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Estimation of Natural Mortality of Newfoundland capelin using the Icelandic method

by

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INTRODUCTION

There are two components of natural mortality of capelin; spawning mortality which is relatively large and occurs over a short time period and mortality through other causes, probably principally predation (see eg. Winters and Carscadden 1978). Winters (1974) provided an estimate of spawning mortality and Friogeirsson (1979) calculated natural mortality (other than spawning mortality) of Icelandic capelin. An examination of the mathematical expression proposed by Friogeirsson (1979) suggests that the estimation of M could be biased by the sampling data, especially the age composition and sex ratio in the samples. We have tested the sensitivity of the model to changes in age-composition by using Icelandic data and to changes in sex ratio by using Canadian and USSR sampling data from the NAFO Div. 3N and Div. 3NOPs stock, respectively.

The Friogeirsson Method:

In this method it is assumed that at age 2 there is a 1:1 sex ratio. Thus, the following expression is derived:

$$N_6e^{4m} + N_5e^{3m} + N_4e^{2m} + N_3e^{m} + N_2 =$$

$$F_6e^{4m} + F_5e^{3m} + F_4e^{2m} + F_3e^{m} + F_2$$

where N_2, N_3..... N_n = Males 2-years-old, 3-years-old ..... n years old

F_2, F_3..... F_n = Females 2-years-old, 3-years-old ... n years old

(We have changed the notation slightly for clarity.)

The average percent age-composition from 10 years sampling data was used for values of N and F and the expression was solved for M. The result was M = 0.7 assuming total spawning mortality and M = 0.5 assuming some post-spawning survival.

Materials and Methods

Since the aim of the Friogeirsson method is to calculate M such that both sides of the expression are equal, that is, a 1:1 sex ratio, a computer program was produced that used a range of values of M (0.001 to 1.00 by increments of 0.001) and calculated the proportions of males for each value of M. The values of M were plotted against proportions of males to evaluate the relationship between the two variables.

Icelandic Capelin:

All data in this section are taken from Friogeirsson (1979).

When complete spawning mortality was assumed the following equation was constructed:

$$0.01e^{4m} + 0.38e^{3m} + 17.69e^{2m} + 27.79e^{m} + 1.27 =$$

$$0.22e^{3m} + 12.94e^{2m} + 37.15e^{m} + 2.55$$

The results (Fig. 1a) indicate that for a wide range of M, the range of proportions of males is quite small. The proportions of males at M = 0.7 (Friogeirsson's solution) was 50.1% and 50.0% males were estimated when M ranged from .663 to .685.

Friogeirsson (op cit) also estimated M when 2% of the females survived spawning using the expression

$$0.01e^{4m} + 0.38e^{3m} + 17.69e^{2m} + 27.79e^{m} + 1.27 =$$

$$12.2e^{2m} + 37.1e^{m} + 2.55$$

The results (Fig. 1B) from this expression show a similar pattern to those when no spawning survival is assumed except that M is now lower. The proportion of males when M = 0.50 (Friogeirsson's solution) was 50% but 50% males were estimated when M ranged from .487 to .506.

To investigate the influence of age-composition on the calculated values of M, the age-compositionswere altered in a systematic fashion. Since standard deviations represent variation around the mean that would encompass expected deviation in the population, we first calculated the standard deviations of the percent age-compositions (Table 1) given by Friogeirsson (1979). It was found that for ages 3 and 4 which dominated in the population, the standard deviations were approximately equal. To determine the effect of different age-compositions on the estimation of M, the percent age-compositions were altered using the standard deviations while keeping the sex ratios the same as in the original data. Two situations were created:

(a) The proportion of 3-year-old males was increased by the standard deviation for that age group and the proportion of 4-year-olds was decreased by the same amount. The same operation was performed for females using the standard deviation for 3-year-old females. The new equation is:

$$0.01e^{4m} + 0.38e^{3m} + 8.12e^{2m} + 37.36e^{m} + 1.27 =$$

$$0.22e^{3m} + 4.38e^{2m} + 45.71e^{m} + 2.55$$

(b) The proportion of 3-year-old males was decreased by the value of the standard deviation and for 4-year-olds increased by the same amount. The age-composition of 3-year-old females was decreased by the value of the standard deviation and for 4-year-olds the value for the age-composition was increased by the same amount.

