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1977 Population Estimates for Squid (*Illex illecebrosus*) in ICNAF Subarea 4 from the International Fishery in 1977

by

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This paper is a summary of the population estimates of squid in ICNAF Subarea 4 using models which have been tried in other areas. Where thought advisable, the models were modified to suit specific situations. The models reviewed are areal expansion, DeLury method and cohort analysis.

Areal Expansion

Data from the groundfish survey program as described by Halliday (1971) provided areal expansion estimates of squid biomass for the years 1970-77. The survey methodology is based on depth strata. Figure 1 is a graph showing biomass estimates of squid from 1970-77 by strata. The location of the strata are shown on the map in Figure 2, (from Halliday 1971). Highest concentrations of squid correspond to the central and western parts of the Scotian Shelf. This agrees well with observations by Scott (1976). The biomass estimates ranged from a high of 204×10^3 tons in 1976 to a low of 1.9×10^3 tons in 1970. The trends in abundance from year to year for the various strata groupings are very similar.

Areal expansion estimates of stock size have been attempted not only by research surveys as outlined above but also based on commercial fishery data. In 1977 for example, biomass estimates from commercial fisheries data for the June-August time period range from the USSR (Burukovsky and Froerman, 1978) estimate on Emerald Bank of 60×10^3 tons to the Polish (Lipinski, 1978) estimate of 205×10^3 tons. A Cuban (Mari, *et al.*, 1978) estimate gave 133×10^3 tons in a directed silver hake fishery. These estimates were all made on the Scotian Shelf in what was shown above as areas of high squid abundance. However, these estimates were not extrapolated to give biomass estimates for the entire Scotian Shelf but rather for areas where fishing effort had been concentrated by the respective foreign fleet. For this reason, they probably underestimate the total shelf biomass. In the case of the Cuban estimate, it may further give an underestimate of squid biomass as squid is considered a by-catch in a directed silver hake fishery.

For a more complete treatment of the advantages and disadvantages of the areal expansion method see Sissenwine (1976).

Leslie Method

This method assumes one is dealing with an isolated stock that is confined within a known area. It also assumes that during the period of fishing there is no natural mortality. When relative abundance (catch per fishing day) is plotted against cummulative catch over the fishing period, stock size can be estimated by dividing the value for the Y-intercept (when Y is catch per fishing day) by the slope of the line of best fit between the two variables. Figure 3 shows a plot of number of squid caught per fishing day versus the cummulative number of squid caught in the international fishery for 1977 in ICNAF Subarea 4. The line of best fit is also drawn to show how the initial stock was estimated. (The equation for the line is $y = 288{,}312.17 - 7.8 \times 10^{-4}$ (x)). The value of the X-intercept 3.7×10^8 represents the initial squid population. The correlation coefficient = 0.94. This represents a biomass of 13,610 tons at the beginning of the fishing season. The catch which is plotted in terms of the number of squid came from Flash data which was reported in metric tons. The conversion from units of weight to numbers was made by dividing the catch weight by the seasonal mean weight per individual as given by Amaratunga *et al.*, (1978). The effort days represent Flash effort adjusted by multiplying them by percent weight of squid in the catch for a particular time period.

Sissenwine (1976) believed that stock size estimates derived from the DeLury method tend to underestimate the actual stock size. He assumed this because the best fit regression line often gave an estimate which was less than the total catch, (this is not the case here). Biologically speaking, the assumption of zero natural mortality during the fishing season is not realistic as squid is a prey item for many fish species and this too would underestimate the population (Mercer, 1975). Emigration and immigration factors which also influence the population estimate, should be taken into account in the discussion but too little is known about them.

The catchability coefficient calculated above 7.8×10^{-4} compared well with the range of valued derived from the Cuban commercial fishery (Mari, *et al.*, 1978).

