.4	.19	107.5	9.5	88.6

Table 6. Maximum equilibrium values of Y and corresponding values of A, E_{msy}, YN, and W_{msy} for set 3 of s (M = .05, r = 0.0) for *Loligo*.

F_r	A	E_{msy}	YN	Y(kg)	W_{msy}(g)
Set 1	1	.74	740.1	36.4	49.2
	.8	.39	290.9	19.7	67.8
	.4	.14	93.6	7.3	78.1
Set 2	1	.74	740.9	38.1	51.5
	.8	.40	286.7	20.7	72.4
	.4	.15	91.4	7.7	84.6
Set 3	1	.77	765.5	38.7	50.5
	.8	.37	275.4	21.1	76.8
	.4	.17	90.6	7.9	87.3

Table 7. Maximum equilibrium values of Y and corresponding values of A, E_{msy}, YN, and W_{msy} for each set of F_r for *Illex*.

M	F_r	A	E_{msy}	YN	Y(kg)	W_{msy}(g)
0.1	Set 1	1.0	.68	674.5	37.1	55.0
		.8	.38	292.7	20.1	68.6
		.4	.18	100.03	7.4	74.1
	Set 2	1.0	.63	626.6	45.0	71.8
		.8	.37	275.5	24.7	89.7
		.4	.15	91.3	9.1	99.9
0.0	Set 1	1.0	.84	841.2	50.9	60.5
		.8	.50	380.6	28.6	75.2
		.4	.24	132.2	10.7	81.0
	Set 2	1.0	.82	822.2	69.8	84.9
		.8	.51	380.5	40.7	107.1
		.4	.21	129.7	15.5	119.3
0.2	Set 1	1.0	.60	604.7	27.9	46.1
		.8	.34	235.1	14.4	61.1
		.4	.14	77.2	5.2	67.6
	Set 2	1.0	.56	564.	31.2	55.3
		.8	.28	207.4	15.8	76.4
		.4	.11	67.1	5.7	84.8

Table 8. Stock size estimates by areal expansion of *Loligo* in SA 5 and 6 for the autumn of each year. The mean weight of individuals in the catch is also given.

Year	Biomass (tons)	*Loligo* Number (10^6)	Weight (g)
1968	72700	1800	40.4
1969	57400	1400	41.0
1970	35400	1000	35.4
1971	22100	1200	18.5
1972	29500	1200	24.6
1973	77500	2700	28.7
1974	72300	2400	30.1
1975	97300	5600	17.4

Table 9. Equilibrium recruitment at E_{msy} as a percent of recruitment to the virgin fishery (R_{EQ}) for A=1.0, 0.8 and 0.4 and M=0.05 and set 2 of F_r for *Loligo* and M=0.1 and set 2 of F_r for *Illex*.

A	*Loligo* E_{msy}	*Loligo* R_{EQ}	*Illex* E_{msy}	*Illex* R_{EQ}
1.0	0.74	100.0%	0.63	100.0%
0.8	0.40	71.6%	0.37	74.5%
0.4	0.15	60.9%	0.17	60.9%

