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AGE, GROWTH AND DISTRIBUTION OF SILVER HAKE (*Merluccius bilinearis*) ON THE SCOTIAN SHELF FROM MODAL ANALYSIS OF LENGTH FREQUENCIES

by

J. J. Hunt
Department of the Environment
Fisheries and Marine Service
St. Andrews, N. B.
Canada

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Introduction

Recent controversy over the ageing of silver hake (*Merluccius bilinearis*) from otoliths has given rise to both variation in technique and attempts to resolve differences through international discussion and workshops (Anderson and Nichy, 1974; Hunt, 1976). Results of otolith exchanges, workshops and other discussions have identified the problem as differing opinions on adult growth rates for this species which are unlikely to be resolved without some form of indirect evidence of age and growth. While hyaline (translucent) and opaque zones are evident in the otolith, separation of annuli, spawning checks, and other zones of slow growth cannot be accomplished without some prior index of growth in relation to probable size-at-age. To date, however, a mutually accepted age-length-key and definition of associated growth parameters for Northwest Atlantic silver hake have not been resolved.

In an attempt to provide indirect evidence of growth and length-at-age and to bypass otolith controversy, an indirect method of ageing by length frequency modal analysis has been developed. This report uses a technique suggested by Buchanon-Wollaston (1929) and adapted to a desk-top calculator and plotter (Doubleday and Halliday, 1975) to analyze silver hake length frequencies into modal components as evidence of length-at-age and growth characteristics.

Materials and Methods

Trawl surveys conducted by Canada and the USSR have provided length frequencies of silver hake caught on the Scotian Shelf and adjacent areas from 1970-76 (Doubleday, et al., 1976; Noskov, 1976) and these data were used throughout the analyses (Table 1). Separate length frequencies by sex were available in each of the years for Canadian data, while all USSR data were combined by sex for October. Length frequencies of commercial catches were not considered because of a two centimeter (cm) length interval as opposed to the 1 cm interval for trawl surveys and the resultant reduction in resolution.

Modal analysis of length frequencies assumes a normal distribution of length-at-age for each group and requires a minimal overlap between adjacent ages. Accuracy of this method depends on sufficient observations at relatively small length intervals over the entire length range of a species and, for silver hake, this implies a length frequency from 0-50+ cm at intervals of 1 cm or less. Both the Canadian and USSR trawl survey data conform to these conditions.

In general, the technique of modal analysis used here consists of plotting the natural logarithm (ℓ_n) of the frequency at each length interval and fitting parabolas to apparent modes by the method of least squares using a Hewlett-Packard 9821A calculator and plotter. The natural logarithm of a normal distribution

$$\ell_n Y = \ell_n (K/\sigma\sqrt{2\pi}) - 0.5\left(\frac{(X-\mu)}{(\sigma)}\right)^2$$

where K is the total number, μ is the mean length and σ is the standard deviation can be reduced to a parabola of the form

$$\ell_n Y = a_o + a_1 + a_2X^2$$

and

$$\mu = -a_1/2a_2$$

$$\sigma = \sqrt{-1/2a_2}$$

$$K = \sqrt{-\pi/a_2} \; . \; \exp (a_o - a_1^2 /4a_2)$$

A parabola was fitted to the left-most part of the frequency distribution (i.e. smallest lengths) and the contribution of this component subtracted from the total frequency and the residual treated as a new length frequency. This process was repeated until all modes had been resolved or until the degree of overlap in adjacent modes made further resolution impossible.

Canadian survey results were analyzed in this way by sex to ascertain if significant differences existed in mean lengths-at-age for males and females. Length frequencies by sex from the same cruise were examined and, if differences in modal length were present for the same relative age group, then this difference was attributed to differing growth rates between males and females.

To assign a specific age to modal lengths, it was necessary to establish a time interval required to reach that length. This was accomplished by selecting January 1st, 1970, as an arbitrary starting date and then plotting all modal lengths from available length frequencies against elapsed time from this date. For example, modal lengths of 20 and 29 cm from a length frequency of silver hake caught in March, 1974 (mean date of a cruise) were plotted as 20 cm and 50 months and 29 cm and 50 months. All resolved modes were plotted in this way and obviously different groups of fish within the same length frequency were plotted with a different symbol. Data points were then joined to give a series of growth curves under the following conditions:

1. Modal length of a group of fish would not be appreciably less in successive months.

2. A mode of fish would not "disappear" from the length frequency at the next time interval except through the effect of total mortality (Z).

Lacking sufficient length frequencies of fish less than 10 cm, an average length in October was calculated from the USSR data and this point used in successive years (i.e. 9, 21, 33 months). In addition, July 1st was accepted as a mean date of spawning (Doubleday& Halliday 1975) to give data points for time zero and length zero.

From the ensuing curves, a series of lengths at 6, 12, 18 ... months was calculated and the mean of these values was assumed to be the best representative of length-at-age for silver hake.

Von Bertalanffy growth curves were then fitted to these values for both males and females by the method of Beverton (p. 57, 1954).

To show distribution and relative abundance of silver hake catches from trawl surveys, the total catch per tow and proportion of the total less than 25 cms in length were plotted on maps of the Scotian Shelf area. Open and solid squares were used, respectively, to indicate catches of <11, <51, <101, < 201 and > 200 fish per 30 minute tow over the Scotian Shelf area.

Results

A length frequency generated by summing known normal distributions over the total length range is shown in Figure 1 and parameters of normal components derived from modal analysis are indicated. These indicate very good agreement with actual values and validate this technique for resolution of Gaussian components from frequency distribution.