The new equation is:

$$0.01e^{4m} + 0.38e^{3m} + 27.26e^{2m} + 18.22e^{m} + 1.27 =$$

$$0.22e^{3m} + 21.50e^{2m} + 28.59e^{m} + 2.55$$

The results from this analysis (Fig. $1C_a$ and $1C_b$) show that the values of M range from 0.60 to 0.77, this range being approximately 22% of the highest value.

Newfoundland Capelin-Canadian Data:

Data for mature capelin collected from ICNAF Div. 3N, June only, 1967-77 (data were not available for 1968, 1970, 1971) were used in this analysis. Ages 3 and 4 were most abundant in the samples and females were dominant (Table 2). The expression used to calculate M was:

$$0.13e^{4m} + 2.61e^{3m} + 16.83e^{2m} + 12.13e^{m} + 0.48 =$$

$$1.53e^{4m} + 6.94e^{3m} + 29.86e^{2m} + 27.50e^{m} + 2.00$$

A reasonable estimate of M could not be calculated (Fig. 2A) by estimating a 1:1 sex ratio presumably because the sex ratio in the sampling data did not approach 1:1.

In an attempt to overcome the problem of the large deviation from an equal sex ratio in the sampling data, the percent composition of each sex was calculated (Table 3) and then the sex ratio was assumed to be 50:50. The new expression was:

$$0.16e^{4m} + 3.48e^{3m} + 28.24e^{2m} + 17.52e^{m} + 0.59 =$$

$$1.16e^{4m} + 5.82e^{3m} + 20.90e^{2m} + 20.41e^{m} + 1.65$$

The results from this analysis revealed that a 50:50 sex ratio could be calculated for all values of M ranging from 0.001 to 0.204 (Fig. 2B).

Newfoundland Capelin-USSR Data:

USSR data for Div. 3NOPs, 1971 to 1978 (V.S. Bakanev, pers. comm.) were used. In most years, small numbers of 1-year-olds were reported. Since 1-year-olds are undoubtedly immature, these values were removed and the percent age-composition by sex was calculated assuming all 2-year-olds reported were mature (Table 4). Data from 1978 were excluded because of the anomalous geographic distribution of mature fish that year; it is known, for instance, that the biomass of spawning fish in Div. 3N was very low in 1978 (Carscadden and Miller 1979). The relatively high proportions of 2-year-old females in 1978 suggests that more immature fish than usual were present in the commercial samples. The resulting expression for this analysis is

$$0.24e^{4m} + 3.39e^{3m} + 20.87e^{2m} + 12.56e^{m} + 0.77 =$$

$$1.79e^{4m} + 6.83e^{3m} + 25.58e^{2m} + 24.66e^{m} + 3.30$$

The results of this analysis (Fig. 3A) indicated that 50% males could not be estimated with the range of M that we used, probably because the sex ratio in the original data was not close to 1:1.

We again set the sex ratio approximately equal (Table 5) which resulted in the following expression:

$$0.40e^{4m} + 4.47e^{3m} + 28.48e^{2m} + 15.33e^{m} + 1.14 =$$

$$1.31e^{4m} + 5.43e^{3m} + 20.00e^{2m} + 20.59e^{m} + 2.71$$

When this expression was solved, it was found that two values of M would satisfy the requirements for an equal sex ratio. These values of M were in the ranges of 0.023-0.062 and 0.657-0.691 (Fig. 3B).

DISCUSSION

The results from this analysis indicate that the estimates of M are highly dependent on the sampling data, both the age-composition and sex ratios. Although the Icelandic data provide biologically meaningful estimates of M, changes in the age-composition which are within the ranges of variation inherent in the data result in values of M that vary by 0.17. This range is quite wide when one considers that the value of M (exclusive of spawning mortality) used in Canadian sequential capelin abundance models (Carscadden and Miller 1979; Miller and Carscadden 1978) is 0.3.