Cohort Analysis

From an analysis of catch data of a year-class, estimates of the population exposed to the fishery may be made at various ages in the life history of the species. For most species these estimates are derived for each year of the fishes life and represent the 'virtual population' or the potentially exploitable population at the beginning of a particular fishing season. For squid however, with its one-year life-cycle this is impossible unless population estimates are made on a shorter time scale throughout the fishing season. In the following analysis catches were summarized in two-week periods throughout the fishing season and a virtual population or cohort analysis done, following the method of Pope (1972), where:

$$N_{i+1} = N_i\, e^{-m} - C_i\, e^{-m/2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

Practically speaking, one has no idea of the stock escapement with potential to spawn at the end of the fishing season. The virtual population is really an estimate of the total removals by fishing and natural mortality.

The catch is based on Canadian Flash weights for the International fishery during 1977 in Subarea 4. The weights were converted to number of animals by dividing the Flash weights by the seasonal mean weights per animal.

Two assumptions have to be made in the analysis. Firstly, one has to estimate the natural mortality rate and assume that it remains constant throughout the fishing season. Secondly, the analysis requires a starting value for the fishing mortality. To test the sensitivity of the analysis to variations in F the cohort analysis was run at a constant value of M = 0.05 and the F values were varied from 0.05 to 0.45 for each 2-week period. The resulting population estimates are given in Table 1. They ranged from 425,767,744 to 425,780,222. The relatively small difference in the estimates showed the insensitivity of the cohort analysis to variations in F. This is in agreement with the results of Sissenwine (1976).

Sissenwine and Tibbetts (1976) assumed a hypothetical monthly value of F = 1.0 for the principle fishing months May to September. Thus a 2-week value for F could be assumed to equal 0.5. The value of F chosen however, is not critical because of the above discussion and an arbitrary terminal F = 0.05 was chosen in order to initiate the analysis.

Following the method of Au (1975) values of natural mortality were estimated based on the life expectancy of the species as reported by various authors. Squires (1967) reported a life cycle of 1-1.5 years (M = 0.03 for 2-week period) while Mesnil (1976) reported a 1-2 year life-cycle (M = 0.02 for a 2-week period). Au (1975) suggested that the life cycle was 12 months or less (M = ≥0.04 for 2-week period), assuming M is constant throughout the life span. Efanov and Puzhakov (1975) estimated a monthly M value of 0.1 (2-week value M = 0.05).

Figure 4 shows a graph of the various population estimates from cohort analysis using the range of values M calculated above. The relationship is in fact exponential as suggested by Pope's equation. The population estimates range from 322,685,312 for M = 0.01 to 425,767,588 for M = 0.05. These correspond to biomass estiamtes at the beginning of the fishing season of 11,940 tons and 15,750 tons respectively.

The maximum population estimate calculated above was made using the value M = 0.05 for a 2-week period. Table 2. shows the results of a cohort analysis using a starting F value of 0.05 which was shown above to be relatively unimportant to the final population estimate. In addition, biomass estimates, listed for each 2-week period in Table 2, were calculated by multiplying the virtual population of each 2-week period by the seasonal mean weight per animal. The results indicate that maximum squid biomass was present during the fishing period ending June 27th. There were nearly 200×10^6 more squid in April than on 27 June yet the biomass estimate for the 27 June period was more than twice as high as that for the April period. This can be easily explained by the rapid growth rate for *Illex*. Although the maximum biomass for 27 June was 37,181 tons this certainly does not imply that the yearly total biomass was at this level. The total fishery in Subarea 4 produced a total offshore catch of 49,143 tons which was accumulated throughout the fishing season

Yield per Recruit

Fishing mortality may be examined in a yield-per-recruit model to test whether the average F-value in the fishery was an optimal one. The estimation of equilibrium yield by the method of Thompson and Bell (1934) was adopted. The procedure is suitable when mean biomass for different ages of the fish are known such as those derived from the cohort analysis.

Table 3 gives the equilibrium yields for different values of F and M. The F and M values are for 2-week periods over the fishing season. The range of F values cover most of those produced by the cohort analysis. The range of M values is the same as those tested in the cohort analysis. As the natural mortality increases from 0.01 to 0.03 the F values giving the maximum yield changes from 0.1 to 0.2 respectively. This is to be expected as a higher level of fishing is needed to offset a higher rate of M. However, when the value of M is increased from 0.03 to 0.05 the value of F maximizing the yield does not increase but rather remains at 0.2 probably reflecting the rapid growth of squid.