Modal lengths derived from length frequencies are shown in Table 2. A total of 21 frequencies were analyzed to obtain mean lengths-at-age for relative age groups, in most cases, by sex. Examination of modal lengths for males and females from the same cruise show little variation up to about 25 cms but indicate a consistent trend towards larger lengths for females over this length compared to males at the same relative age. Consequently, modal lengths for males and females were treated separately, although modal lengths from combined frequencies up to 24 cm were accepted on the basis of minimal difference between sexes. Modal lengths from Table 2 plotted agains time elapsed from January 1st, 1970, are shown in Figures 2 (a) and (b). The smallestobserved modal lengths are at 9.0 and 8.4 cms in October 1972 and 1974, and the next series of modes are at about 20 cms in July-August. Assuming fish with a modal length near 9 cms in October to be a recruiting year class and that this year class would be well represented in the following July-August period, it follows that growth in this time period must be 10-12 cms. An average October length of 8.73 cms was calculated and used for successive October lengths. Accepting July as a probable spawning month (Noskov, 1976), a length of zero was entered for successive July observations. By joining observed lengths and extrapolating through estimated values, a series of probable growth curves was generated as shown in Figures 2 (a) and (b) for males and females. These curves appear to be smooth and show a tendency towards a typical Von Bertalanffy growth curve. Comparison of curves for males and females confirms a different growth rate beween sexes with length-at-age diverging at about 0.5 cm per year above 24 cms in length.

Mean lengths-at-age at six month intervals were obtained by determining lengths in January, 1970-76, and July, 1970-76, from the above curves and assigning respective ages to the calculated length and results are shown in Table 3. Von Bertalanffy parameters were derived for these mean lengths-at-age and the resultant curves are shown in Figures 3(a) and 3 (b) and appear to adequately describe growth of silver hake, at least over the initial four years of life.

The asymptotic length calculated for females (37.88 cm) may be lower than the actual value based on observed lengths (Table 1) because of few resolved modes above 30 cms. However, inclusion of fish from a closely related species *(Merluccius albidus)* in length frequencies may incorrectly indicate the presence of fish above 40 cms in length. This species has been encountered on Canadian research cruises, generally at lengths above 40 cm and requires careful examination to separate it from *M. bilinearis* (personal observation).

Examination of derived growth curves (Figs. 2(a) and 2(b) indicate some variation in growth rate between the 1968 and 1975 year classes.

Distribution and abundance of silver hake from cruise surveys are shown in Figure 4 where open squares have been used to show total catch per 30 minute tow and closed squares to indicate the proportion less than 25 cm in length. Winter (March) and summer (July-August) distributions are shown for each of the years 1970-1976 with additional surveys in October and December, 1973. Winter surveys, because of inclement weather and restricted vessel operation, do not adequately survey the entire Scotian Shelf and consequently may miss part of the overwintering distribution.

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Summer distributions show a widespread abundance over the Shelf area with highest concentrations in the Emerald Bank-Sable Island Bank area. Abundance is limited to an area west of 60° latitude and is discontinuous at about 66° latitude, suggesting a possible stock boundary between Sable Island Bank "stock" and Brown's Bank - Georges Bank "stock". In general, small fish are found inshore of the larger (>24 cm) adult fish. Concentrations of adult fish were found in the west Sable Island Bank area described by Sarnits and Sauskan (1967) as a major spawning area with above average densities in 1970 and 1974.

Conclusions

Modal analysis of silver hake length frequencies indicate well defined modes for both males and females in the 10-35 cm length range. Lengths at which these modes occur are consistent within narrow limits of year class variation from year to year. Derived growth rates for males and females show some divergence at lengths above 25 cm with females reaching a larger calculated asymptotic length (37.88 cm vs 36.01 cm for males). Von Bertalanffy growth parameters derived from calculated mean lengths-at-age show a good fit to data and indicate an approximate mean length of 30 cm at 36 months of age. Results of the present analysis are in good agreement with length at age estimates made by Doubleday and Halliday (1975) using commercial catch length frquencies. The growth curve derived from this independent data is similar to the ones obtained here and supports the conclusion that growth of silver hake can be adequately derived from length frequency modal analysis.

Validation of growth characteristics derived from modal analysis will require comparison with those derived from otolith ageing. However, with indirect evidence of growth from modal analysis, interpretation of otoliths should be facilitated to the point of anticipating probable age at length.

Distribution and abundance of silver hake obtained from research vessel cruises indicate some segregation of size groups and a possible stock boundary. In summer, juvenile fish appear to concentrate inshore of the larger adult fish, but both size groups are found over the entire Shelf area with localized areas of high density. Distribution appears to be discontinuous at about 66° longitude. Winter distributions suggest more dense aggregations in several areas.

References

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Table 1. Length frequencies of silver hake from research vessel cruises 1970-76.