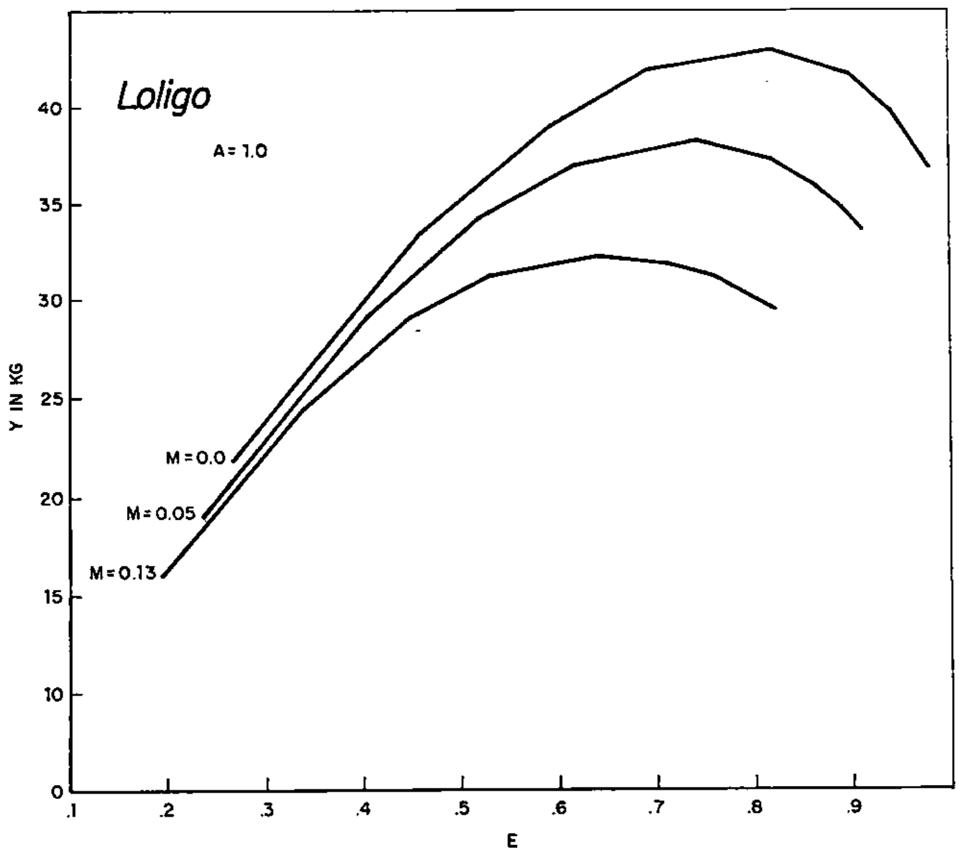

Fig. 1. Equilibrium yield per 1000 recruits to virgin fishery for set 2 of Fr and A=1.0.

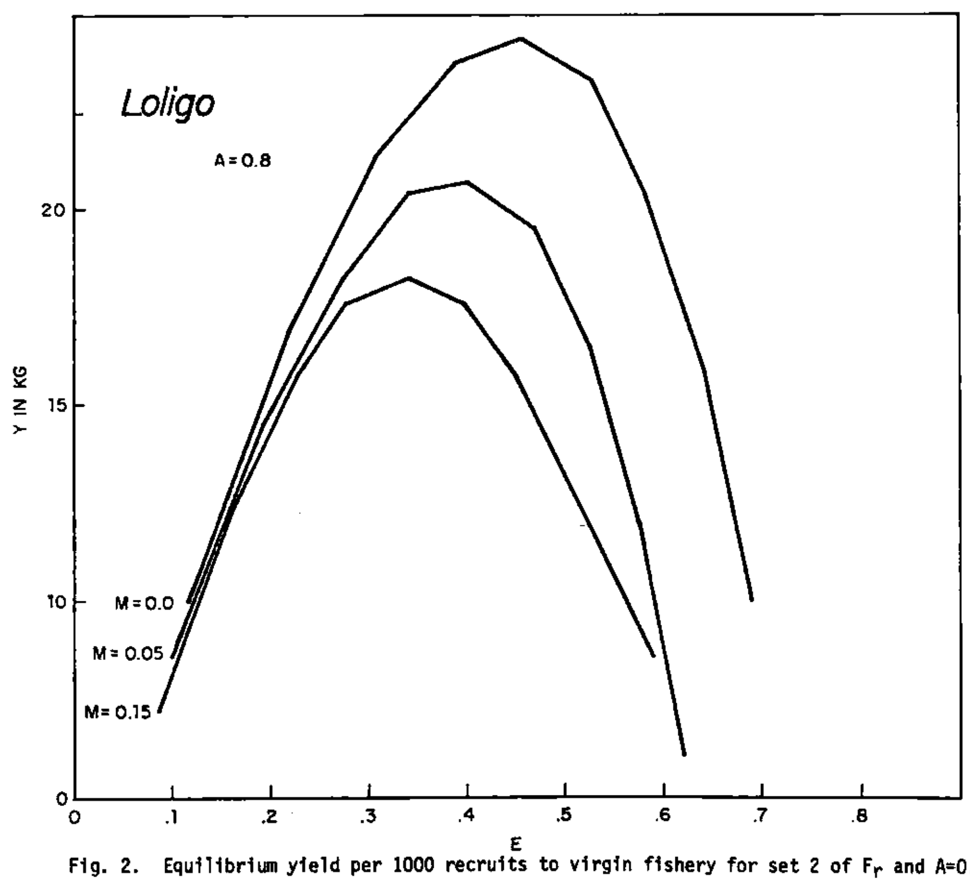

Fig. 2. Equilibrium yield per 1000 recruits to virgin fishery for set 2 of F_r and A=0.8.