Using a value of M = 0.05 the F for maximum equilibrium yield is 0.2. This F-value can be compared with the average F for the time period considered. The cohort analysis model assumes that there is no immigration or emmigration occurring in the population. Although there is no conclusive evidence it appears that *Illex* migrates to inshore areas in the spring as juveniles and moves offshore in the fall to spawn in deeper water. Therefore an average value of F should be calculated at the height of the fishing season when immigration and emmigration have a minimal effect. From Table 2 most of the catch was taken between 30 May and 5 September. Values of F from the cohort analysis are relatively constant during this period. The average F-value for this period was 0.28 which is somewhat higher than the optional F of 0.2 from the Thompson and Bell model.

Exploitation Rate

The exploitation rate can be derived from the Baranov catch equation using catch in numbers:

$$C = \frac{F\ A\ N}{Z} = u\ N \qquad (2)$$

$$u = \frac{C}{N} \qquad (3)$$

Therefore the exploitation rate (u) can be expressed in terms of the number caught for a particular time period divided by the population (N) at the beginning of that period. Using the data in TAble 2 and selecting the period of 30 May to 5 September as the time when the fishery is most concentrated;

$$u = \frac{268,260,000}{356,740,526} = 0.75 \qquad (4)$$

Since u may be calculated assuming a Ricker Type II fishery as:

$$u = \frac{FA}{Z} = \frac{F(1-e^{-z})}{Z} \qquad (5)$$

Equation 5 translates, using a summed F = 2.23 for the above period with a M = 0.05 x 8 periods = 0.40 and Z = 2.63, as u = 0.79.

The rapid growth rate of squid for the period, under discussion, (74g-231g) indicates that by considering exploitation rates based upon weights can be misleading. A catch of 1,000 tons in late May would yield 13.5 x 10^6 animals while the same catch in September would produce 4.3 x 10^6 or a change of 68% in numbers.

During the 1978 Havana Squid meeting (ICNAF Summ. Doc. 78/VI/3) an exploitation rate of 0.38 was calculated for Subarea 4. This rate was derived by dividing the weight of the catch by the biomass. Such a calculation would not take into account the change in growth and thus would produce a lower exploitation rate.

Discussion

Data summarized in Table 4 presents population and biomass estimates for *Illex* using the various mathematical models. There are great discrepancies in estimates made by the areal expansion method (Table 4). Those presented in Cuba cannot strictly be compared because they were calculated for different areas and for different time periods of the year. Estimates of this kind for areas where catch rates were high should not be extrapolated to give density estimates for other areas with low catch rates.

It can be assumed from Scott (1976) and from yearly abundance estimates of squid (Fig. 1), that the international fishery exerted effort in those areas of traditional squid abundance (Waldron, 1978). Biomass estimates presented in this paper for the fishing area are indicative of the major population concentration.

The Leslie and cohort analyses provided very similar estimates. Since they are based on catch data from the international fishery they should be considered estimates for those areas in which fishing effort was concentrated and not for the entire Scotian Shelf. The estimates may be biased because of the lack of information on immigration and emigration. Lack of knowledge of seasonal squid distribution precludes making a population estimate for the entire Shelf area. According to the cohort analysis the maximum biomass present during the season was about 37,000 M.T. for the two-week period ending June 27. The estimates are considerably lower than those made using the areal expansion method except perhaps for the Canadian estimate. The populations given in Table 4 were calculated for the beginning of the fishing season and were converted to biomass estimates for April when the relative average weight per animal was very low. The exploitation rate should be calculated using biomass estimates instead of population numbers because of the rapid growth rate of *Illex*. Table 2 shows that nearly half of the initial number of squid were fished before the maximum biomass estimate was reached on June 27. If the opening of the fishing season had been delayed until July 1 the potential fishable biomass would have been considerably higher. A yield function should be derived for *Illex* in order to calculate seasonal yields more accurately knowing the date of the maximum yield will provide a suggested opening date.

