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Optimum Rate of Exploitation and Virtual Population Analysis for Short-finned squid, *Illex illecebrosus*, in Subareas 3 and 4

by

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Optimum rate of exploitation for Illex has been studied by Au (1975) and Sissenwine and Tibbetts (1976). However, the present Author considers that both models have some defects as given below,

1. These models are made for Illex fishery in Subarea 5 and Statistical Area 6 which has the fishing season from April to September, while the fishing season extends from early summer (May-July) to October-November in Subareas 3 and 4.
2. The rate of exploitation calculated results in a maximum catch in terms of Y/R. However, it is not necessarily optimum rate of exploitation when catch per effort and average size of squid caught are taken into account.
3. There is some doubt to apply Beverton-Holt reproduction curve to Illex to estimate the effect of spawners decreased by fishing.

In order to make up for the defects mentioned above, the Author calculated, for the squid fishery in Subareas 3 and 4, F_{max}, $F_{0.1}$ and average weights of Illex taken under various values of M by the method of Thompson and Bell (1934). The ratios of residual size of spawners to that in natural condition are indicated instead of applying any particular reproduction curve to Illex.

On the other hand, virtual population analysis was made using catch statistics in Subarea 4 for 1977 to calculate intial stock sizes in number of Illex and F for various values of M and terminal F or terminal stock size. Based on series of figures thus calculated, combinations of M and stock size (intial or terminal) when F is either F_{max} or $F_{0.1}$ are estimated.

Optimum rate of exploitation

Average weights of Illex by month are calculated from average mantle lengths by month on the east coast of New foundland and the mantle length-weight relationship from Squires (1967) and from Mercer (1973), respectively (Table 1).

Table 1 Average mantle lengths of Illex by month on the east coast of Newfoundland from Squires (1967) and calculated average weights by month using mantle length-weight relationship* from Mercer (1973)

Month	ML (cm)		BW (g)
	♂	♀	♂+♀
May	13.1	13.9	41
Jun.	16.3	17.3	83
Jul.	18.9	20.0	133
Aug.	21.0	22.3	190
Sep.	22.7	24.1	246
Oct.	24.0	25.6	297
Nov.	25.1	26.8	345

* $W_{(g)} = 0.004034\ ML_{(cm)}^{3.5110}$ for male

$W_{(g)} = 0.01301\ ML_{(cm)}^{3.1090}$ for female

For the fishing season, six different periods with constant monthly F are assumed; from May, June or July towards October or November. Five different values of monthly M are also assumed; 0.02, 0.05, 0.1, 0.2 and 0.3.

Expected yields when 1,000 Illex are recruited at the beginning of May are calculated for various values of F in the unit of 0.1 (0.05 in the vicinity of F_{max}) by the method of Thompson and Bell. $F_{0.1}$ is read on the figures drawn. E value is accumulated catch in number divided by 1,000 (number recruited) and E_{max} corresponds to F_{max} and $E_{0.1}$ to $F_{0.1}$. Average weight of Illex caught is calculated from the yield divided by accumulated catch in number. The ratio of residual size of spawners to that in natural condition ($e^{-F \times \text{period of fishing season}}$) is also calculated.

The results of calculation are shown in Table 2 and 3 and Fig. 1 to 5. Based on the results obtained, it can be generally noted that Y/R values greatly depend on M (which is unknown) and fishing season, that is, if M is smaller or fishing season opens later, Y/R values are larger. However, higher F is required during shorter fishing season when the fishing season starts late. It is also noted that, despite that $F_{0.1}$ is considerably smaller than F_{max} (less differences between $E_{0.1}$ and E_{max}), the resulting yield does not decrease greatly. If fishing mortality rate decreases from F_{max} to $F_{0.1}$, average weight of Illex taken is larger and the residual size of spawners must be greater.

Y/R values are almost doubled in this analysis compared with those in Sissenwine and Tibbetts. This may be caused by late opening of fishing season in Subareas 3 and 4 and by the difference of the growth equations used. Sissenwine and Tibbetts used the growth equation from Efanov and Puzhakov (1975) and the present paper is based on Squires. The mantle lengths by month are smaller in the former equation than those in the latter.

