NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N3097 NAFO SCR Doc. 98/96

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1998

Management Implications from Sexual Differences in Maturation and Spawning Mortality of Northeast Arctic Cod

Tore Jakobsen and Adnan Ajiad

Institute of Marine Research, P.O.Box 1870 Nordnes
N-5024 Bergen, Norway

Absttract

There is evidence of sexual differences in maturation of Northeast Arctic cod and indications of high mortality among the mature males. Both factors affect the composition of the spawning stock by sex and age. The higher mortality in males could be caused by spawning and this is investigated by adding spawning mortality in calculations of the life history of a year class to see if the results fit observed sex ratios in commercial landings from the Lofoten spawning fishery. The results indicate a higher mortality rate in mature males than in mature females. This may be caused by an additional spawning mortality, but could also be caused by the fishery and the results are not conclusive. Increasing the fishing mortality rates has largest impact on the female spawning stock and will generate a surplus of male spawners. The results have implications for estimation of biological reference points and the way spawning stock biomass is used in management considerations. Estimation of the female SSB is necessary if maternal effects shall be taken into account.

Introducction

The stock assessment for Northeast Arctic cod (a.k.a. Arcto-Norwegian cod) is not split by sex. However, Ajiad et al. (1998) show that there has been a clear and consistent sexual difference in maturation in Northeast Arctic cod in recent years. On average males reach maturity approximately one year earlier than the females. This will influence the sex composition in the spawning stock and the SSB (spawning stock biomass) will be a biased measure of both female and male spawning potential. The SSB is important in management advice because it is used in estimation of biological reference points for both biomass and fishing mortality. There is increasing evidence that maternal effects are important (Kjesbu et al., 1991, Marshall et al., 1998). Failing to take the female spawning stock into account might therefore have implications for fishery management.

The research has been concentrated on the female spawners, while the the male spawners have attracted less interest. The results of Trippel and Neilsen (1992) and Trippel and Morgan (1994a, b) indicate that paternal effects play a modest role in the spawning process. However, the earlier maturation in males has a large effect on the sex ratio in the spawning stock and this might be of significance to the recruitment.

Samples from commercial landings on the spawning grounds show that the ratio male/female spawners changes with age. Males dominate the youngest age groups, whereas females dominate the oldest. This might be explained by differences in fishing mortality between immature and mature fish, but there could also be an effect from sexual difference in spawning mortality.

In the stock assessment a natural mortality rate of 0.2 is assumed for the older age groups. It is difficult to distinguish spawning mortality from other natural mortality, but spawning mortality could be the most important factor among mature fish. Beverton et al. (1994) examined individual maturation cohorts of Northeast Arctic cod and their results indicate that spawning mortality might be higher in fish maturing at age 6 or 7 than in fish maturing later. Their estimate of natural mortality rate for these three groups were 0.27, 0.17 and 0.15, respectively.

The aim of this study is to see if there is any evidence of difference in spawning mortality between males and females. The results are then used together with the results of Ajiad et al. (1998) to identify possible implications for fishery management.

Material and Methods

Most of the data are taken from Ajiad et al. (1998) and are from research surveys in the period 1989-1997. The rest of the data are from commercial landings in the Lofoten region, the main spawning grounds for Northeast Arctic cod. These landings are from gill net, long line, hand line and Danish seine (trawling is prohibited in the area). Both the survey data and the commercial fishery data comprise age, length and maturity stage (for more details, see Ajiad et al., 1998). Data from the most recent assessment of Northeast Arctic cod (ICES, 1999) are also used.

The study of spawning mortality was made by simulating the progress of a year class in the stock by applying the average natural and fishing mortality rates for 1989-1997 (ICES, 1999), including estimates of the fishing mortality rates for immature and mature fish, respectively. The simulation was done separately for females and males, using the maturity ogives (means for 1989-1997) in Ajiad et al. (1998). The mean ratio 1989-1997 of male/female spawners at each age was then compared to those observed in the commercial landings from the same period.

The mean selection pattern for Northeast Arctic cod in 1989-1997 increases up to age 8 and appears to be fairly constant for older ages. The lower exploitation of the younger fish is caused mainly by gear selectivity and minimum landing size regulations which allow temporary closures of areas with much undersized fish. As the fish mature they will be caught also in the spawning fishery in coastal areas and mature fish will therefore be subject to a heavier fishing pressure than immature fish of the same age and size. However, to calculate separate selection patterns for immature and mature fish, respectively, requires that all catches are split into mature and immature fish and these data are not readily available. The selection patterns used in this study are therefore based on a subjective evaluation of the available information, taking into account i.a. the proportion of the catch taken in coastal fisheries.