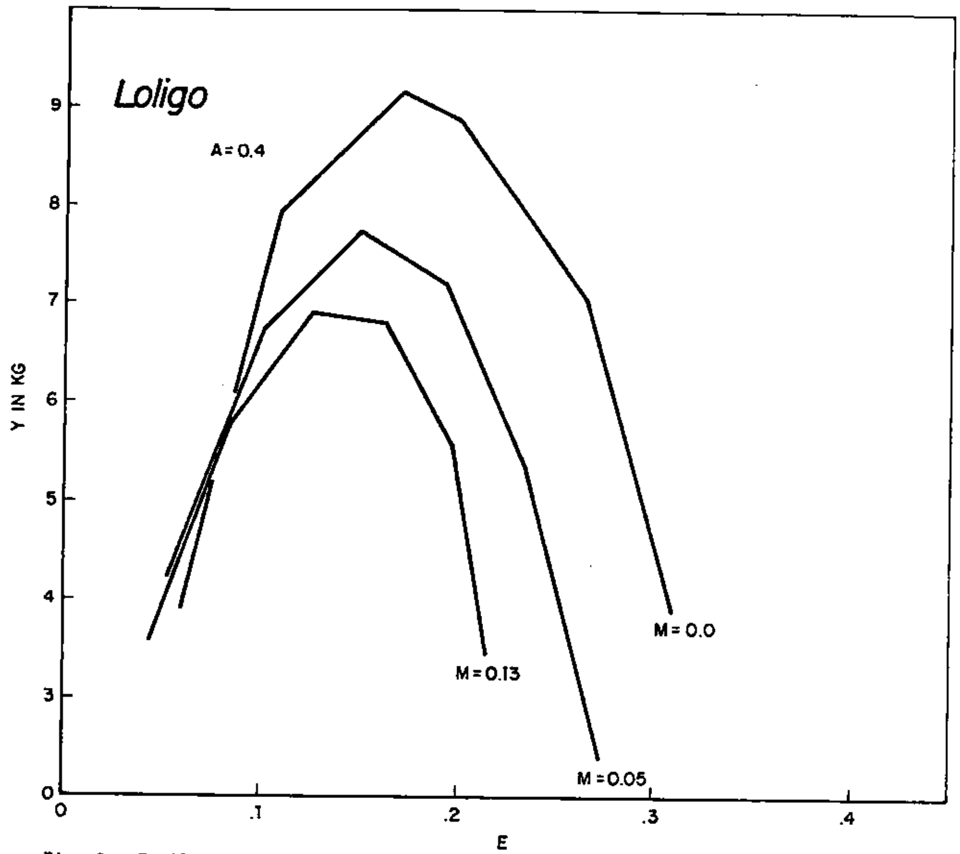

Fig. 3. Equilibrium yield per 1000 recruits to virgin fishery for set 2 of F_r and A=0.4