Table 2 F_{max}, E_{max}, Yields (Y) per 1,000 Illex recruited, average weights ($\overline{W}$) of Illex caught and ratios (R) of residual size of spawners to that in natural condition for various values of M and fishing season (t_c-t_λ)

M	0.02						0.05					
t_c	May		Jun.		Jul.		May		Jun.		Jul.	
t_λ	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.
F_{max}	0.30	0.30	0.45	0.35	0.75	0.50	0.35	0.30	0.50	0.40	0.75	0.60
E_{max}	0.80	0.84	0.85	0.83	0.89	0.86	0.80	0.78	0.81	0.79	0.81	0.80
Y (kg)	96	109	122	134	153	164	88	98	111	121	138	147
$\overline{W}$ (g)	119	130	144	162	171	192	110	125	137	153	169	183
R	0.17	0.12	0.10	0.12	0.05	0.08	0.12	0.12	0.08	0.09	0.05	0.05

M	0.1						0.2					
t_c	May		Jun.		Jul.		May		Jun.		Jul.	
t_λ	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.
F_{max}	0.35	0.30	0.50	0.45	0.75	0.70	0.45	0.35	0.70	0.60	1.05	0.95
E_{max}	0.73	0.71	0.72	0.71	0.70	0.71	0.68	0.62	0.63	0.61	0.56	0.55
Y (kg)	76	83	96	102	117	122	59	62	73	75	86	87
$\overline{W}$ (g)	105	117	133	143	167	173	86	99	116	123	154	158
R	0.12	0.12	0.08	0.07	0.05	0.03	0.07	0.09	0.03	0.03	0.02	0.01

M	0.3					
t_c	May		Jun.		Jul.	
t_λ	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.
F_{max}	0.55	0.45	0.85	0.85	>1.3	>1.3
E_{max}	0.64	0.60	0.55	0.55	0.45	0.45
Y (kg)	47	49	58	59	65	66
$\overline{W}$ (g)	74	82	107	107	147	147
R	0.04	0.04	0.01	0.01	0.01	0.002

Table 3 $F_{0.1}$, $E_{0.1}$, Yields (Y) per 1,000 Illex recruited, average weights ($\bar{W}$) of Illex caught and ratios (R) of residual size of spawners to that in natural condition for various values of M and fishing season (t_c-t_λ)

M	0.02						0.05					
t_c	May		Jun.		Jul.		May		Jun.		Jul.	
t_λ	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.
$F_{0.1}$	0.25	0.20	0.30	0.30	0.50	0.40	0.30	0.25	0.40	0.30	0.50	0.40
$E_{0.1}$	0.74	0.72	0.73	0.78	0.81	0.80	0.75	0.70	0.76	0.72	0.73	0.72
Y (kg)	93	105	115	132	148	161	87	85	110	118	133	143
$\bar{W}$ (g)	126	147	157	169	183	200	116	122	145	165	181	198
R	0.22	0.25	0.22	0.17	0.14	0.14	0.16	0.22	0.13	0.16	0.13	0.13

M	0.1						0.2					
t_c	May		Jun.		Jul.		May		Jun.		Jul.	
t_λ	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.
$F_{0.1}$	0.30	0.25	0.40	0.30	0.50	0.40	0.30	0.30	0.40	0.40	0.60	0.50
$E_{0.1}$	0.68	0.63	0.67	0.62	0.62	0.60	0.57	0.58	0.52	0.53	0.48	0.50
Y (kg)	75	73	94	98	111	117	57	61	69	74	82	86
$\bar{W}$ (g)	110	116	141	159	179	194	99	105	133	138	170	174
R	0.17	0.22	0.14	0.17	0.14	0.14	0.17	0.12	0.14	0.09	0.09	0.05

M	0.3					
t_c	May		Jun.		Jul.	
t_λ	Oct.	Nov.	Oct.	Nov.	Oct.	Nov.
$F_{0.1}$	0.40	0.30	0.50	0.40	0.70	0.50
$E_{0.1}$	0.56	0.49	0.45	0.42	0.38	0.34
Y (kg)	47	46	55	54	61	59
$\bar{W}$ (g)	83	94	121	130	162	174
R	0.09	0.12	0.09	0.09	0.06	0.08

Virtual population analysis

From the bi-weekly catches from Hurley and Waldron (1978), Numbers of Illex caught per four weeks (≒ a month) in Subarea 4 for 1977 are recalculated (Table 4). M per four weeks used are 0.02, 0.05, 0.1, 0.2 and 0.3 as are similar when Y/R values are calculated. The terminal F per four weeks are 0.001, 0.005, 0.01, 0.02, 0.05, 0.1 and 0.2 and by virtual population analysis the initial stock size in number and F are estimated.