The influence of different sex ratios is illustrated by the analysis of the Canadian and USSR data. With the Canadian data, even when sex ratios were set equal, values of M covered a wide and unreasonable range (0.001-0.204). The sampling data from the USSR catches were also unreliable; in one case an estimate of M could not be calculated and when sex ratios were set equal, two values of M satisfied the equation.

It is probable that the unequal sex ratios in the Canadian and USSR data resulted from sampling bias. Many of the Canadian samples in the more recent years came from midwater trawls and the Soviet fishery is conducted largely by midwater trawls. On the spawning grounds, females may be in midwater while males stay near the bottom, thus making midwater trawls more selective for females (Winters and Campbell 1974). Norwegian purse seine data may be more suitable for this analysis; however, these data are to a large extent in graphical form making their interpretation subject to some error. Since the method used in this paper appears to be sensitive to sampling biases, only original data should be used.

The poor results obtained from the Canadian and USSR data may be a result of violation of the assumption of complete spawning mortality. Friogeirsson (1979) assumed a spawning survival of females of only 2% in his calculations and this resulted in a reduction of his estimate of M from 0.7 to 0.5. Winters and Campbell (1974) suggested that spawning survival in Newfoundland female capelin is probably less than 20% and Prokhorov (1960) reported some post-spawning survival in Barents Sea capelin. Since small changes in spawning survival result in large changes in the estimation of M, further calculations to estimate M incorporating spawning survival are somewhat meaningless unless reliable estimates of the latter variable can be made.

The model proposed by Friogeirsson (1979) appears to be correct; however, it is sensitive to any biases inherent in the sampling data. Since it is probable that most of the data collected either by research vessels or the commercial fishery is biased to some degree because of such factors as gear selectivity or behavior of fish, the results from Friogeirsson's (1979) model presented should be used only with extreme caution.

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Table 1. Average age-composition (from Table 1, Friogeirsson 1979) and standard deviation by sex of Icelandic capelin.

Age	Average percent composition		Standard deviation	
	Male	Female	Male	Female
2	1.27	2.55	1.42	2.51
3	27.79	37.15	9.57	8.56
4	17.69	12.94	9.66	8.62
5	0.38	0.22	.18	.14
6	0.01	-	-	-

Table 2. Percent age-composition for capelin in ICNAF 3N, June, using Canadian data.

Age/Year	1967	1969	1972	1973	1974	1975	1976	1977	Average
Males									
2	0.2	2.6				1.0			0.48
3	32.4	10.4	10.9	0.7	14.4	13.0	11.8	3.4	12.13
4	14.4	31.3	19.1	12.7	18.9	13.7	7.4	17.1	16.83
5	1.8	1.7	.3	1.3	13.3	0.9	0.8	0.8	2.61
6					.9		0.1		.13
TOTAL	48.8	46.0	30.3	14.7	47.5	28.6	20.1	21.3	32.18
Females									
2	0.2	8.9		1.0	0.4	5.4	0.1		2.00
3	25.1	25.4	30.0	8.3	14.3	26.3	57.4	33.2	27.50
4	15.9	16.9	36.0	70.3	14.1	22.5	18.4	44.8	29.86
5	9.2	2.6	3.1	5.7	22.0	9.1	3.1	.7	6.94
6	1.0	0.3	.6		1.9	7.8	.6		1.53
TOTAL	51.4	54.1	69.7	85.3	52.7	71.1	79.6	78.7	67.83

Table 3. Percent age-composition by sex assuming a 1:1 sex ratio for capelin from ICNAF Div. 3N, June.