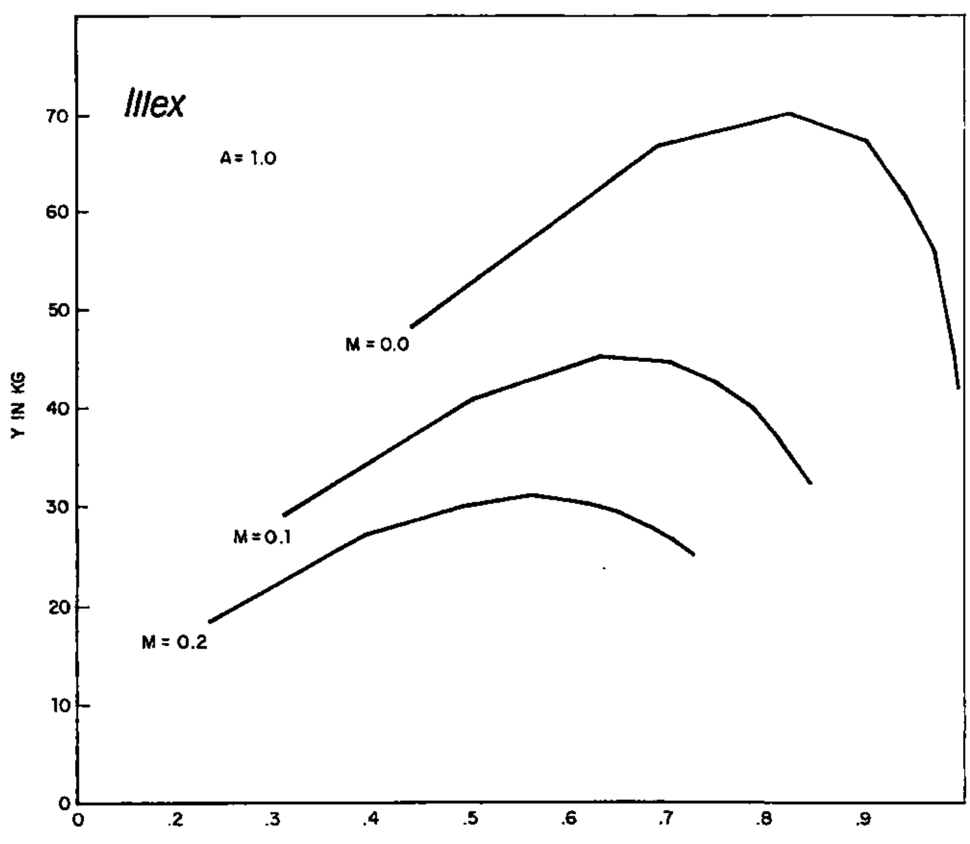

Fig. 4. Equilibrium yield per 1000 individuals recruited to the virgin fishery for A=1.0 and set 2 of F_r.

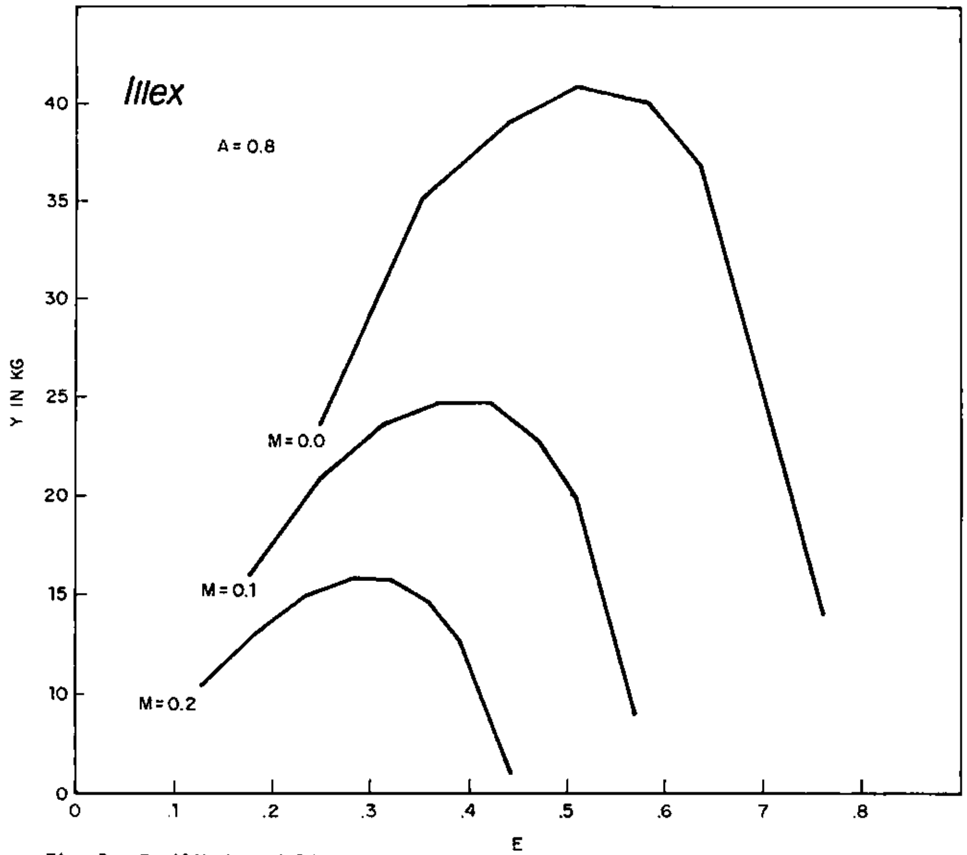

Fig. 5. Equilibrium yield per 1000 individuals recruited to the virgin fishery for A=.8 and set 2 of F_r.