Table 4 Numbers of Illex caught per four weeks in Subarea 4 for 1977 recalculated from Hurley and Waldron (1978)

Period	Number (10^3)
Apr. 17-	770
May 16-	44,330
Jun. 13-	98,660
Jul. 11-	77,160
Aug. 8-	39,890
Sep. 5-	24,500
Oct. 3-	12,680
Oct. 31-	3,080
Nov. 28-	606
Total	301,676

It can be learned from Fig.6 that if terminal F is larger than 0.05 (this terminal F means that the stock size at the end of November is 13-15 x 10^6 in number or 4.8-5.5 x 10^3 tons in weight), the intial stock size estimate depends only on M. If terminal F is smaller than 0.02 (similarly, 30-37 x 10^6 in number or 11.0-13.6 x 10^3 tons in weight), the estimated initial stock size increases sharply. Such a small terminal F is not unrealistic if large extent of emigration occurres in the late fishing season due to the spawning migration.

Fig.7 and Fig.8 show estimated F values (average F from mid-May to October) and ratios of the residual size of spawners to that in natural condition ($e^{-\text{average F x five and half months}}$) from the combinations of various M and terminal F.

If there is information on M and/or terminal F (terminal or initial stock size estimates. stock size estimates in fishing season can be converted to terminal or initial stock size), assessment on Illex could be done basing on $F_{0.1}$ and relative residual size of spawners.

Estimation of Illex stock size has been made by areal expansion method by bottom trawl net. However, considerable amounts of Illex are detected by acoustic devices above the sea bottom which are not available to bottom trawl net. Therefore, stock size survey by midwater trawl net is recommended. Concerning natural mortality, quantitative stomach content survey for demersal fishes; Silver hake, White hake, Pollock, Cod, Halibut, and so on is recommended as the stock sizes of these fishes can be estimated more precisely than that of Illex.

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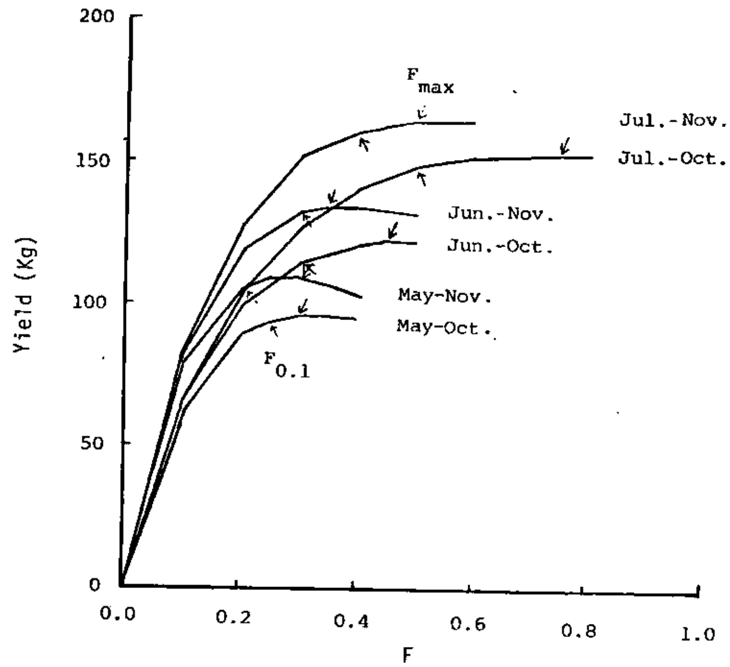

Fig.1 Yield per 1,000 Illex recruited for monthly M = 0.02 and for each fishing season