The results were used to estimate yield, SSB and numbers of spawners per recruit (at age 3) for the sexes separately. The implications for fishery management advice are discussed.

Results

In spite of the difference in maturation, there is little difference in growth between the sexes. In immature fish the females tend to be slightly longer (approximately 0.5 cm) than the males in the same age group. In mature fish the difference tends to increase with age (Ajiad et al., 1998), but is still small. In this study growth, or more precisely weight at age, is assumed to be the same for both sexes.

In the simulations it is assumed that males and females are equally represented in the stock before maturation. The survey data were examined to check this assumption and no significant deviation from a fifty-fifty distribution was found.

In the present study, the time period was too short to take maturation cohorts into consideration. Instead, the following scenarios for spawning mortality were tested:

1. It is constant with age and the same for both sexes.
2. It is constant with age, but different for the sexes.
3. It increases with age in the same way for both sexes.
4. It increases with age, but in a different way for the sexes.

Fishing mortality for immature and mature fish, respectively, was assumed to be the same for both sexes. The sum of least squares was used as indicator of the best fit between the obtained ratios of male/female spawners and the values observed in the commercial fishery data for the age groups 5-13 (data on older fish were too noisy). Within realistic ranges of total mortality rates the results were fairly consistent, showing a difference in spawning mortality in the range 0.01-0.10, mostly close to 0.05, with males always having the higher value. Changing assumptions about other natural mortality or the exploitation of the immature fish made little difference. However, the fit tended to be poorest for the oldest and the youngest fish and no reasonable trend in assumed spawning mortality with age could change that. Considering only the oldest age groups (10-13) indicated a larger difference in spawning mortality, approximately 0.15. The table below shows the ratios male/female spawners observed in the commercial data and the corresponding results of a simulation with no female spawning mortality and male spawning mortality assumed to be constant with age.

Age	Observed male/female ratios	Simulated male/female ratios
5	3.82	3.52
6	1.98	2.15
7	1.28	1.39
8	1.09	0.95
9	0.91	0.86
10	0.90	0.78
11	0.72	0.73
12	0.66	0.68
13	0.54	0.64

The simulations indicate that there might be a higher spawning mortality for males than for females, but they give no indication of how large part of the natural mortality rate can be ascribed to spawning mortality. In the calculation of yield, SSB and numbers of spawners per recruit, the natural mortality for females is assumed to be 0.2 and for males it is assumed to be 0.25, i.e. a difference of 0.05. Table 1 shows the part of worksheets used in the calculations and also demonstrates most of the set-up for the worksheet used to estimate spawning mortality.

Figure 1 shows the results of the yield per recruit calculations. F_{max} for females is at 0.25, for males at 0.34 and for both sexes combined at 0.29. The yield per recruit is higher for females than for males and the difference decreases as the fishing mortality rate increases. At recent levels of fishing mortality (0.4-0.8) the difference will be 4-9%.

Because of the assumed spawning mortality in males, there will be approximately 10% more females than males in a pristine stock and the biomass of females will be 30% higher. However, these differences are quickly reduced with increasing fishing mortality rate and at recent levels they are 1-2% and 4-7% in number and biomass, respectively.

Figure 2 shows SSB per recruit for each sex and Figure 3 shows the ratio male/female SSB. In a pristine stock the female SSB will be 30% larger than the male SSB, but there is a substantial effect of the fishing mortality and the SSB levels will be equal already at F=0.2. At recent levels of fishing mortality the male SSB is 15-40% larger than the female SSB. This also means that the female SSB is more rapidly reduced from the pristine stock level as fishing mortality increases (Figure 4).

The difference is more pronounced in the number of spawners (Figures 5 and 6). In a pristine stock the numbers of male and female spawners will be approximately the same, but at an F of 0.45 there will be 50% more males than females in the spawning stock and nearly twice as many if F exceeds 1.0.

Discussion

The data indicate that the natural mortality is higher in mature males than in mature females in the Northeast Arctic cod stock and the difference might be due to spawning mortality. Although the difference appears to be relatively small it has an effect on the estimation of F_{max} and if the spawning mortality is removed from the calculations, the combined F_{max} will be reduced from 0.29 to 0.25. It could also have some effect on the calculation of other reference points and should therefore not be ignored as a potential source of bias.