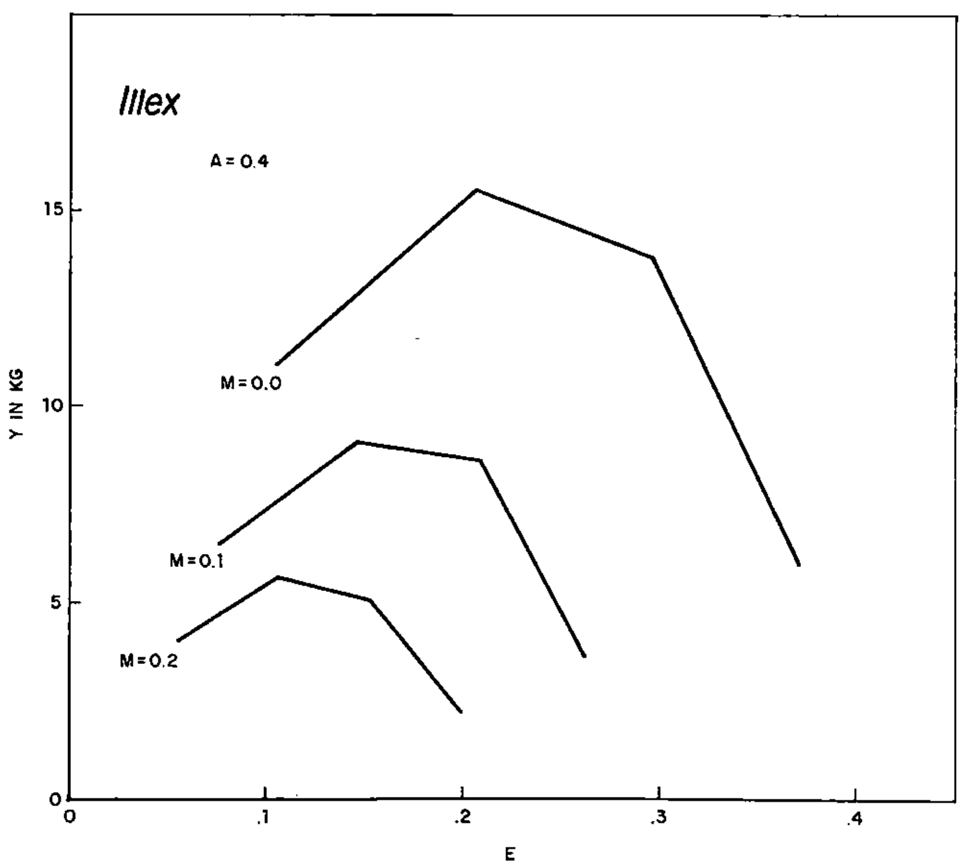

Fig. 6. Equilibrium yield per 1000 individuals recruited to the virgin fishery for A=0.4 and set 2 of F_r.