YEAR	1970			1971		1972			1973			
MONTH(S)	MAR	JUNE	JULY	MAR	JULY	MAR	JULY	OCT*	JULY	OCT*	OCT	DEC
AREA	4WX	4W	4WX	4WX	4WX	4WX	4WX	4W	4WX	4W	4WX	4WX
LENGTH (CM)												
5								1				
6	1	1						4				2
7	1							13		3		
8					1			13		3		2
9				1		1		22		1		4
10	8	8	1	1	3	1		22				4
11	10	12				7	1	18	1			3
12	8	43	1	6	1	10		5	1			2
13	11	46		2		13	3	1	5			
14	12	65	4	8	10	10	7		12			
15	4	51	10	1	20	9	16		23		1	
16	3	33	30	5	24	8	23		31		2	
17	4	11	34	4	37	10	42	2	60		5	1
18		1	74	2	83	7	55	1	93	3	8	2
19	1	1	83		64	2	68	4	152	11	12	2
20	2		125		45	2	75	21	153	25	66	5
21	12		150	6	33	4	45	64	154	49	118	13
22	22		169	8	14	15	40	112	130	83	136	21
23	59		111	21	11	25	31	113	61	107	110	22
24	86		68	72	5	59	22	163	35	79	61	35
25	97		75	114	14	69	26	90	58	65	23	15
26	101	1	191	173	27	51	42	59	255	47	14	12
27	28		362	146	95	24	72	50	503	34	22	8
28	39		494	107	153	2	77	40	738	54	52	3
29	31		428	131	142	3	45	30	551	89	69	7
30	29		298	172	110		50	38	362	103	69	3
31	18		198	128	90		33	30	179	84	55	3
32	12		103	67	68	2	36	33	88	63	32	
33	3		79	41	47		35	16	79	24	16	1
34	1		58	12	27		30	11	45	16	14	
35	2		31	4	9		21	5	47	13	6	
36			30	4	7		13	5	40	11		
37	1		27	3	9		8	5	36	3	7	2

YEAR	1974						1975			1976	
MONTH(S)	MAR	MAR	JUNE	JULY	JULY	OCT*	MAR	JULY	OCT*	MAR	JULY
AREA	4WX	4WX	4W	4V	4WX	4W	4WX	4WX	4WX	4WX	4WX
LENGTH (CM)											
5											
6						3					
7						8					
8						10					
9						5	3				
10						3	8				
11		2	3		2	1	6				
12		1	5			2	21				
13		5	16		1	1	27			3	
14		2	35		4		7	1		4	1
15		2	67	1	10	1	8	3		1	2
16			127	5	15		6	9	1	3	3
17			141	11	40		8	16	3		14
18			81	27	80	7	1	22	8	1	21
19			74	35	117	4		28	15		34
20		3	28	47	153	7	1	62	20	3	86
21		5	18	41	116	18	4	70	48	2	95
22	3	31.	11	16	98	37	11	66	72	5	93
23		69	15	6	46	69	18	49	95	6	46
24	5	107	48	8	48	76	43	26	164	13	32
25	9	86	131	27	106	85	64	14	147	9	30
26	1	44	259	86	274	94	53	13	124	1	79
27	4	21	403	124	504	69	56	22	69	5	184
28	4	15	373	123	563	52	36	47	35	5	267
29	2	13	357	82	469	60	13	99	38	1	263
30	7	14	356	43	391	97	8	77	24	1	206
31	4	9	400	20	305	92	1	86	41		151
32	4	7	536	13	201	86	5	53	28		110
33	5	1	519	7	158	43	5	55	26	1	80
34	1	6	469	8	101	26	1	27	20		47
35	1	3	352	7	57	13	1	17	7		35
36	1	2	230	3	47	6	4	14	5		44
37	1	1	155	1	37	5	4	6	3		36

*Data from Noskov (1976)reduced to o/oo

Table 2. Modal lengths of silver hake from research vessel cruises 1970-76

	YEAR	1970		1970		1970		1971		1971		1972		1972		1972		1973		1973		1973	
	MONTH	MAR		JUNE		JULY		MAR		JULY		MAR		JULY		OCT		JULY		OCT		OCT	
	AREA	4WX		4W		4WX		4WX		4WX		4WX		4WX		4W		4WX		4W		4WX	
	SEX	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
A	MEAN															9.04							
	σ															1.67							
B	MEAN	12.68		13.83		18.72	19.94			18.62	19.19	14.69		19.28	19.95	23.83		20.42	20.05	23.08		21.88	22.06
	σ	2.11		1.67		1.76	1.97			1.90	2.63	2.55		2.29	2.56	1.80		1.92	2.02	1.88		1.66	1.68
C	MEAN	24.90				27.53	28.87	26.51	26.62	27.90	29.37	24.72		26.81	28.07	29.98		27.73	28.85	30.17		28.60	30.49
	σ	1.94				1.67	1.44	1.83	1.78	1.57	1.66	1.66		1.53	1.54	2.89		1.11	1.42	1.93		1.52	1.77
D	MEAN	29.94						29.67	31.38		33.13			30.98	33.14			32.40		35.86			34.69
	σ	1.95						.78	1.13	1.64				1.54	2.20			1.12		1.70			1.45

	YEAR	1973		1974		1974		1974		1974		1974		1975		1975		1975		1976	
	MONTH	DEC		MAR		JUNE		JULY		JULY		OCT		MAR		JULY		OCT		JULY	
	AREA	4WX		4WX		4W		4Vs		4WX		4W		4WX		4WX		4W		4WX	
	SEX	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
A	MEAN											8.41		12.73				17.67			
	σ											2.81		1.56				1.05			
B	MEAN	23.44		24.04	24.41	16.95		19.77		19.91	20.35	25.40		25.61	25.96	21.26	21.38	24.46		21.18	21.14
	σ	2.09		1.19	1.71	2.15		1.86		2.20	1.86	2.56		2.09	2.02	2.17	2.05	2.39		1.93	1.99
C	MEAN			28.38	30.55	28.05		26.94	28.18	27.88	28.57	31.70				29:41		31.80		28.11	29.87
	σ			.93	1.31	2.10		1.42	1.57	1.72	1.77	1.60				1.60		2.00		1.71	1.97
D	MEAN				34.69	33.24			34.39	31.52	32.70									32.98	
	σ				1.45	1.8			1.28	1.58	1.79									1.27	

Table 3 . Calculated mean length-at-age from growth curves of silver hake.