The high exploitation rate of between 0.75 and 0.79 is considerably larger than that recommended by STACRES (ICNAF Sum.Doc. 78/VI/3). This could have serious repercussions upon the 1978 available biomass if the Subarea 4 population is distinct from that in Subarea 3 and if recruitment is dependant upon parent stock size.

A preliminary analysis of 1977 monthly data for Subareas 3 and 4 was inconclusive because the calculated F-values of the cohort were unable to stabalize over such a short time scale. Because of this, it was impossible to calculate an exploitation rate for this area in order to obtain a total rate for Subareas 3 and 4.

Au (1975) suggested that the exploitation rate when recruitment is independent of parent stock size is 0.65. If there is an independence between squid stocks in Subareas 3 and 4 as well as no dependence of recruitment on parent stock size, an exploitation rate of 0.75 is still too large.

It would appear that regulation of a squid fishery solely upon a quota system is not satisfactory. The need for regulation of this fishery by a combination of effort and quotas is recommended. However, before this statement can be fully analysed, there is a distinct need to standardize effort and define more precisely a directed squid fishery.

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TABLE 1. EFFECT OF VARYING 'F' WITH CONSTANT 'M'

F	M	POPULATION
0.05	0.05	425,780,222
0.10	0.05	425,773,203
0.20	0.05	425,769,693
0.25	0.05	425,768,991
0.30	0.05	425,768,524
0.35	0.05	425,768,189
0.40	0.05	425,767,939
0.45	0.05	425,767,744

TABLE 2. COHORT ANALYSIS BASED ON CATCHES OF SQUID FOR 2-WEEK PERIODS IN THE INTERNATIONAL FISHERY IN 1977. A CONSTANT VALUE OF M = 0.05 IS ASSUMED. A TERMINAL VALUE OF F = 0.05 WAS USED.

DATE	No. of Animals		F	Biomass of Animals (kg)	
	CATCH (x 10^3)	POPULATION		CATCH	POPULATION
April 17	90	425,780,222	.000	3,330	15,753,868
May 2	680	404,926,897	.002	32,640	19,436,491
May 16	9,250	384,515,169	.025	555,000	23,070,910
May 30	35,080	356,740,526	.106	2585,920	26,398,799
June 13	54,780	305,128,214	.203	6080,580	33,869,232
June 27	43,880	236,819,458	.211	6889,160	37,180,655
July 11	35,140	182,473,038	.220	6536,040	33,939,985
July 25	42,020	139,301,332	.370	7815,720	25,910,048
Aug. 8	21,280	91,525,004	.272	4213,440	18,121,951
Aug. 22	18,610	66,306,682	.339	4298,910	15,316,844
Sept. 5	17,470	44,922,349	.509	4035,570	10,377,063
Sept. 19	7,030	25,696,796	.329	1623,930	5,935,036
Oct. 3	8,700	17,583,315	.708	2305,500	4,659,578
Oct. 17	3,980	8,240,571	.684	1054,700	2,183,751
Oct. 31	1,080	3,956,940	.328	286,200	1,048,589
Nov. 14	2,000	2,710,623	1.413	634,000	859,267
Nov. 28	600	627,804	3.907	190,200	199,014
Dec. 11	6	12,000	.050	1,902	3,804

Table 3. Yield (kg) per 1000 individuals for different rates of fishing and natural mortality. (after Thompson and Bell, 1934)

F \ M	.01	.03	.05
.1	95.6	82.2	71.1
.2	94.7	83.8	74.4
.3	80.6	73.0	66.5
.4	68.6	63.4	58.9
.5	60.1	56.5	53.2

Table 4. Biomass estimates of squid using various mathematical models.