The evidence of a spawning mortality is not conclusive. The calculations are based on average values, but in the period studied there were large variations in fishing mortality rate, recruitment and, to a lesser degree, maturation which might affect the results. However, the observed male/female ratios are fairly consistent over the period.

Another possible explanation for the change in male/female ratio with age is that mature males are targeted more in the fishery than mature females. To clarify this a comprehensive study of the catch at age data is needed and it could in practice prove difficult to distinguish between additional fishing mortality and additional natural mortality.

Whatever the cause of the additional mortality on mature males, this together with the sex difference in maturation has a large impact on the male/female ratio in the spawning stock. If the female SSB is considered a better measure of recruitment potential than the combined stock, assuming that the latter is proportional to the female SSB will give biased results. Furthermore, if maternal effects shall be taken fully into account, spawning classes, size composition, condition etc. need to be considered. A measure of the female SSB and detailed data on its composition will then be required.

The calculations show that in a pristine stock the numbers of male and female spawners are approximately equal. This indicates that a surplus of males is not needed to ensure that enough eggs are fertilized to give satisfactory recruitment. However, the pristine stock is far outside the range covered by the data and depensatory mechanisms could easily result in another male/female ratio.

The results show that increasing the fishing mortality creates a surplus of males in the spawning stock. This means that there will be a large number of males which apparently are not needed to ensure fertilization of the eggs. These males will compete with the other mature fish for food which could have a negative effect on egg production and quality.

It is quite possible that taking sexual differences in maturation into account and using the female spawning stock as basis could have important consequences for management advice. Unfortunately, the historical SSB estimates for Northeast Arctic cod are not easily split by sex and a considerable effort is needed to establish a reliable time series of female SSB. It would also be interesting to see if other cod stocks show the same properties and to make further studies on the consequences of changing to the female spawning stock as basis for management advice.

References

AJIAD, A., JAKOBSEN, T. and NAKKEN, O. 1998. Sexual difference in maturation of Northeast Arctic Cod. NAFO Symposium on variation in maturation, growth, condition and spawning stock biomass production, Lisboa 1998. 24 pp.

BEVERTON, R. J. H., HYLEN, A. and OSTVEDT, O. J. 1994. Growth, maturation, and longevity of maturation cohorts of Northeast Arctic cod. ICES mar. Sci. Symp., 198: 482-501.

ICES, 1999. Report of the Arctic Fisheries Working Group. ICES CM 1999/Assess 2 (in press).

KJESBU, O., KLUNGSØYR, J., KRYVI, H., WITTHAMES, P. and GREER WALKER, M. 1991. Fecundity, atresia, and egg size of captive Atlantic cod (*Gadus morhua*) in relation to proximate body composition. Can. J. Aquat. Sci. 48: 2333-2343.

MARSHALL, T., KJESBU, O., YARAGINA, N., SOLEMDAL, P. and ULLTANG, Ø. 1998. Is spawner biomass a sensitive measure of the reproduction and recruitment potential in Northeast Arctic cod. Can. J. Fish. Aquat. Sci., 1998 (in press).

TRIPPEL, E.A. and NEILSEN, J.D. 1992. Fertility and sperm quality of virgin and repeat-spawning Atlantic cod (*Gadus morhua*) and associated hatching success. Can. J. Fish. Aquat. Sci. 49: 2118-2127.

TRIPPEL, E.A. and MORGAN, M.J. 1994a. Age-specific paternal influences on reproductive success in Atlantic cod (*Gadus morhua*) of the Grand Banks, Newfoundland. ICES mar. Sci. Symp., 198: 414-422.

TRIPPEL, E.A. and MORGAN, M.J. 1994b. Sperm longevity in Atlantic cod (*Gadus morhua*). Copeia 1994: 1025-1029.

Table 1. Worksheets used in the simulations and in Yield, SSB and Spawner per Recruit calculations.

