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The Logistic Model for Determining Size at Maturity in Species Differentiation and Stock Discrimination for Northwest Atlantic Redfishes

by

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ABSTRACT

The systematics of Northwest Atlantic redfishes has been confused for decades. Although morphological differences in redfish have been extensively discussed, the biological evidences have not yet been established to substantiate the species and/or stock status of redfishes. The logistic model was utilized to estimate the size at maturity from sex and maturity data of 4,501 *Sebastes marinus* and 43,988 beaked redfishes (*S. mentella* and *S. fasciatus*) in Northwest Atlantic. The size at maturity for female redfishes were significantly larger than that of males for both *S. marinus* and beaked redfishes. The significant differences of size at maturity in females between beaked redfishes and *S. marinus* were observed. The males, however, did not show the significant difference between groups. A geographic cline of size at maturity, a reduction by NAFO Divisions, was noted in beaked redfishes.

INTRODUCTION

The classification and nomenclature of Northwest Atlantic redfishes has been confused for decades. Morphological and anatomical differences for the three redfish forms, *Sebastes marinus*, *S. mentella* and *S. fasciatus*, have been described by several researchers (Templeman and Sandeman 1957; Templeman 1959, 1976, 1980; Barsukov 1968, 1972; Barsukov and Zakharov 1972; Litvinenko 1974, 1980; Ni 1981a and b). However, the argument was still centered on the differences of morphological characters being merely geographic variation of the same species rather than among species (NAFO 1981). This species versus stock problem arises because many biologists accept a biological species concept (Mayr 1969), "Species are groups of interbreeding natural populations that are reproductively isolated from other such groups". Therefore, this research is designed to investigate the differences of size at maturity in redfishes from Northwest Atlantic so as to explore the biological evidence to substantiate the biological species and/or stock status of redfishes.

MATERIALS AND METHODS

Sex and maturity data of 4,501 *S. marinus* and 43,988 beaked redfishes (*S. mentella* and *S. fasciatus* combined) were collected from NAFO Div. 0-4X between 1957 and 1969 (Table 1). Sample sites were mainly along the continental slopes at bottom depth from 100 m to 750 m. All analyses were conducted for two groups of redfishes: *S. marinus* and beaked redfishes.

The microscopic examination of many testes, taken from small redfish throughout the year and especially during the season when testes of mature male redfish might be expected to contain sperm, suggested that if the testes were translucent, stringlike and with widths less than 1 mm then the fish could be considered as immature. A similar microscopic examination in which the egg sizes of female redfish of different lengths were examined suggested that if there was no evidence of previous spawning (thicken gonad wall, no old eye pigment, etc.) and the eggs were smaller than 0.2 to 0.3 mm in diameter than the females could be considered as immature. Fish which did not meet these criteria were considered as mature (Ni and Templeman 1982).

Measurements of redfish were all fork lengths to the nearest cm (from the most anterior part of the lower jaw with the mouth closed to the middle rays of the caudal fin). In the analysis the fish have been grouped in 5 cm groups for length frequently study and in 2 cm groups for estimatng size at maturity.

Fork length versus proportion mature for each sex were then plotted in each NAFO division. The sigmoid shape seemed to conform a logistic equation, as applied on pacific ocean perch by Gunderson (1976), of the form (Ashton 1972).

$$\hat{p} = \frac{1}{1 + e^{-(a+b\ell)}} \quad \text{or} \quad \frac{e^{a+b\ell}}{1 + e^{a+b\ell}} \qquad (1)$$

where $\hat{p}$ = estimated proportion for matured fish,

ℓ = fork length (cm),

a = coefficient

b = coefficient for the steepness of the logistic curve.

Then logit, a contraction of the phrase "logistic unit" or "log odds", is given by

$$\text{logit } \hat{P} = \text{In } \frac{\hat{P}}{1-\hat{P}} = a + b\ \ell \qquad (2)$$

The size at maturity (L50) is defined as the length at which 50% of the fish are in mature stage. Because the logistic curve is symmetrical, the area under the curve and to the left of L50 is equal to the area above the curve and to the right of it.

The BMDPLR program (Engelman 1981) calculated the observed mature proportion, its predicted probability and coefficients of the logistic equation. Thus, the size at maturity could be estimated as the minus ratio of coefficients (i.e. - a/b) by substituting P = 0.5 in equation (2).