AREAL EXPANSION:	205,000 MT	(Polish) - for fishing area of Polish fleet
	60,000 MT	(USSR) - from USSR fishing fleet for Emerald Bank
	133,000 MT	(Cuban) - for fishing area of Cuban fleet
	50,500 MT	(Canadian) - for Scotian Shelf based on an abundance survey

LESLIE: No. of squid = 367,745,115
Average weight/animal in April = 37×10^{-6} MT
Biomass at beginning of fishing season (mid-April) = 13,610 MT

COHORT ANALYSIS:

Range of Estimates: (at beginning of fishing season)	Minimum (M = 0.01); No. of squid = 322,685,312; Biomass = 11,940 MT
	Maximum (M - 0.05); No. of squid = 425,767,588; Biomass = 15,750 MT

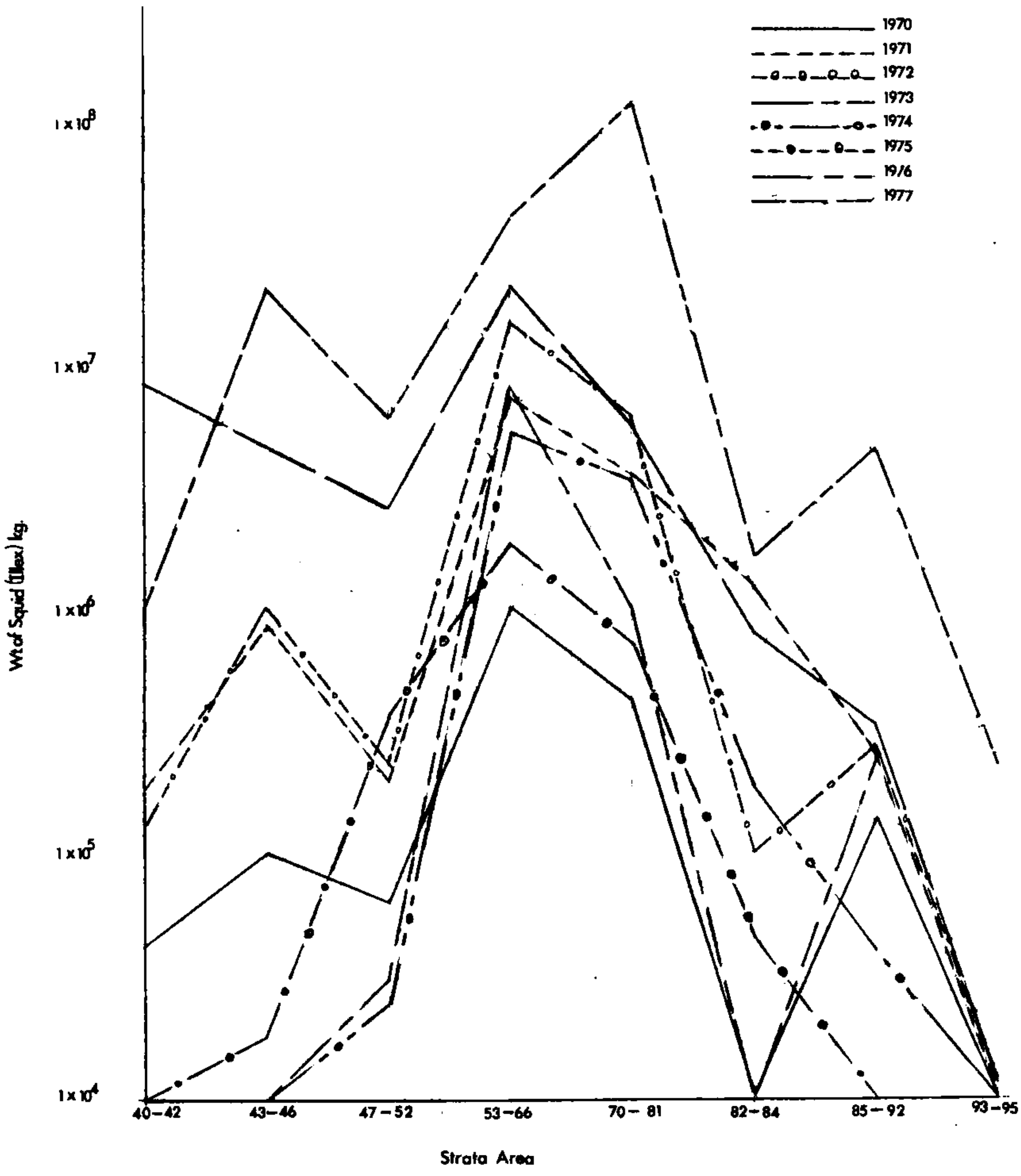

Fig. 1. Canadian research cruise biomass estimates of squid for different strata between the years 1970–77.