NORTHEAST ARCTIC COD

FEMALES

F-factor 1.00

AGE	N	I-surv	M-surv	Imm	Mat	CANU	YIELD	BIOM	SSB	Fimm	Fmat	F	M1	Msp	M	Zimm	Zmat	Z	WECA	WEST	MORP
3	1.0000	1.0000	0.0000	1.0000	0.0000	0.0306	0.0236	0.3100	0.0000	0.037	0.370	0.037	0.350	0.350	0.350	0.387	0.720	0.387	0.77	0.31	0.00
4	0.6791	0.6791	0.0000	0.6791	0.0000	0.1018	0.1262	0.5093	0.0000	0.185	0.647	0.185	0.250	0.250	0.250	0.435	0.897	0.435	1.24	0.75	0.00
5	0.4397	0.4397	0.0000	0.4211	0.0186	0.1526	0.2792	0.5847	0.0247	0.462	0.924	0.478	0.200	0.200	0.200	0.662	1.124	0.678	1.83	1.33	0.04
6	0.2232	0.2172	0.0060	0.1726	0.0506	0.1066	0.2783	0.4889	0.1108	0.647	1.109	0.735	0.200	0.200	0.199	0.847	1.309	0.934	2.61	2.19	0.23
7	0.0877	0.0740	0.0137	0.0452	0.0425	0.0520	0.1950	0.2982	0.1445	0.832	1.294	1.030	0.200	0.200	0.199	1.032	1.494	1.229	3.75	3.40	0.48
8	0.0257	0.0161	0.0095	0.0053	0.0203	0.0166	0.0879	0.1272	0.1008	0.924	1.294	1.205	0.200	0.200	0.200	1.124	1.494	1.405	5.29	4.96	0.79
9	0.0063	0.0017	0.0046	0.0004	0.0059	0.0042	0.0290	0.0439	0.0409	0.924	1.294	1.263	0.200	0.200	0.200	1.124	1.494	1.463	6.95	6.98	0.93
10	0.0015	0.0001	0.0013	0.0000	0.0014	0.0010	0.0084	0.0138	0.0137	0.924	1.294	1.289	0.200	0.200	0.200	1.124	1.494	1.489	8.60	9.50	0.99
11	0.0003	0.0000	0.0003	0.0000	0.0003	0.0002	0.0022	0.0033	0.0033	0.924	1.294	1.293	0.200	0.200	0.200	1.124	1.494	1.493	10.16	10.13	1.00
12	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0006	0.0009	0.0009	0.924	1.294	1.294	0.200	0.200	0.200	1.124	1.494	1.494	12.00	12.00	1.00
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0002	0.924	1.294	1.294	0.200	0.200	0.200	1.124	1.494	1.494	12.81	12.50	1.00
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.924	1.294	1.294	0.200	0.200	0.200	1.124	1.494	1.494	13.29	13.90	1.00
15+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.924	1.294	1.294	0.200	0.200	0.200	1.124	1.494	1.494	18.01	15.00	1.00
	2.4635			2.3238	0.1397	0.4657	1.0306	2.3807	0.4399		F5-10	1.000									

MALES

F-factor 1.00

AGE	N	I-surv	M-surv	Imm	Mat	CANU	YIELD	BIOM	SSB	Fimm	Fmat	F	M1	Msp	M	Zimm	Zmat	Z	WECA	WEST	MORP
3	1.0000	1.0000	0.0000	1.0000	0.0000	0.0290	0.0223	0.3100	0.0000	0.035	0.350	0.035	0.350	0.400	0.350	0.385	0.750	0.385	0.77	0.31	0.00
4	0.6805	0.6805	0.0000	0.6744	0.0060	0.0985	0.1221	0.5104	0.0045	0.175	0.612	0.178	0.250	0.300	0.250	0.425	0.912	0.428	1.24	0.75	0.01
5	0.4434	0.4410	0.0024	0.3774	0.0660	0.1566	0.2867	0.5898	0.0878	0.437	0.874	0.490	0.200	0.250	0.206	0.637	1.124	0.696	1.83	1.33	0.15
6	0.2210	0.1996	0.0215	0.1108	0.1103	0.1112	0.2902	0.4841	0.2415	0.612	1.049	0.804	0.200	0.250	0.221	0.812	1.299	1.026	2.61	2.19	0.50
7	0.0793	0.0492	0.0301	0.0198	0.0595	0.0480	0.1799	0.2695	0.2021	0.787	1.224	1.093	0.200	0.250	0.235	0.987	1.474	1.328	3.75	3.40	0.75
8	0.0210	0.0074	0.0136	0.0019	0.0191	0.0132	0.0701	0.1042	0.0947	0.874	1.224	1.186	0.200	0.250	0.244	1.074	1.474	1.430	5.29	4.96	0.91
9	0.0050	0.0007	0.0044	0.0000	0.0050	0.0032	0.0223	0.0351	0.0348	0.874	1.224	1.220	0.200	0.250	0.249	1.074	1.474	1.469	6.95	6.98	0.99
10	0.0012	0.0000	0.0011	0.0000	0.0011	0.0007	0.0063	0.0110	0.0105	0.874	1.224	1.206	0.200	0.250	0.247	1.074	1.474	1.454	8.60	9.50	0.96
11	0.0003	0.0000	0.0003	0.0000	0.0003	0.0002	0.0018	0.0027	0.0027	0.874	1.224	1.222	0.200	0.250	0.250	1.074	1.474	1.472	10.16	10.13	1.00
12	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0005	0.0007	0.0007	0.874	1.224	1.224	0.200	0.250	0.250	1.074	1.474	1.474	12.00	12.00	1.00
13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0002	0.874	1.224	1.224	0.200	0.250	0.250	1.074	1.474	1.474	12.81	12.50	1.00
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.874	1.224	1.224	0.200	0.250	0.250	1.074	1.474	1.474	13.29	13.90	1.00
15+	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.874	1.224	1.224	0.200	0.250	0.250	1.074	1.474	1.474	18.01	15.00	1.00
	2.4517			2.1844	0.2673	0.4607	1.0023	2.3177	0.6797		F5-10	1.000									