In order to examine the differences of size at maturity among areas, the sample variance of L50 was calculated from the variance and covariance of coefficients a and b (Ashton 1972).

$$S^2(L50) = \frac{1}{b^2} \{S^2(a) + \frac{a^2}{b^2} S^2(b) - \frac{2a}{b} \text{cov } (a,b)\} \qquad (3)$$

RESULTS

Sex Ratio

Magnusson (1955) reported that the European male and female redfish were living almost completely separated in certain seasons, especially from the end of copulation till the spawning of the larvae. Therefore, the sex ratio might serve as an important character for the homogeneity of the redfish population, and also, as a good indicator for the redfish migration. The sex ratio (male/female) were around 1 and ranged from 0.77 (Div. 30) to 1.30 (Div. 3M) for beaked redfishes and fom 0.76 (Div. 3L) to 1.33 (Div. 3P) for S. marinus (Table 1).

Size Composition

Percentage length frequencies for both beaked redfishes (Fig. 1) and S. marinus (Fig. 2) were displayed in each NAFO Divison. Males were exhibited on the left side of every 5 cm length category in the histograms with the indication of immature and mature proportion whereas females were shown on the right side. No calculation could be conducted for S. marinus in Div. 2GH and 4STVWX due to lack of specimens.

Generally speaking, the females were noted relatively larger than the males in redfishes and the size of S. marinus were found much larger than that of beaked redfishes. S. marinus with fork length less than 20 cm were seldom recorded because morphological characters used in differentiating redfishes may not be as well defined.

In Baffin Bay (Subarea 0 and 1), mature females could rarely be found for either S. marinus or beaked redfishes even for very large size specimens (70 cm in S. marinus and 45 cm in beaked redfishes). However, mature males were noted in specimens with size larger than 30 cm and 20 cm for S. marinus and beaked redfishes respectively. In Northern Labrador (Div. 2GH) a larger proportion of mature males (>25 cm) of beaked redfishes were encountered whereas females were mainly in immature stage. Mature fish were dominant in Southern Labrador (Div. 2J) for S. marinus (>25 cm in males and >35 cm in females) and for male beaked redfishes (>20 cm), but the immature females of beaked redfishes were still abundant.

Size at Maturity

For beaked redfishes and S. marinus, the fork length versus proportion mature were plotted for each sex and NAFO Division (Fig. 3). The logistic equation was computed to estimate the parameters (coefficients a and b) and predicted probability of mature fish. The theoretical sigmoid curve was also plotted on Fig. 3. The size at maturity (L50) and standard error (SE) were then calculated and listed with sample size and proportion mature (Table 2). Interpretation of size at maturity should be cautious if the sample size was small (<30) and the numbers of immature or mature specimens were insufficient.

It was clearly demonstrated that the sizes at maturity for female redfish were significantly larger than that of males for both beaked redfishes and S. marinus in every NAFO Division encountered (Fig. 3). Significant differences of size at maturity in females between beaked redfishes and S. marinus were observed in Div. 2J to 4R. The males, however, did not show the significant difference of size at maturity between groups.

The usage of L50 to describe maturity size should be verified by the display of the coefficient b and the standard error (SE) in Table 2. A better representation of L50 would be encountered if the coefficient b is large (i.e. sharp steepness of logistic curve) and a small standard error. However, the small b value with large SE value for beaked redfishes may suggest a mixture of S. mentella and S. fasciatus, if the sample size is large.

A geographic cline of size at maturity was observed in beaked redfishes: it was gradually decreased from north (29.14 cm in Subarea 0 and 29.45 cm in Subarea 1) down to south (15.96 cm in Div. 4X) for males and from 45.09 cm in Subarea 1 down to 25.96 cm in Div. 4X for females (Fig. 4). However, S. marinus displayed less geographic variation of size at maturity except the males in Subarea 1 and Div. 2J.

DISCUSSION

The size at maturity is an important biological parameter for both reproduction and growth, because, after the onset of maturity, energy that might have been used for growth will be required for gonad maturation and in some cases, for making spawning migrations. Growth can be expected to be more reduced after the onset of maturity than it otherwise would have been. This should also be a good indicator for species differentiation and stock discrimination, particularly for the sibling species and/or stocks (e.g. redfishes).

The plot of proportion mature versus body length yields a sigmoid curve. This has been well-recognized by fisheries biologists. Probit method (Bliss 1934) is the most common technique to estimate size at maturity and was applied to Atlantic fishes by Fleming (1960) and others. Although the logit method in preference to the probit method was discussed by Ashton (1972), as far as practical considerations are concerned, estimates for L50 show little difference.