Age/Year	1967	1969	1972	1973	1974	1975	1976	1977	Average
Males									
2	.2	2.84				1.8			0.59
3	33.2	11.30	17.9	2.3	15.2	22.7	29.5	8.1	17.52
4	14.8	34.0	31.6	43.2	20.0	24.0	18.3	40.2	28.24
5	1.8	1.9	.5	4.6	14.0	1.6	1.9	1.8	3.48
6					.9		.3		.16
TOTAL	50.0	50.0	50.0	50.1	50.1	50.1	50.0	50.1	49.99
Females									
2	.2	8.3		.6	.4	3.8			1.65
3	24.5	23.5	21.5	4.9	13.5	18.4	35.8	21.1	20.41
4	15.5	15.6	25.8	41.2	13.4	15.8	11.5	28.5	20.90
5	9.0	2.4	2.3	3.3	20.9	6.4	1.9	.4	5.82
6	.9	.3	.4		1.8	5.5	.3		1.16
TOTAL	50.1	50.1	50.0	50.0	50.0	49.9	49.5	50.0	49.94

Table 4. Percent age-composition of capelin for ICNAF Div. 3NOPs from USSR data.

Age/Year	1971	1972	1973	1974	1975	1976	1977	1978	Average*
Males									
2	.8	0.1	.6	0.5	2.1	1.3	0.1	1.6	0.77
3	28.7	15.0	1.5	13.8	8.8	19.3	0.9	41.4	12.56
4	22.9	28.9	27.7	15.6	16.4	11.7	23.0	13.4	20.87
5	1.8	1.9	5.6	10.6	0.8	0.8	2.1	1.6	3.39
6			0.3	0.2	0.5	0.1	0.6		0.24
TOTAL	54.2	45.9	35.7	40.7	28.6	33.2	26.7	58.0	37.38
Females									
2	4.4	2.7	2.5	1.1	5.0	3.3	4.0	9.6	3.30
3	32.6	25.0	7.2	16.6	23.0	48.0	20.2	20.4	24.66
4	8.1	24.9	46.2	17.6	24.0	11.5	46.8	8.0	25.58
5	0.6	1.5	8.1	22.2	10.4	3.0	2.1	4.0	6.83
6	0.1		0.2	1.9	8.9	1.1	0.3		1.79
TOTAL	45.8	54.1	64.2	59.4	71.3	66.9	73.4	42.0	62.16

* (Excluding 1978)

Table 5. Percent age-composition by sex assuming a 1:1 sex ratio for capelin from ICNAF Div. 3NOPs from USSR data.

Age/Year	1971	1972	1973	1974	1975	1976	1977	1978	Average*
Males									
2	0.7	0.1	0.9	0.7	3.7	1.9	0.1	1.4	1.14
3	25.8	16.4	2.0	17.0	15.4	29.1	1.7	35.7	15.33
4	20.6	31.5	38.8	19.2	28.6	17.6	43.1	11.6	28.48
5	1.7	2.1	7.8	13.0	1.4	1.2	4.0	1.4	4.47
6			0.4	0.2	0.9	0.1	1.1		.40
TOTAL	48.8	50.1	49.9	50.1	50.0	49.9	50.0	50.1	49.82
Females									
2	4.8	2.5	2.0	0.9	3.5	2.5	2.7	11.4	2.71
3	35.6	23.1	5.6	14.1	16.1	35.8	13.8	24.3	20.59
4	8.8	23.1	35.9	14.9	16.8	8.6	31.9	9.5	20.00
5	0.6	1.4	6.3	18.8	7.3	2.2	1.4	4.8	5.43
6	0.1		.2	1.6	6.2	0.8	.2		1.31
TOTAL	49.9	50.1	50.0	50.3	49.9	49.9	50.0	50.0	50.04

* (Excluding 1978)