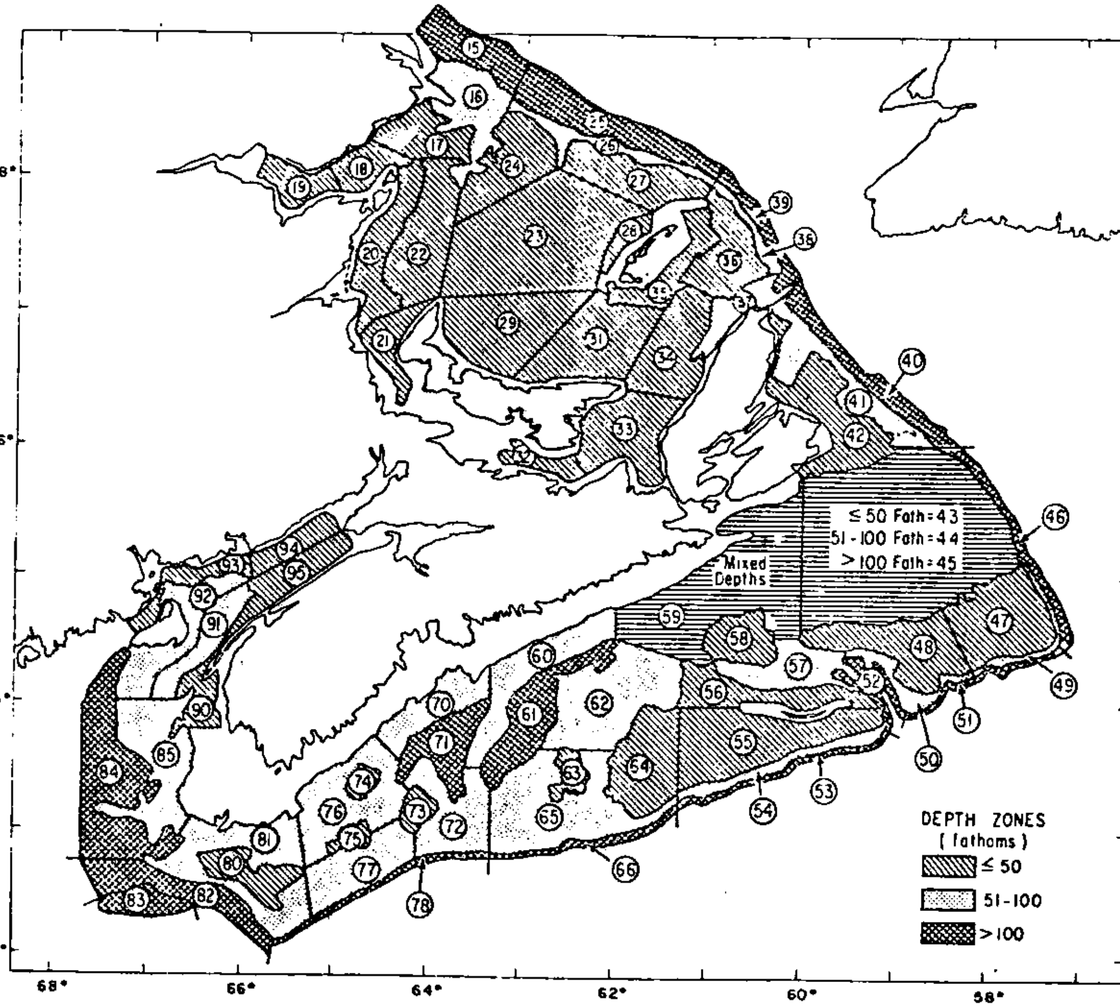

Fig. 2. Stratification zones for ICNAF area 4 (from Halliday *et al.* 1971).