The fitness of length-maturity relationship with logistic model varied with areas. Generally speaking, the model suffered from not having enough mature females in northern waters (Subarea 0 and 1, Div. 2G and 2H) or from the difficulties in identification of immature male S. marinus. However, a trend of the differences between observed and predicted proportion mature could be gathered by comparing with redfish species distribution (Ni and McKone 1981, Ni 1982). For beaked redfishes the fitness of the logistic curve were noted better in Davis Strait (Subarea 0 and 1) as well as in the Gulf of St. Lawrence (Div. 4RST) since S. mentella was the only dominant species. This was also observed on Nova Scotian Shelf (Div. 4VWX) and in southern Newfoundland waters (Div. 3P) (Payne and Ni 1982, Power and Ni 1982) where S. fasciatus was predominant. Unsatisfactory fitness were observed in southern Labrador waters (Div. 2J), in northeastern Newfoundland waters (Div. 3K), and on Flemish Cap (Dvi. 3M), where two beaked redfish species were encountered. A slight improvement of the fitness was noted on Grand Bank (Div. 3LNO), where a mixture of S. fasciatus and S. mentella occurred in deep waters.

No mature female redfishes were observed in Davis Strait (NAFO Subarea 0 and 1), with a negligible 3.53% proportion mature of S. mentella in West Greenland (Subarea 1). It suggests strongly that S. marinus and S. mentella are migratory species, as noted by Maslov (1964) for the European redfish. The refishes immigrated norhter waters for feeding or some other reasons. More number of females than males were noted with exception of S. mentella in West Greenland.

With regard to the differences of reproductive biology among redfish species, there appears to be no significant differences in size at maturity between male S. marinus and beaked redfishes. However, there were significant differences in females. It was interesting to observe that the geographic variation of size at maturity in beaked redfishes was somewhat different from the geographic cline noted with meristics (Ni 1982). The difference was that the meristics had a reduction from north to south (with exception on Flemish Cap) whereas the size at maturity had a reduction by NAFO Divisions (Fig. 4).

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Table 1. Sample size and sex ratio of Sebastes marinus and beaked redfishes (S. mentella and S. fasciatus) in NAFO Divisions.

NAFO Div.	Beaked redfishes N	Beaked redfishes sex ratio male/female	S. marinus N	S. marinus sex ratio male/female	% S. marinus to all redfishes
0	776	0.86	(13)[a]	(0.44)	1.65
1	596	1.11	136	0.81	18.58
2G	468	1.28	0	-	0
2H	1,057	0.96	(1)	-	0.09
2J	3,998	1.09	1,037	0.71	20.60
3K	3,351	0.98	424	1.29	11.23
3M	2,689	1.30	737	1.21	21.51
3L	2,127	1.13	74	0.76	3.36
3N	2,570	1.03	190	0.98	6.88
30	2,496	0.77	53	1.12	2.08
3P	9,591	0.94	1,809	1.33	15.87
4R	5,422	1.00	(26)	(1.89)	0.48
4S	2,172	1.17	0	-	0
4T	1,673	1.05	(1)	-	0.06
4V	1,080	0.82	0	-	0
4W	2,710	0.90	0	-	0
4X	1,212	0.89	0	-	0
Total	43,988	1.08	4,501	0.99	9.28

[a]: small sample size.

Table 2. Proportion mature (PM), size at maturity (L50 in cm) and its standard error (SE), estimated coefficient b for the logistic equation by sex and NAFO Division in beaked redfishes and S. marinus.