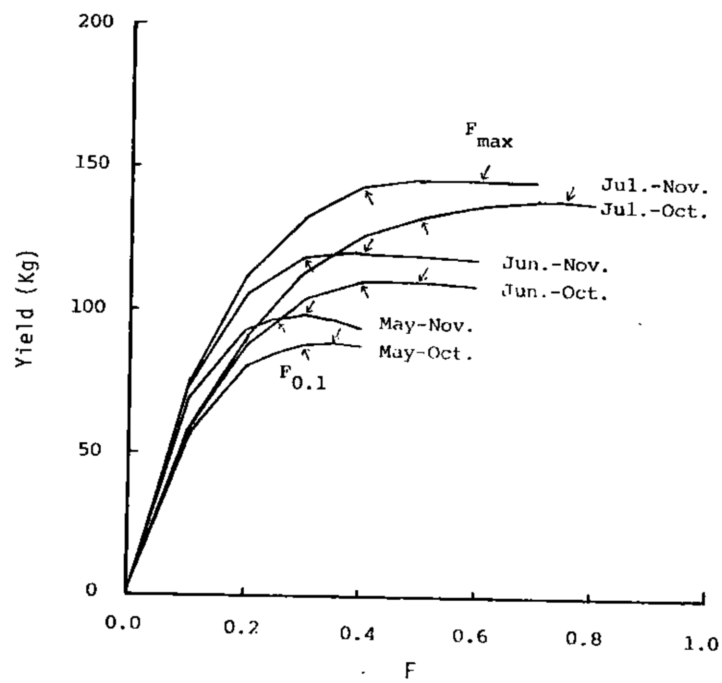

Fig.2 Yield per 1,000 Illex recruited for monthly M = 0.05 and for each fishing season

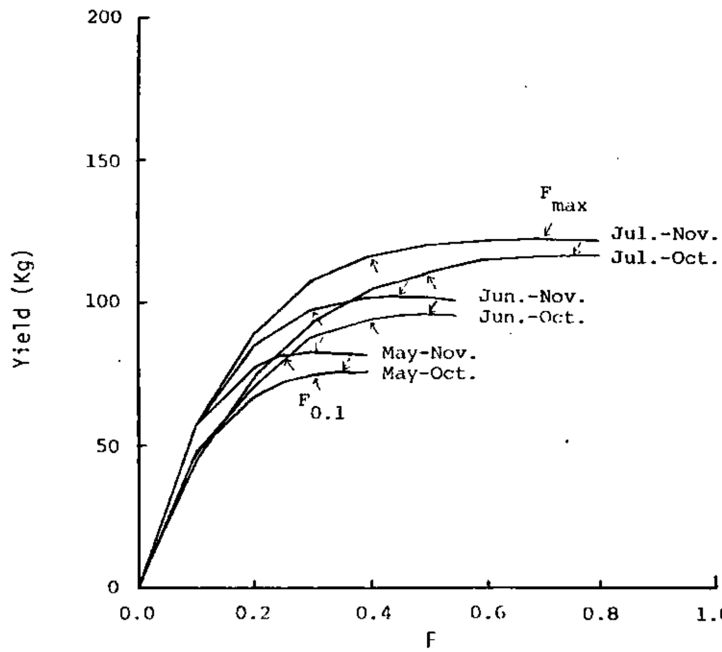

Fig.3 Yield per 1,000 Illex recruited for monthly M = 0.1 and for each fishing season

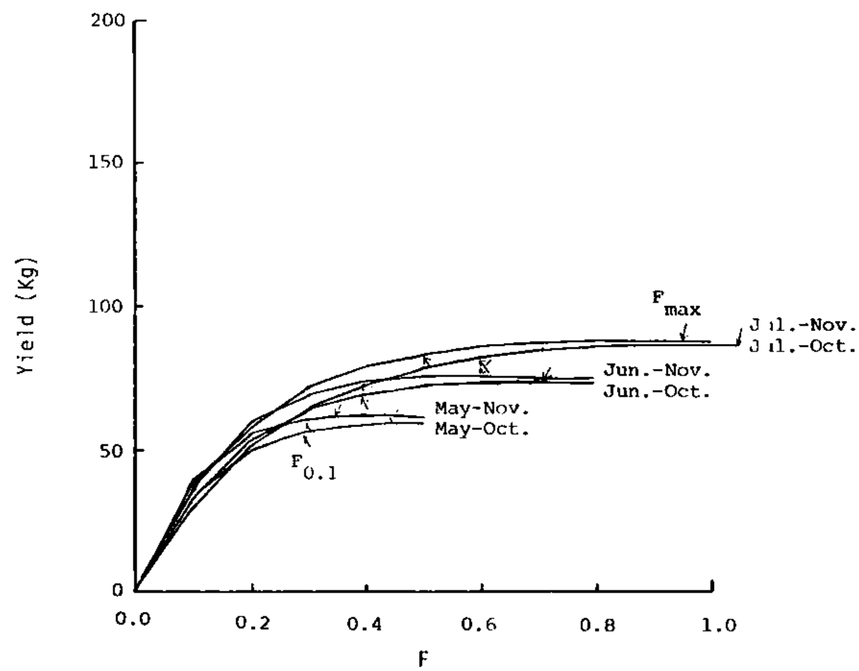

Fig.4 Yield per 1,000 Illex recruited for monthly M = 0.2 and for each fishing season