(a) Males

Age (months)	Length (cm)							Mean
6	12.4	12.5	12.8	11.8	12.6	11.0		12.18
12	15.2	18.6	19.2	20.4	21.2	19.9	22.5	19.57
18	23.6	23.5	25.2	23.5	24.8	25.5		24.35
24	27.5	27.8	26.9	27.8	28.2	27.5	30.0	27.96
30	31.8	29.5	30.8	28.6	31.2			30.38
36	31.0	32.5	33.0	31.8				32.08

(b) Females

Age (months)	Length (cm)							Mean
6	11.3	12.5	12.5	13.0	12.0			12.26
12	21.4	20.0	19.2	19.9	20.0	20.0		20.08
18	24.8	25.0	23.5	25.6	23.8			24.54
24	27.6	29.2	28.1	28.5	28.5			28.38
30	30.8	31.5	30.0	30.5				30.70
36	33.5	33.7	32.0	33.5				33.18
42	34.0							34.00

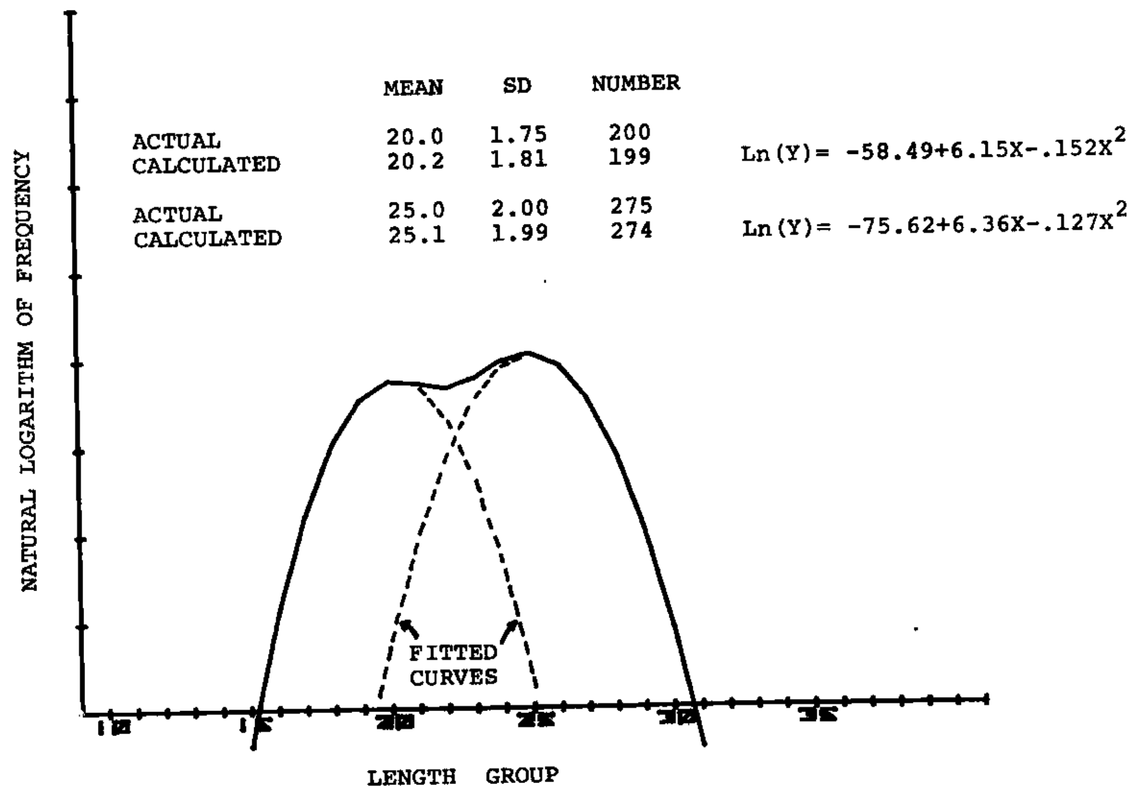

Fig.1. Resolution of known Gaussian components from a generated length frequency.