NAFO	Beaked redfishes (S. mentella and/or S. fasciatus)										S. marinus									
	Male					Female					Male					Female				
Div.	N	PM(%)	L_{50}	SE	b	N	PM(%)	L_{50}	SE	b	N	PM(%)	L_{50}	SE	b	N	PM(%)	L_{50}	SE	b
0	358	31.29	29.14	0.465	0.389	418	0	-[a]			(4)[b]	(75)	(52.35)	(118.94)	(1.051)	(9)	0	-[a]		
1	313	17.89	29.45	0.620	0.501	283	3.53	(45.09)[c]	2.495	0.229	61	95.08	(40.76)[d]	4.694	0.212	75	0	-[a]		
2G	263	89.35	29.01	0.802	0.425	205	11.71	(59.69)[c]	12.79	0.095	0					0				
2H	517	68.09	27.68	0.461	0.278	540	21.85	43.14	0.684	0.230	(1)									
2J	2086	90.84	24.93	0.483	0.330	1912	38.76	40.57	0.397	0.145	430	97.67	26.43	0.726	0.748	607	89.79	38.19	0.469	0.657
3K	1661	92.72	20.80	0.582	0.309	1690	57.63	35.88	0.301	0.233	239	99.16	(21.13)[d]	0.937	3.389	185	87.03	38.15	0.921	0.604
3M	1518	77.54	21.47	0.215	0.550	1171	50.30	30.61	0.252	0.460	404	94.55	22.23	0.958	0.362	333	56.46	39.21	0.490	0.402
3L	1128	92.64	21.80	0.667	0.330	999	65.17	34.65	0.315	0.302	32	81.25	21.15	0.910	0.794	42	16.67	41.21	2.335	0.309
3N	1307	95.33	16.32	0.709	0.362	1263	63.10	29.58	0.271	0.303	94	100	-[a]			96	39.58	40.57	0.590	0.528
3O	1084	72.97	18.23	0.218	0.686	1412	48.02	27.73	0.136	0.756	(28)	96.43	-[d]			(25)	(16.0)	(39.01)	(0.324)	(6.494)
3P	4643	82.55	18.56	0.095	0.809	4948	44.06	29.61	0.090	0.804	1031	99.71	(16.95)[d]	5.778	0.304	778	49.10	40.32	0.233	0.513
4R	2711	60.24	18.71	0.152	0.726	2711	44.72	26.60	0.134	0.773	(17)	100	-[a]			(9)	(88.89)	(40.51)	(43.18)	(1.468)
4S	1170	75.64	19.23	0.239	0.615	1002	48.60	26.89	0.250	0.810	0					0				
4T	857	83.90	18.77	0.263	0.776	816	50.37	28.12	0.178	0.925	0					(1)				
4V	486	96.09	17.40	0.307	1.460	594	78.79	26.36	0.259	0.958	0					0				
4W	1283	81.92	17.37	0.180	1.010	1427	61.53	24.44	0.189	0.599	0					0				
4X	571	77.76	15.96	0.246	0.691	641	38.22	25.96	0.380	0.590	0					0				