Figure 1. Yield per recruit

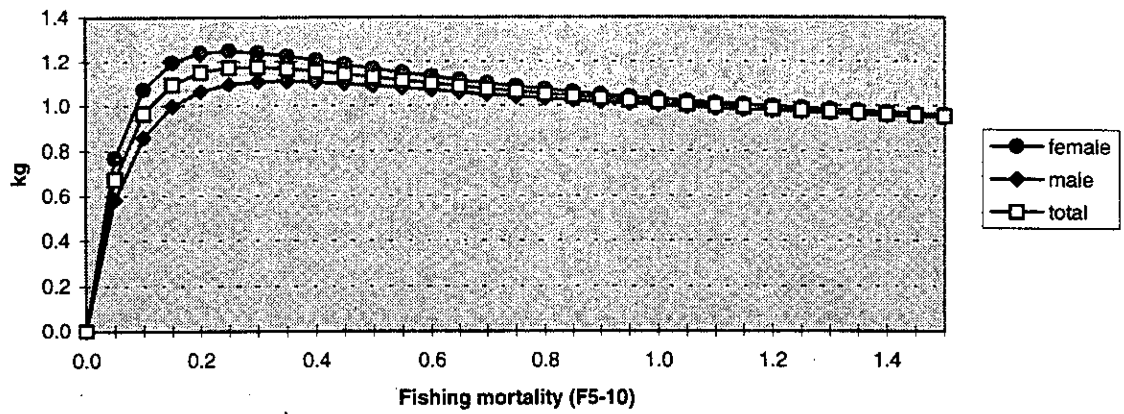

Figure 2. Spawning stock biomass per recruit

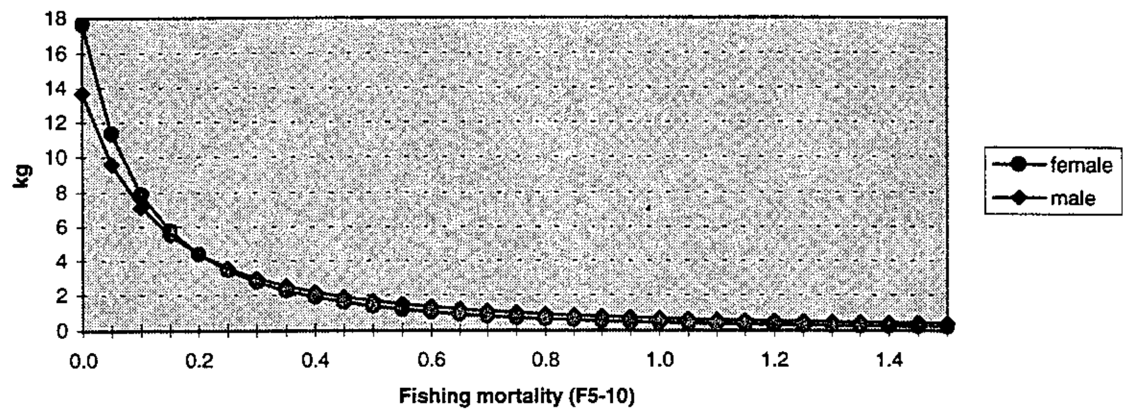

Figure 3. Ratio male/female SSB