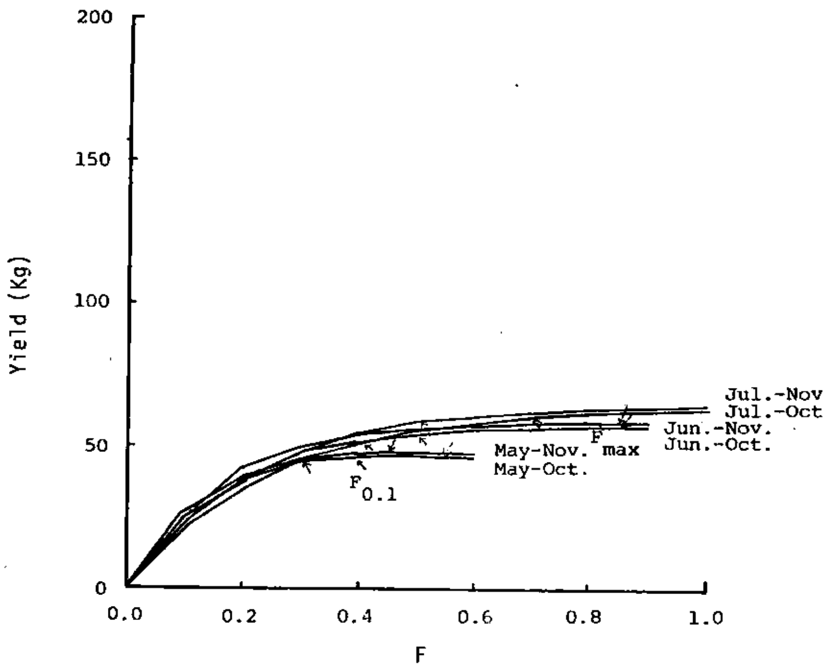

Fig.5 Yield per 1,000 Illex recruited for monthly M = 0.3 and for each fishing season

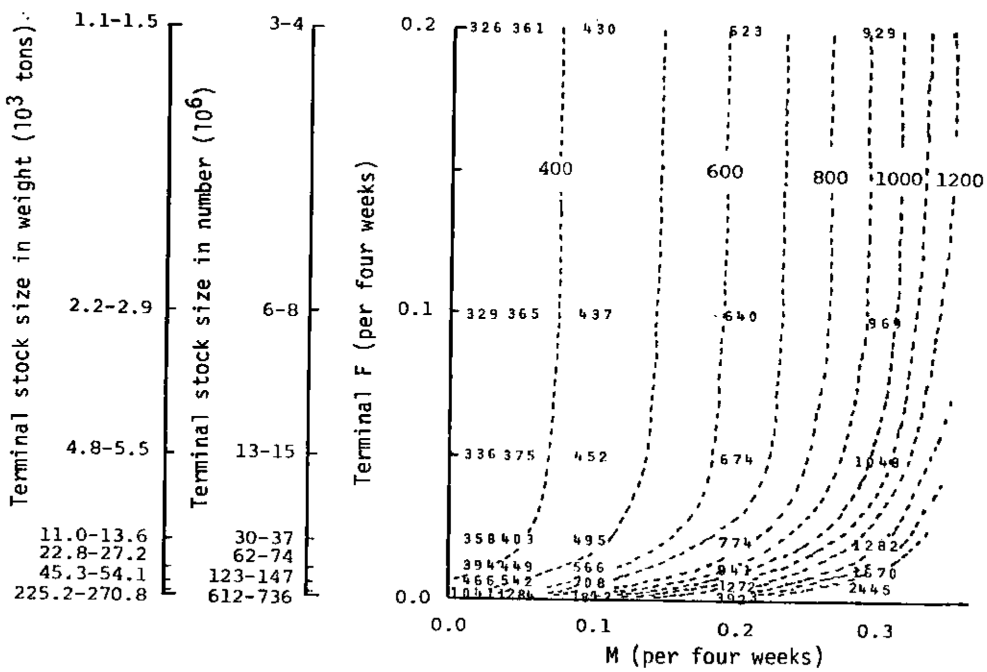

Fig.6 Intial stock sizes in number (10^6) of Illex in Division 4 for 1977 estimated from combinations of various M and terminal F