[a] no immature or mature fish, no estimate can be made

[b] small sample size, interpretation should be cautious

[c] insufficient number of mature

[d] insufficient number of immature

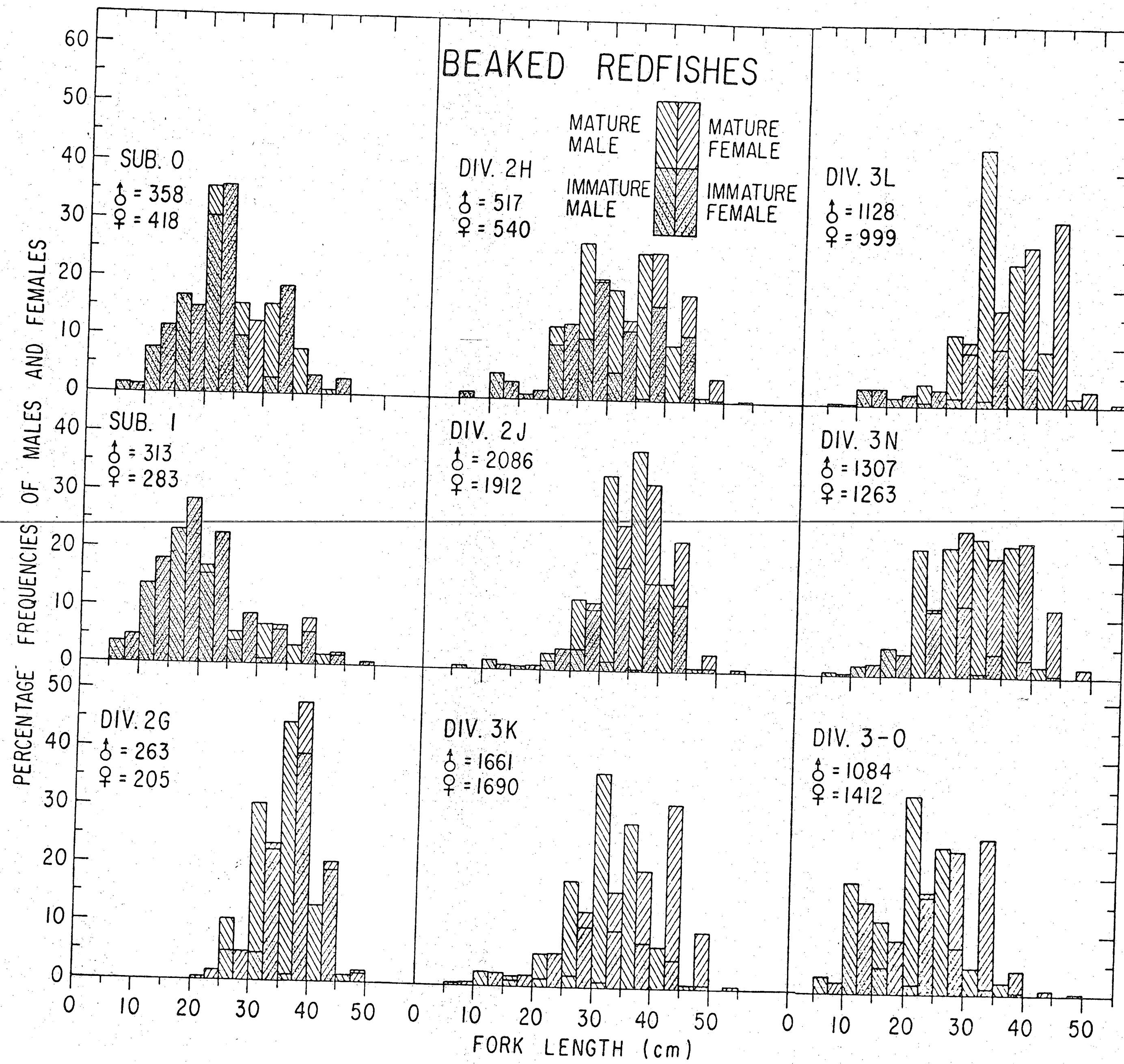


Fig. 1 - 1 Length frequency distribution with proportion mature by sex in NAFO Divisions for beaked redfishes.