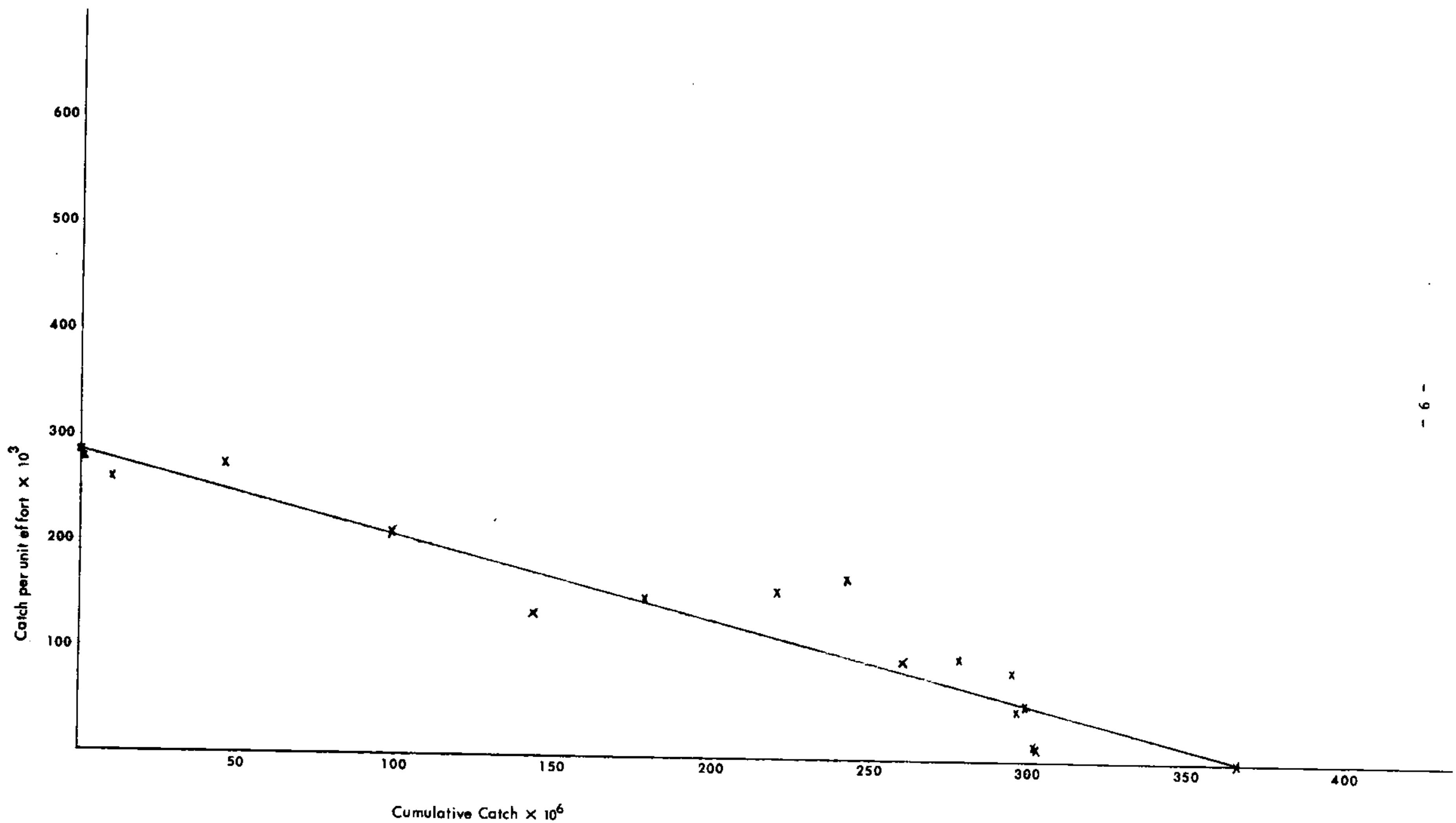

Fig. 3. Leslie population estimate for the 1977 international squid fishery. Catches refers to number of squid. The units of effort used were adjusted fishing days from FLASH.