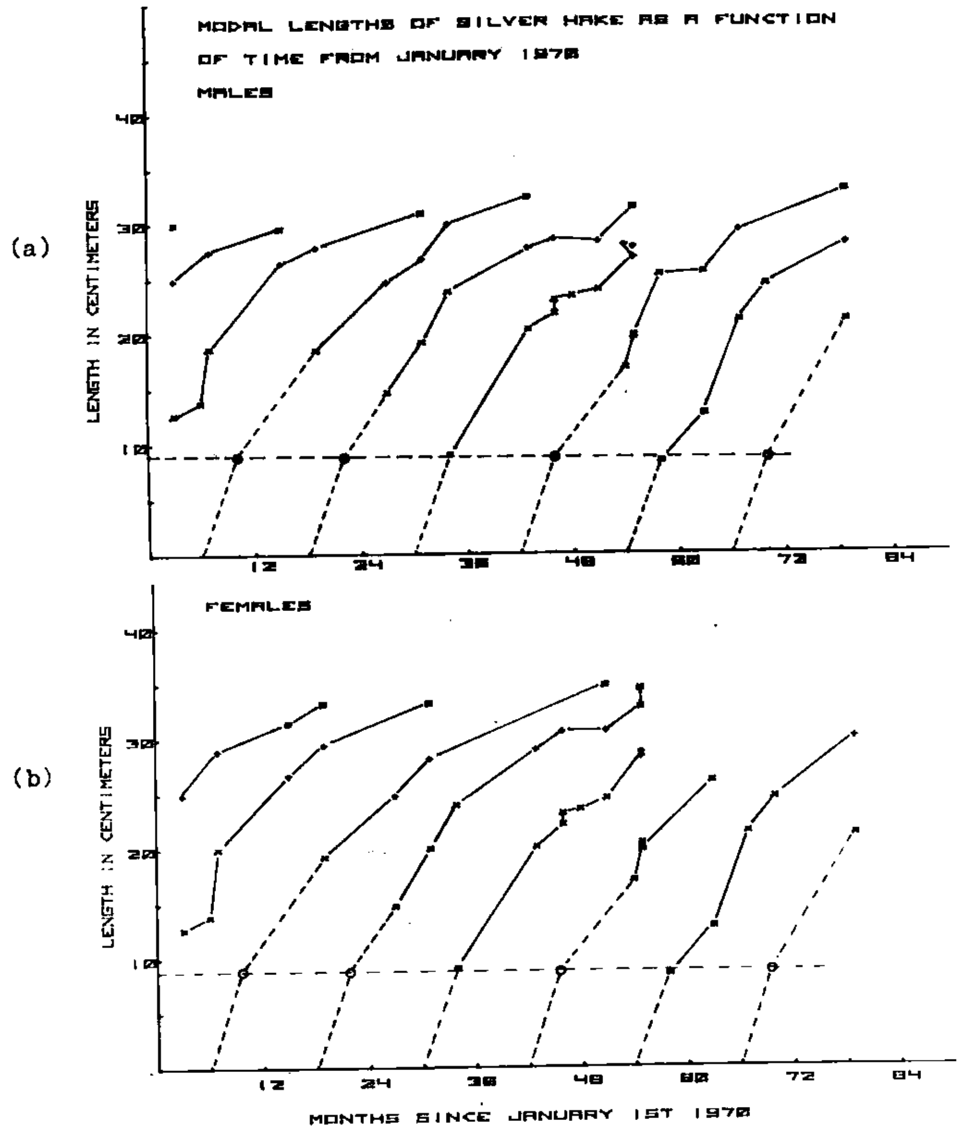
MODAL LENGTHS OF SILVER HAKE AS A FUNCTION
OF TIME FROM JANUARY 1970
MALES
(a)
LENGTH IN CENTIMETERS
40
30
20
10
12
24
36
48
60
72
84
FEMALES
(b)
LENGTH IN CENTIMETERS
40
30
20
10
12
24
36
48
60
72
84
MONTHS SINCE JANUARY 1ST 1970

Fig. 2.

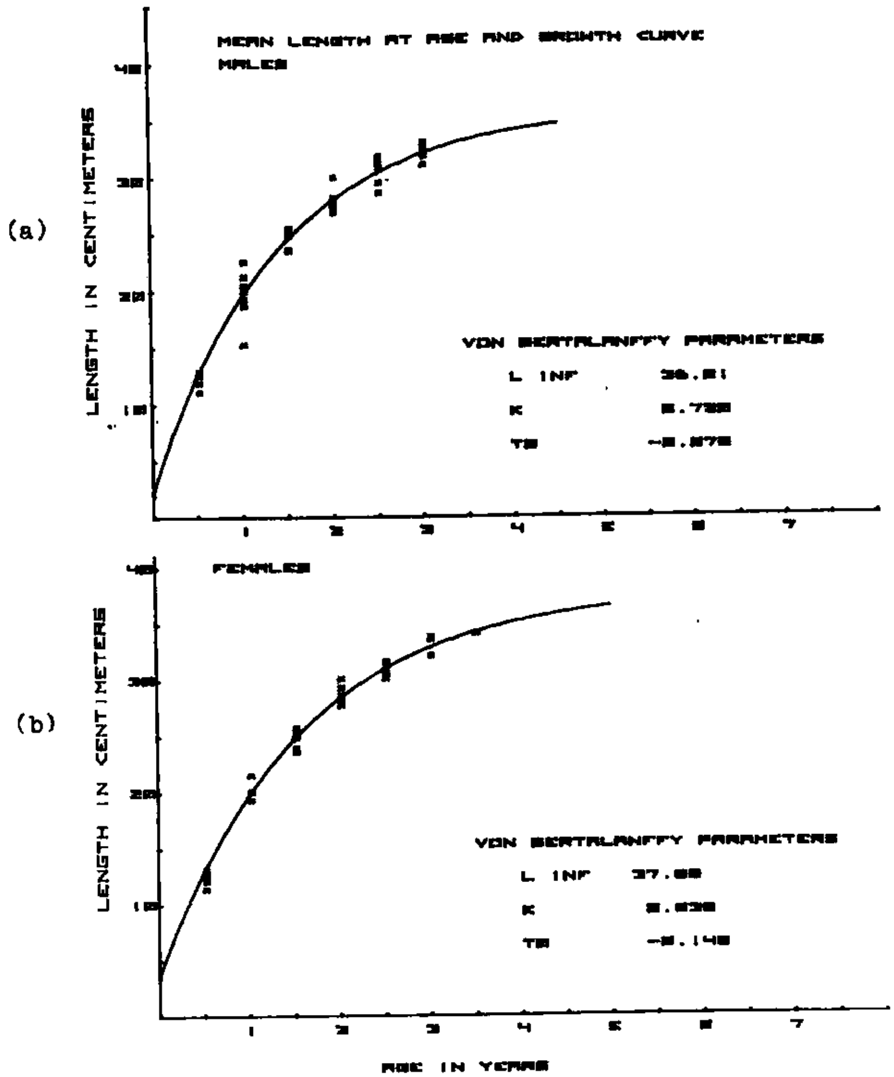
MEAN LENGTH AT AGE AND GROWTH CURVE
MALES
(a)
LENGTH IN CENTIMETERS
VON BERTALANFFY PARAMETERS
L INF
K
T0
FEMALES
(b)
LENGTH IN CENTIMETERS
VON BERTALANFFY PARAMETERS
L INF
K
T0
AGE IN YEARS