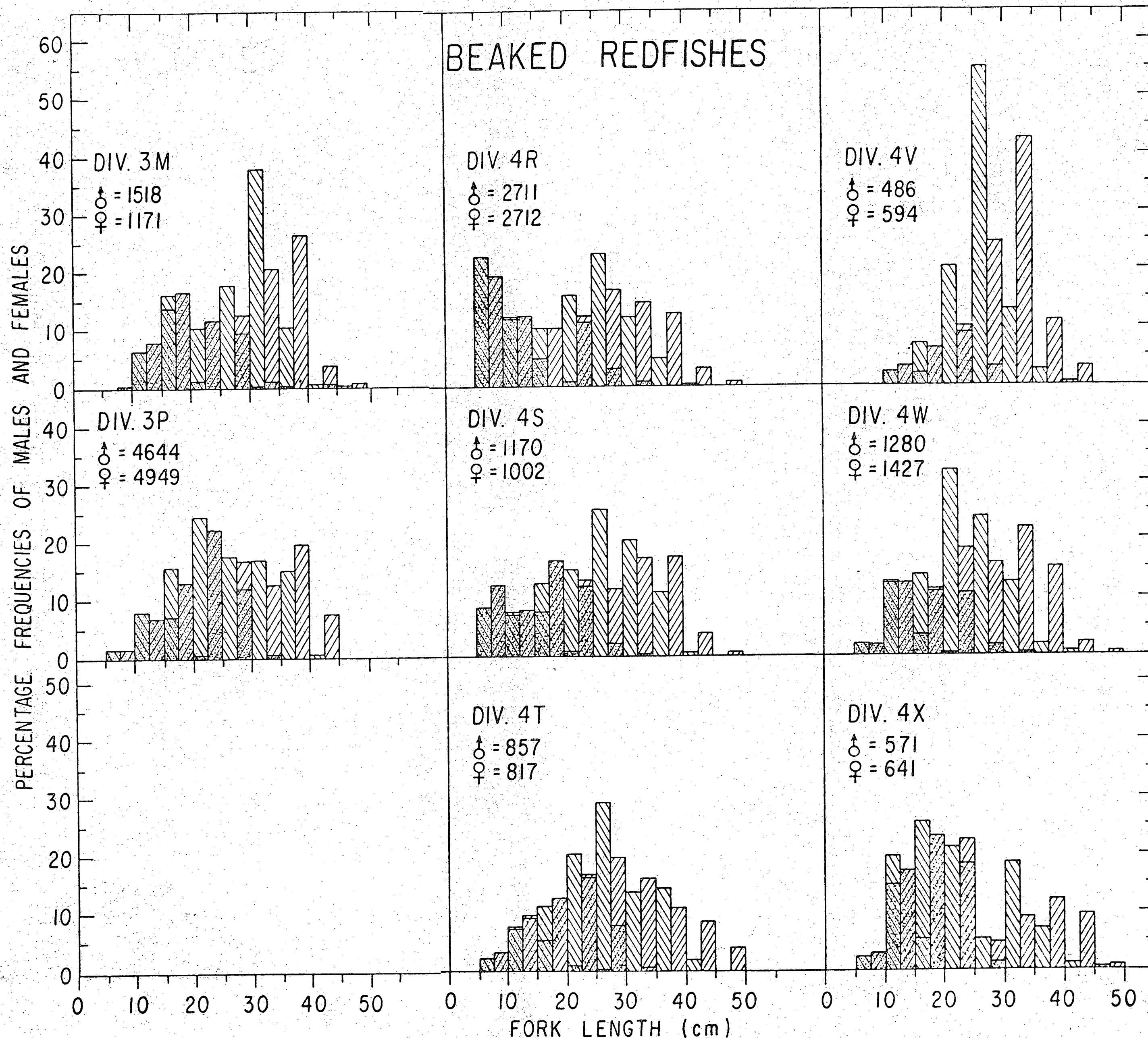

BEAKED REDFISHES
DIV. 3M
♂ = 1518
♀ = 1171
DIV. 4R
♂ = 2711
♀ = 2712
DIV. 4V
♂ = 486
♀ = 594
DIV. 3P
♂ = 4644
♀ = 4949
DIV. 4S
♂ = 1170
♀ = 1002
DIV. 4W
♂ = 1280
♀ = 1427
DIV. 4T
♂ = 857
♀ = 817
DIV. 4X
♂ = 571
♀ = 641
PERCENTAGE FREQUENCIES OF MALES AND FEMALES
FORK LENGTH (cm)