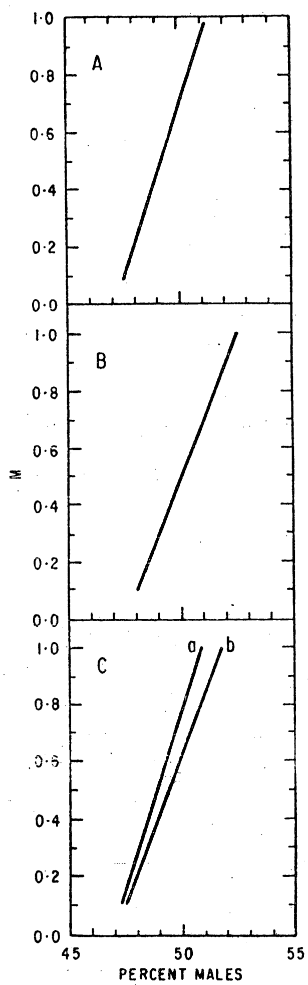

Fig. 1. Relationship between M, natural mortality of Icelandic capelin and percent males.

A. Original Icelandic data assuming complete spawning mortality.

B. Original Icelandic data assuming 2% spawning survival for females.

C. Original Icelandic data altered:

  a. by increasing the proportions of 3-year-olds and decreasing the proportions of 4-year-olds.

  b. by decreasing the proportions of 3-year-olds and increasing the proportions of 4-year-olds.

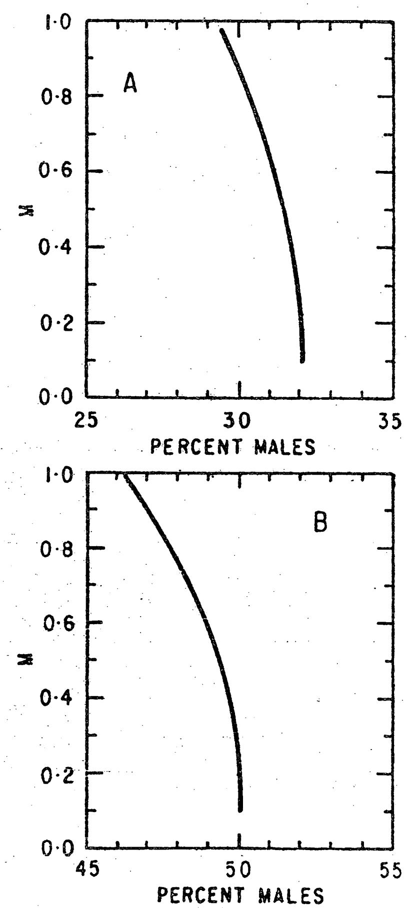

Fig. 2. Relationship between M, natural mortality of Newfoundland capelin and percent males using Canadian data when:

A. True sampling data are used
B. a 1:1 sex ratio is assumed.

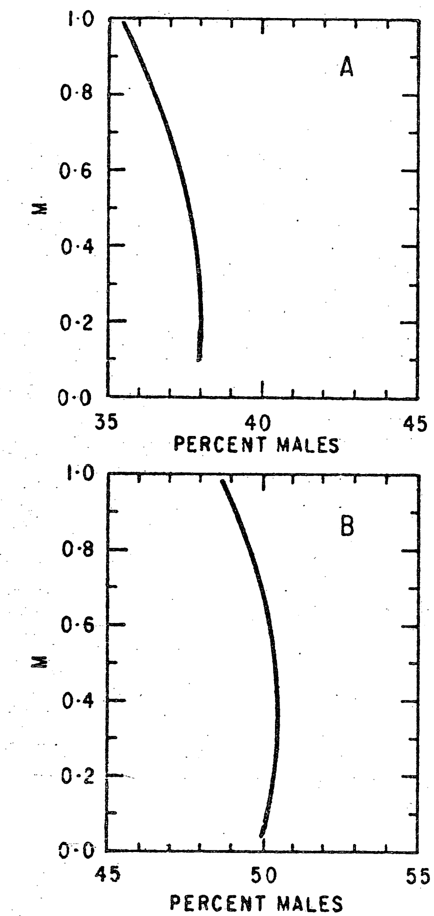

Fig. 3. Relationship between M, natural mortality of Newfoundland capelin and percent males using USSR data when:

A. True sampling data are used
B. a 1:1 sex ratio is assumed.