Fig. 3.

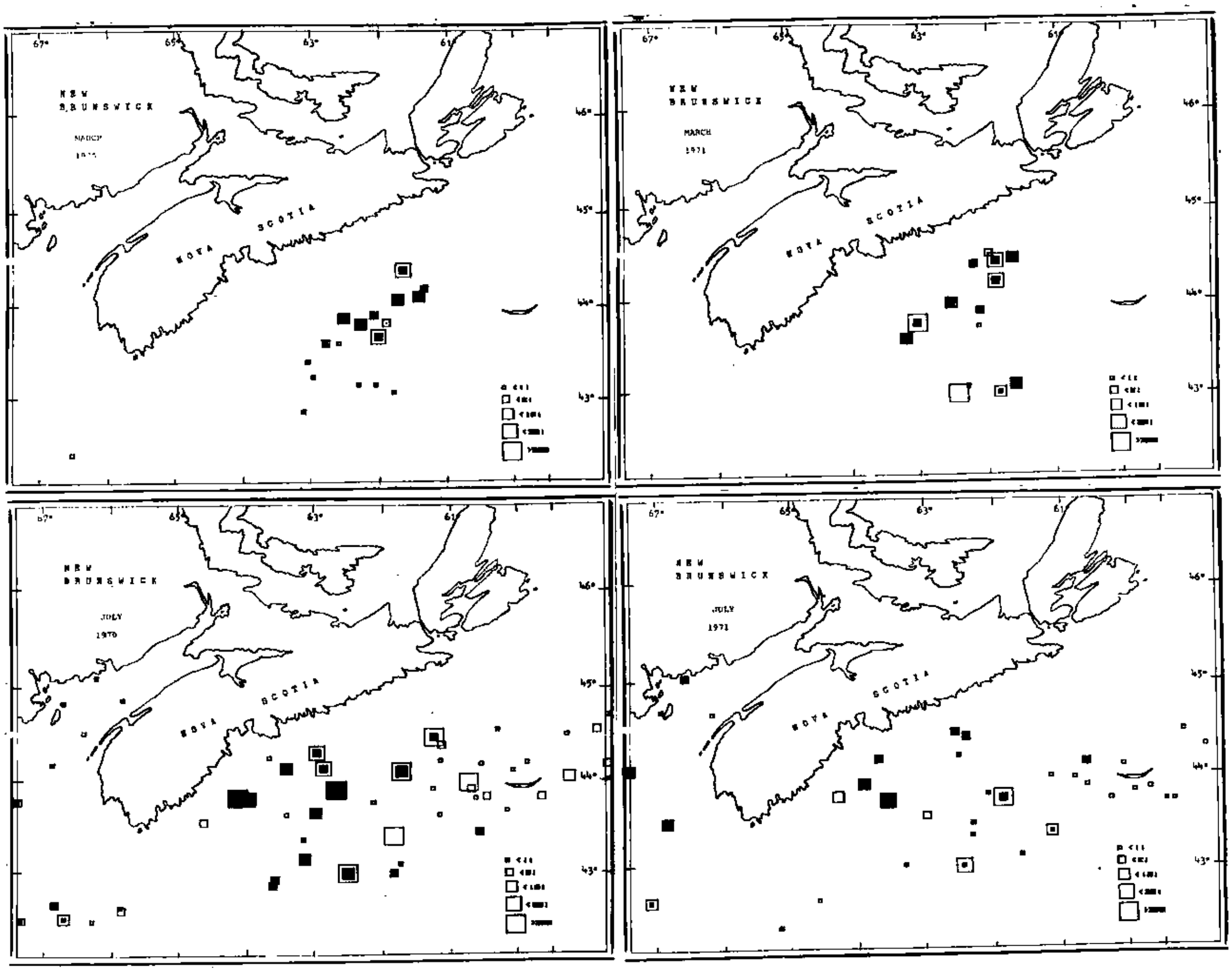

Fig. 4. Distribution of silver hake from Canadian research cruises, 1970-76. Total number per tow(open square) and number per tow less than 25cm in length(closed square).