Fig. 1 - 2

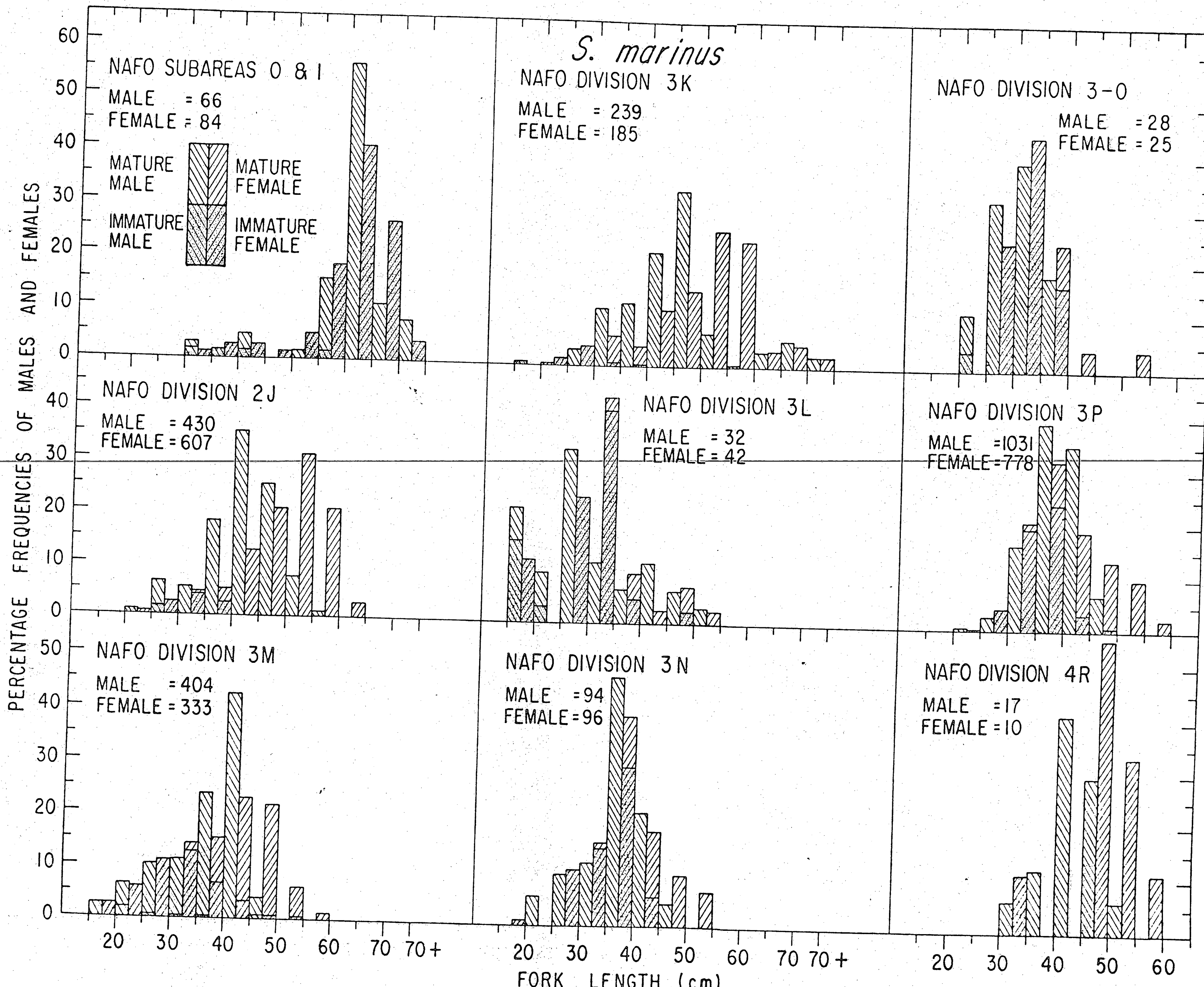
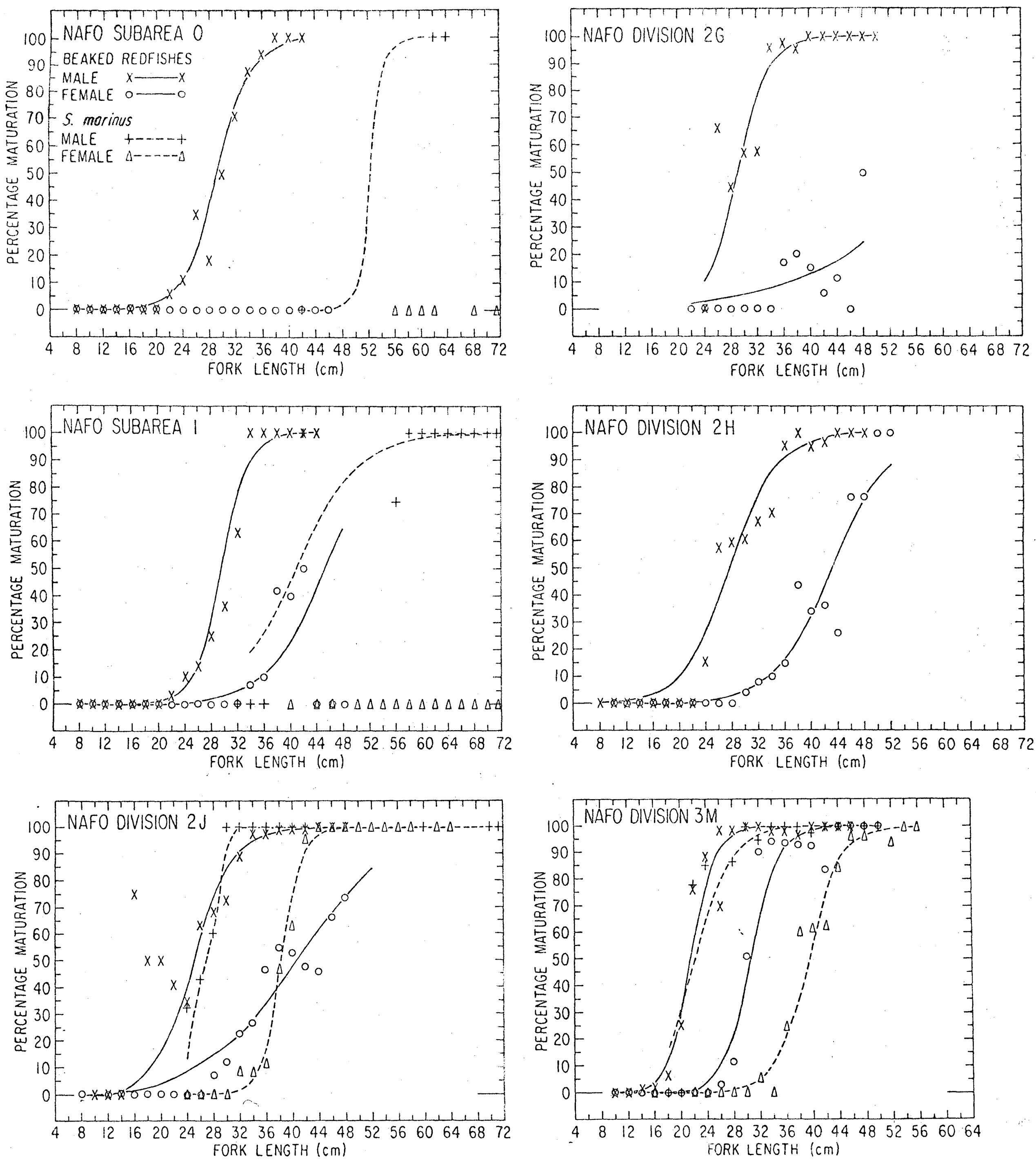


Fig. 2 Length frequency distribution with proportion mature by sex in NAFO Divisions for *S. marinus*.