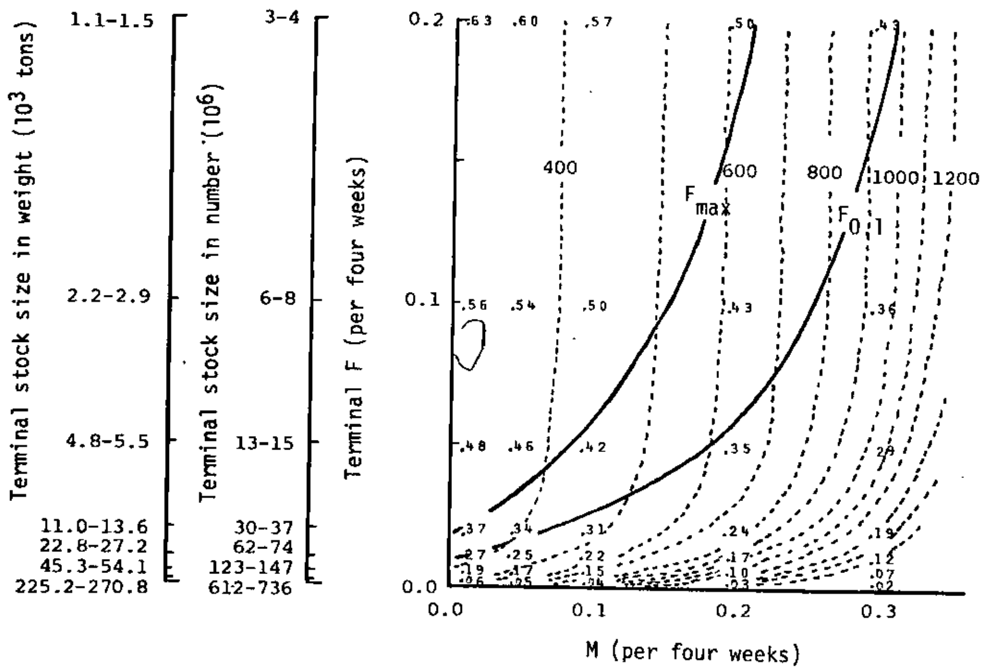

Fig.7 F values in Subarea 4 for 1977 estimated from combinations of various M and terminal F. The dotted lines show the initial stock size in number (10^6)

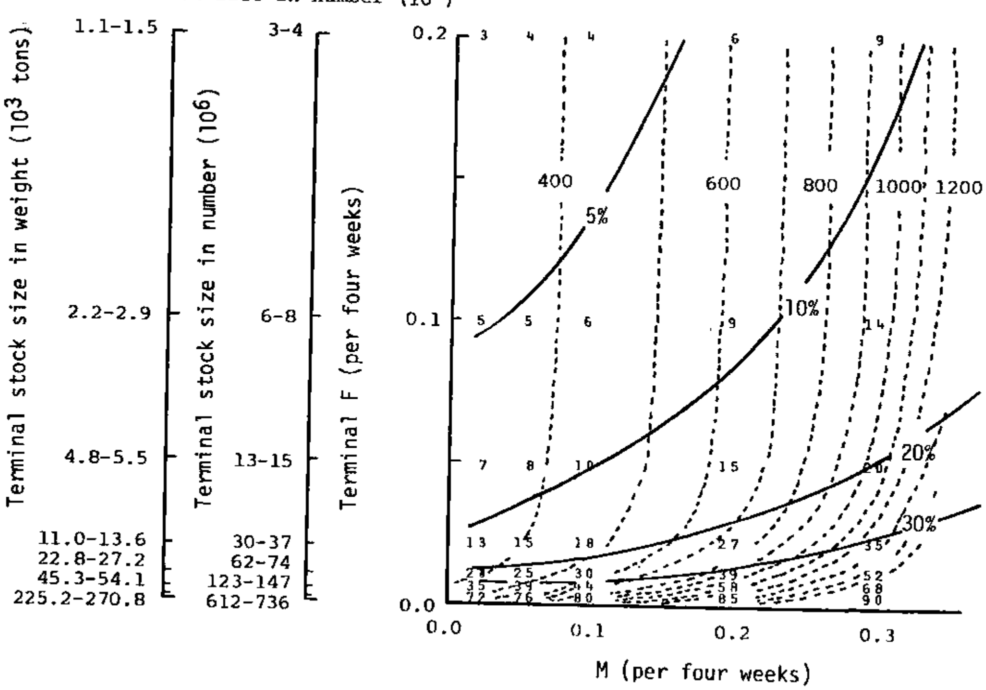

Fig.8 Ratios of the residual size of spawners to that in natural condition without fishing mortality estimated from combinations of various M and terminal F. The dotted lines show the initial stock size in number (10^6)