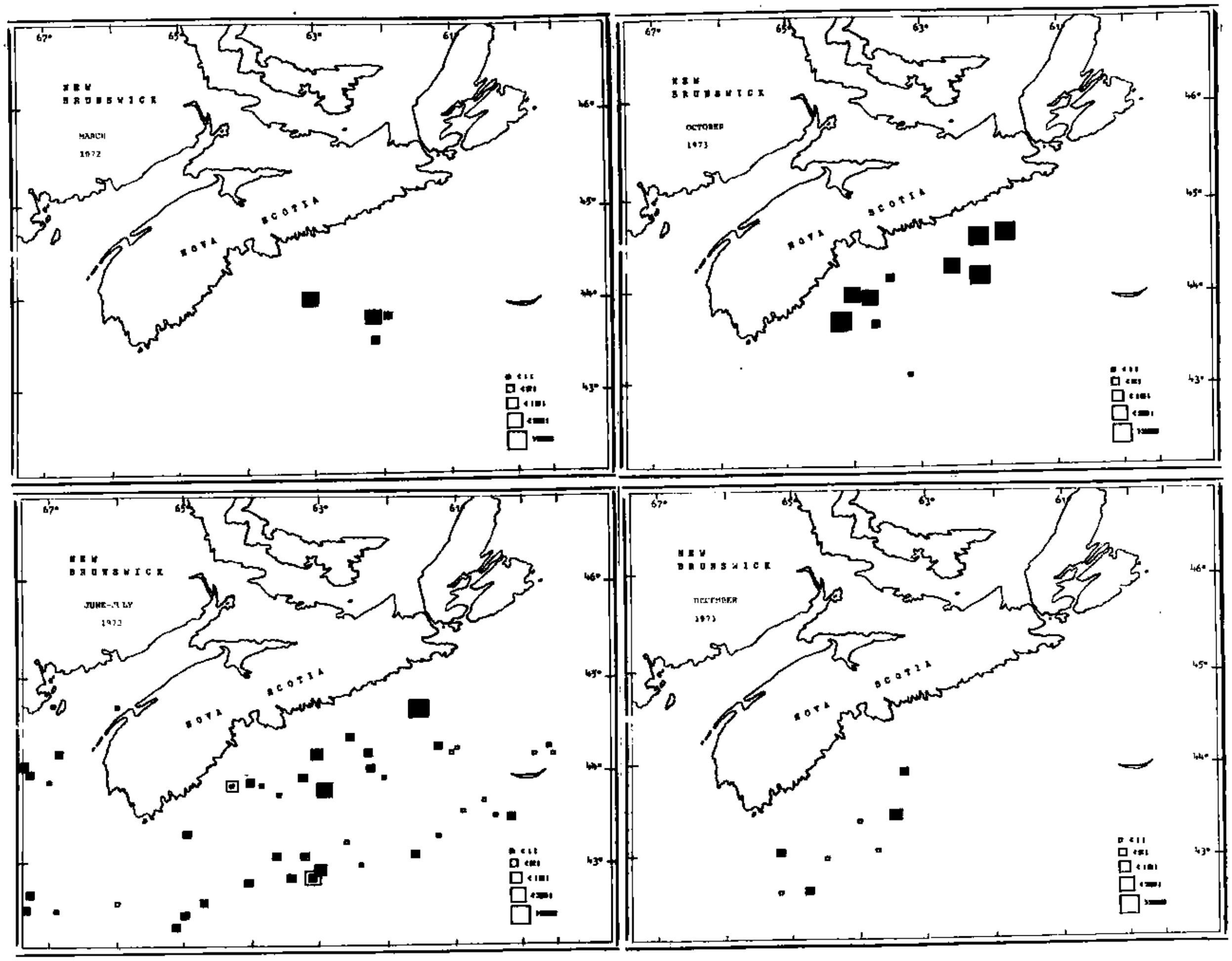

Fig. 4. Continued

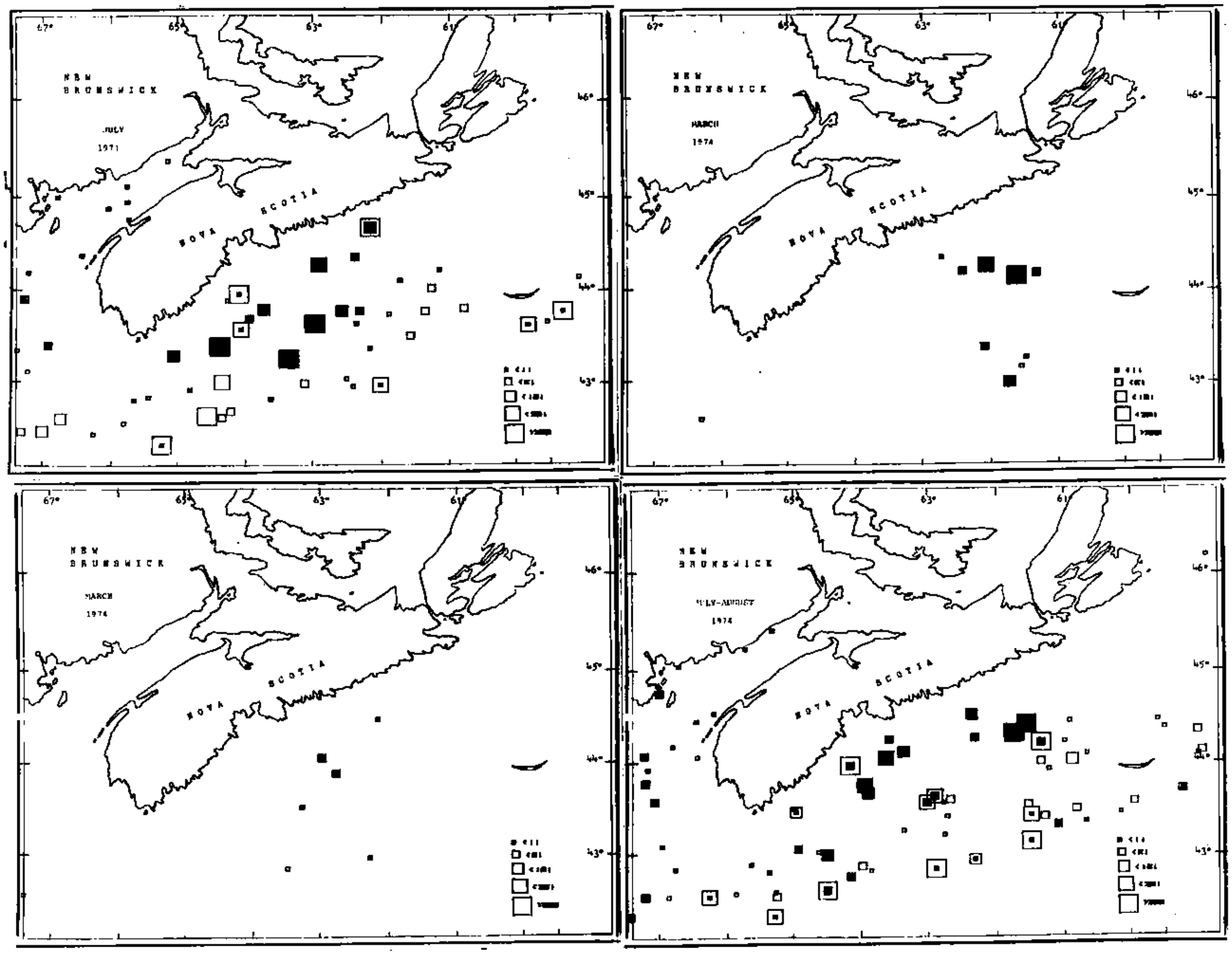