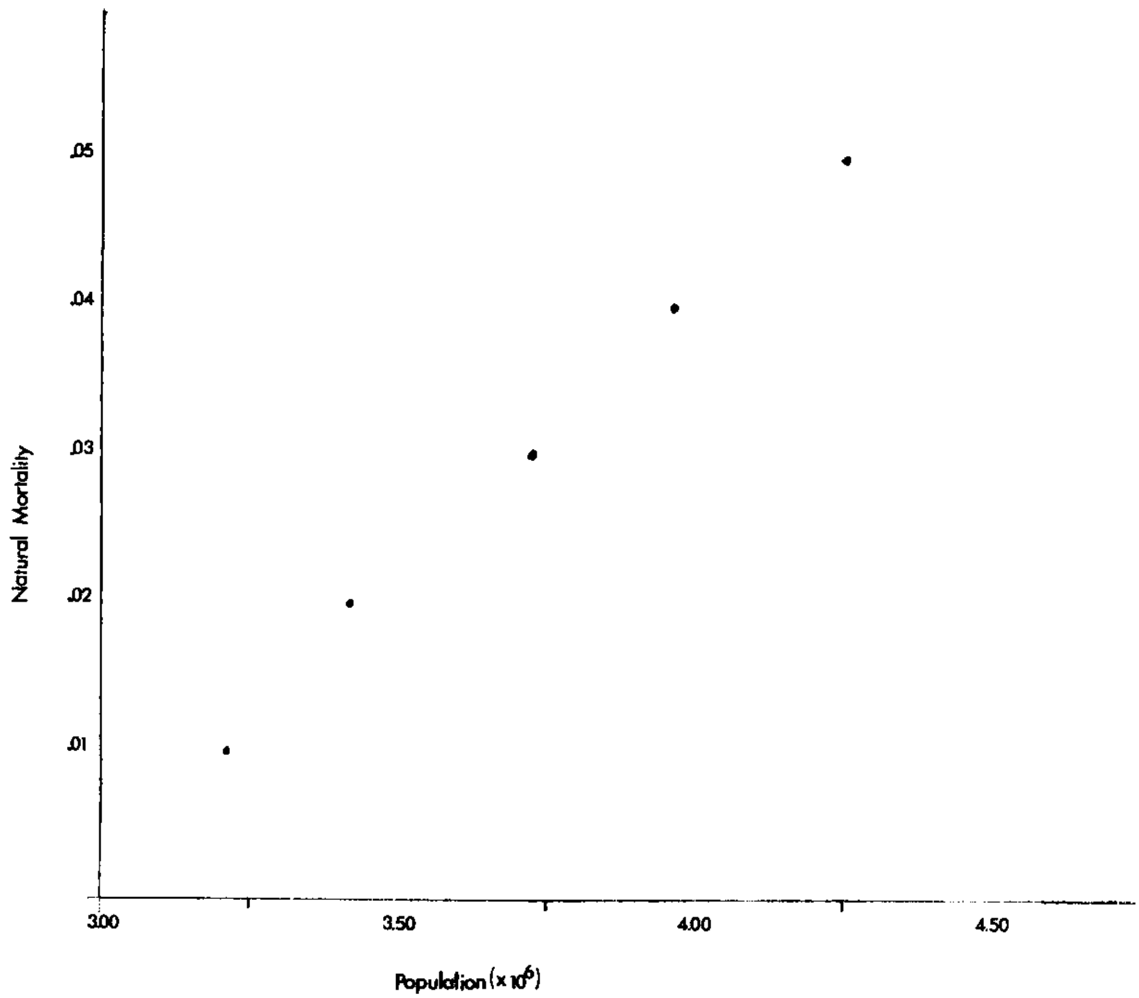

Figure 4. Graph showing the relation between the population estimates for the 1977 International fishery and different values of natural mortality from cohort analysis.