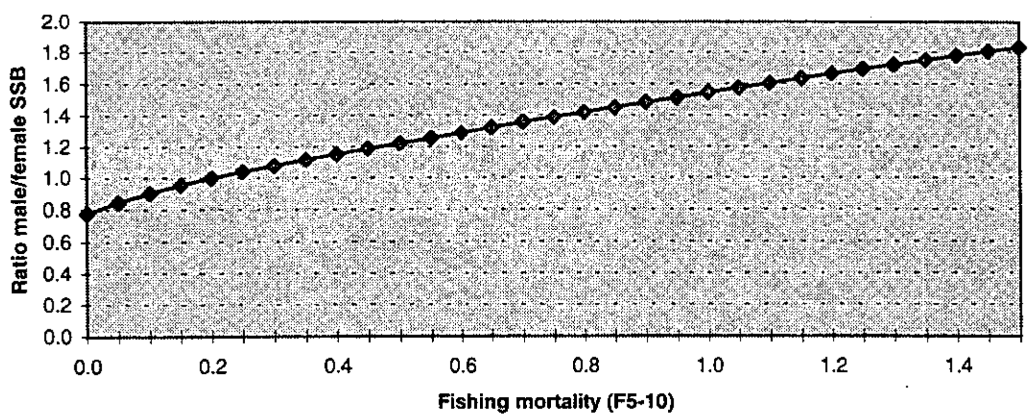

Figure 4. SSB relative to virgin SSB

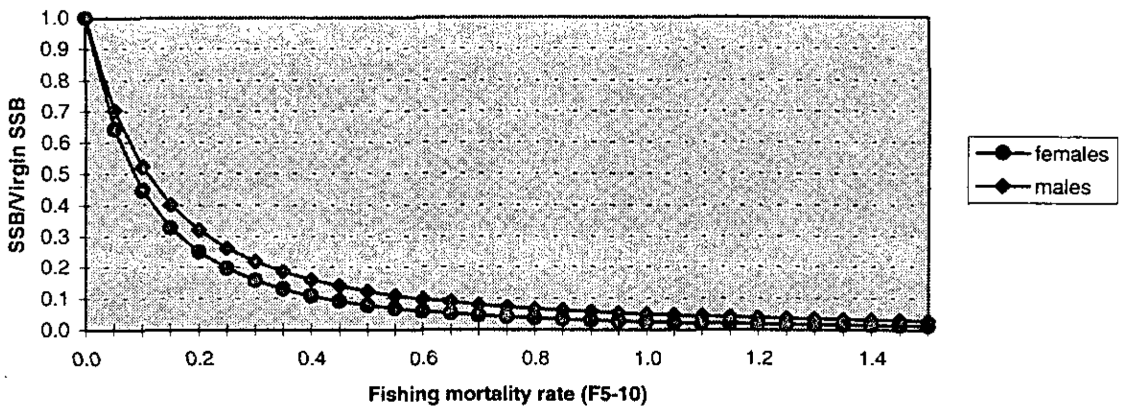

Figure 5. Spawners per recruit

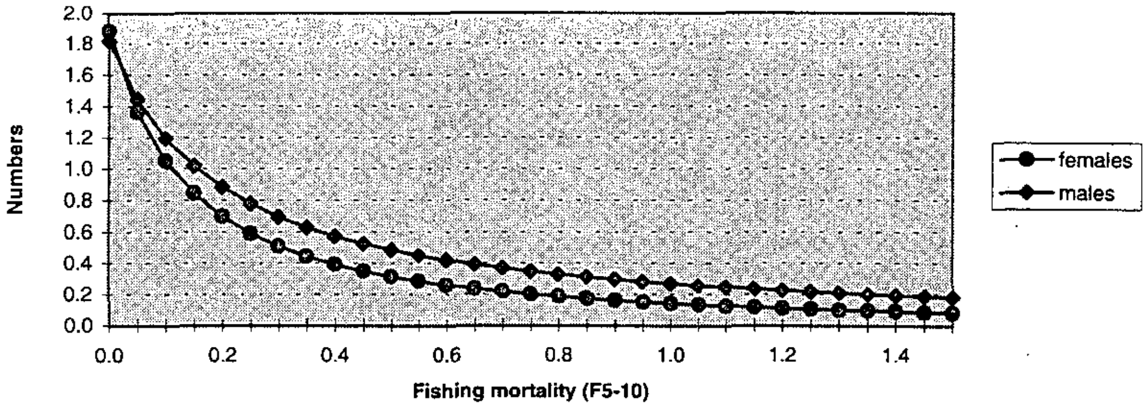

Figure 6. Ratio male/female spawners