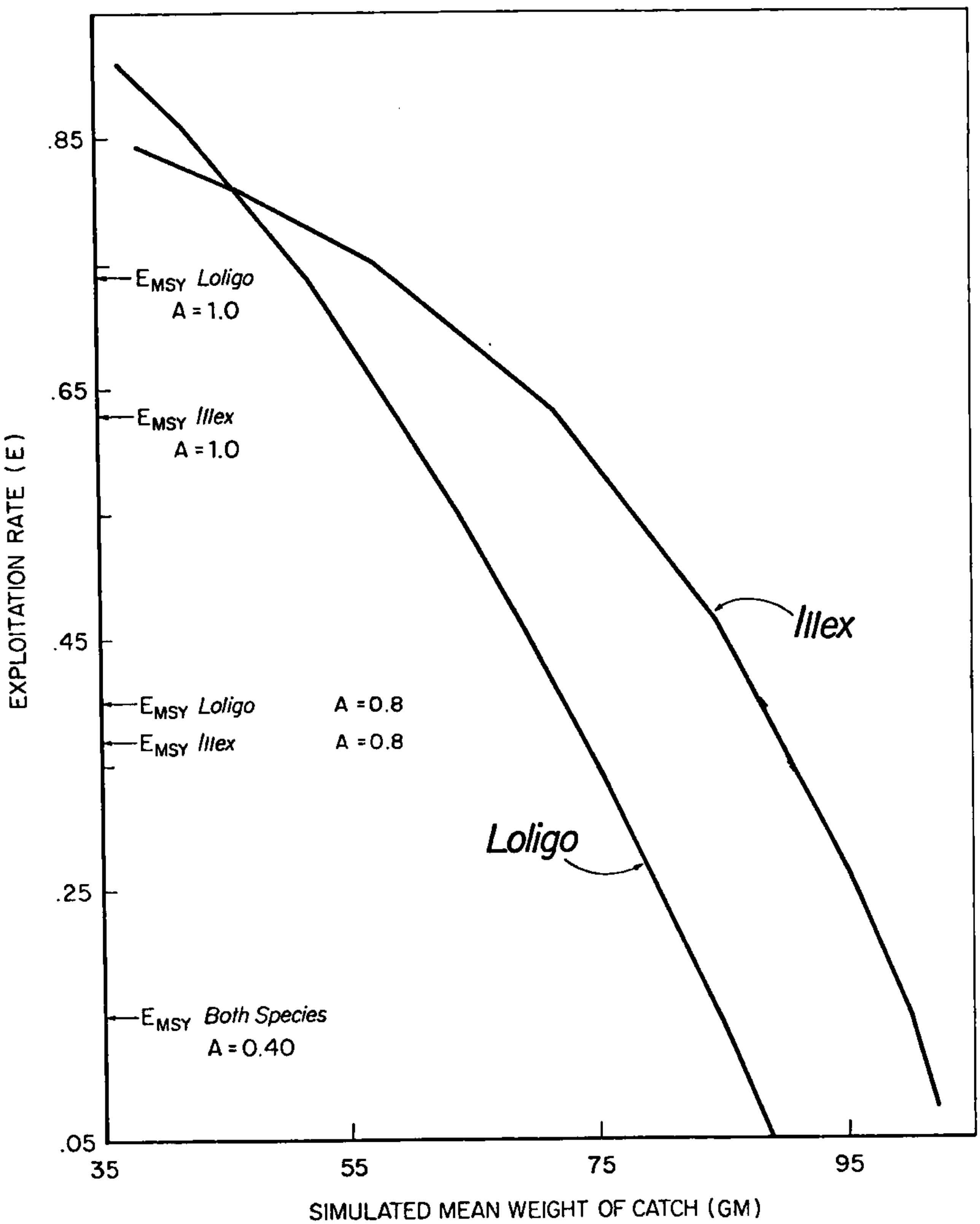

Figure 7. Relationship between E and the mean weight per individual of the catch of *Loligo* (set 2 of F_r and M=0.05) and *Illex* (set 2 of F_r and M=0.1).

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Appendix I

Appendix

The catch of squid by species and country from SA 5&6 as estimated in Table 1. Four criteria for allocating catches of squid to species are given in this paper and the specific application of each of these to obtain the estimates in Table 1 is indicated below:

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1974												
Bulg		3	3	3	3	3	3					3
Can	3											
Ita	1	1	1							1	1	1
Jap	1	1	1	1	1	1	1	1	1	1	1	1
Pol			2	2	2	2	2			3,4	3,4[a]	3,4[a]
Rom		3		3	3	3	3					
Spa	1	1	1	1	1	1	1	1	1	1		
USSR	4		4	4	3,4	3,4	3,4	3,4	4	4	4	3,4
USA	4	4	4	4	4	1,4	1,4	1,4	4	4	4	4
1975												
Bulg		3	3	3	3	3						
FRG										3		3
GDR				3	3	3	3,4	3,4			3,4	3
Ita	2	2	2	2		2	3,4		2	3,4	3	3
Jap	3	2	2	2,4	2			2	2	3,4	3	3
Pol	1	1	1	1	1	1	1	1	1	1	1	1
Rom								2				
Spa	1	1	1	2		2	2	2	3			
USSR	2		2	2	3	4	2	2	2	4	2	4[b]
USA	1	1	1	1	1	1	1	1	1	1	1	1

[a]Catch of *Loligo* and *Illex* for November and December is based on the difference between total catch reported for the year and the sum of estimated monthly catches prior to November.

[b]Data from R/V *Cryos* (Fra-SP).