Fig. 4. Continued

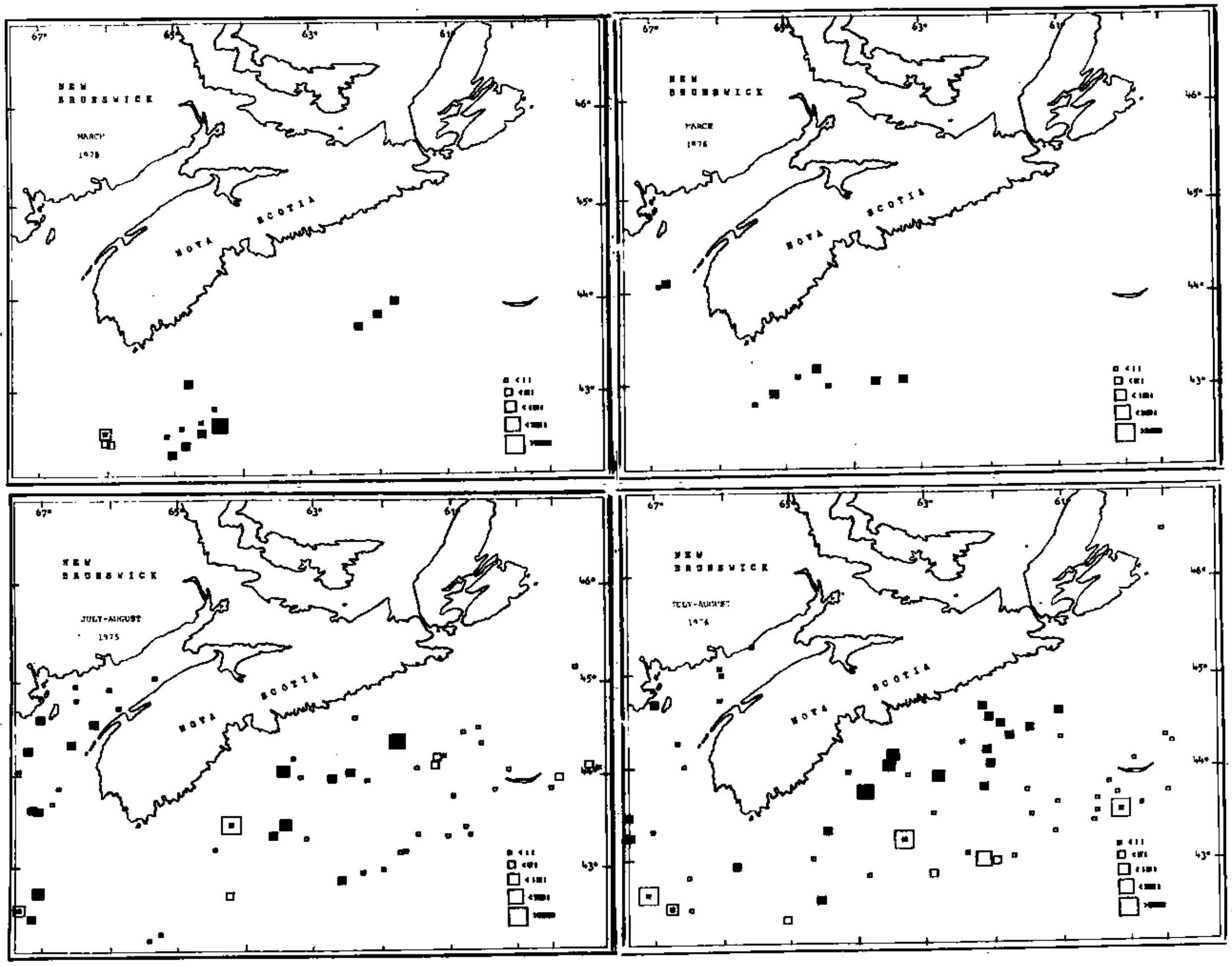

Fig. 4. Continued