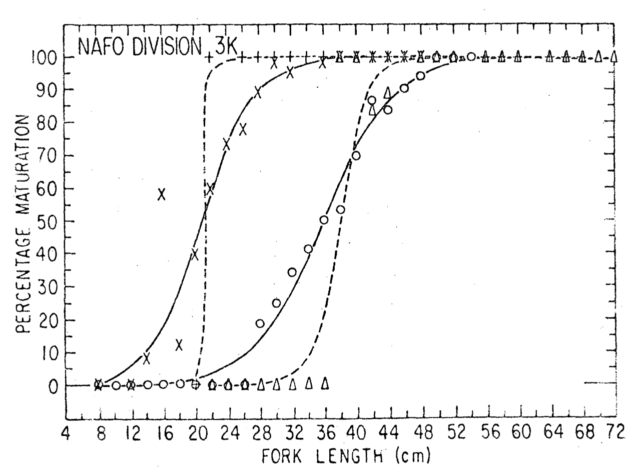


Fig. 3 - 1 The proportion mature versus fork length by sex for beaked redfishes and S. marinus in NAFO Divisions..

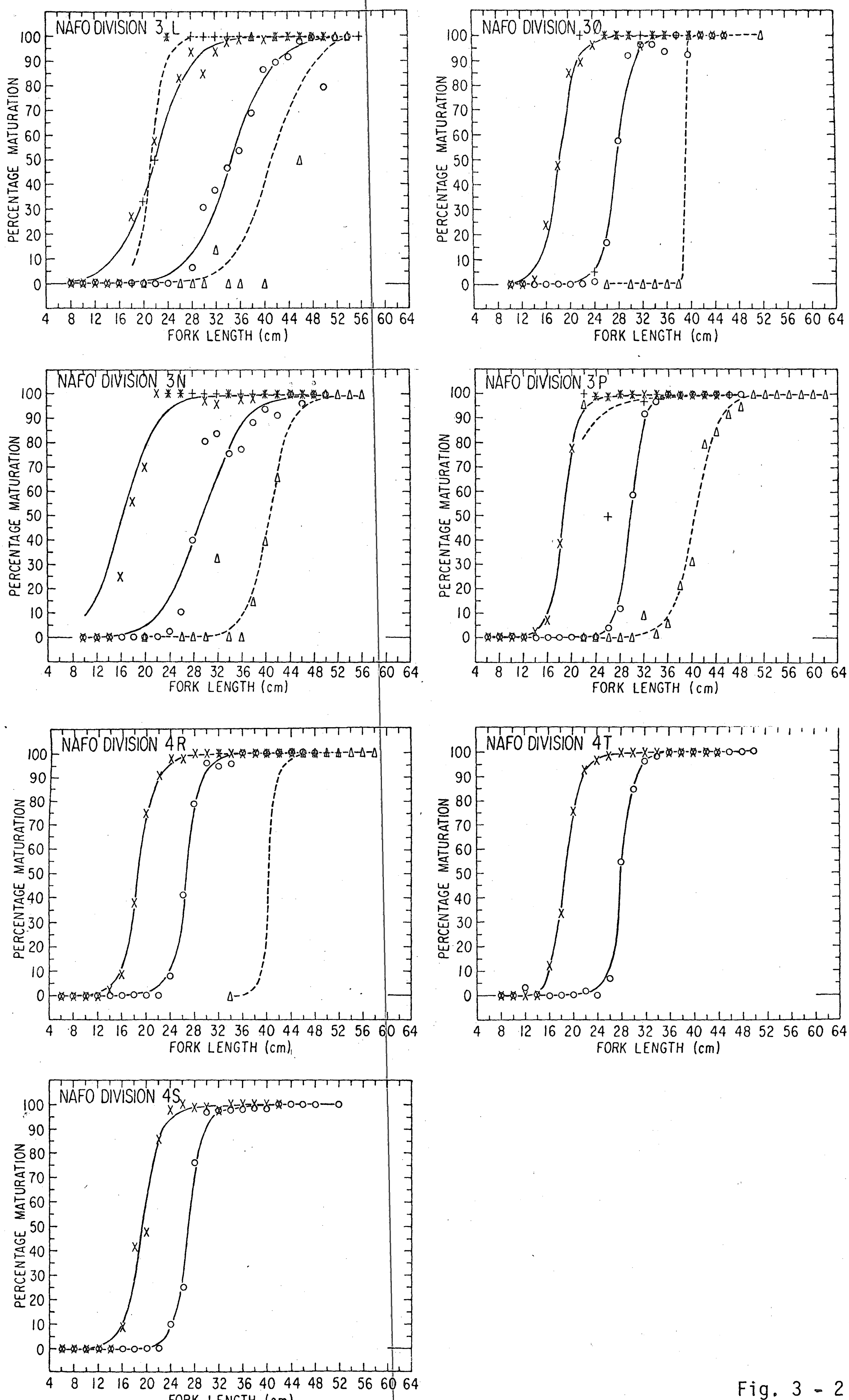
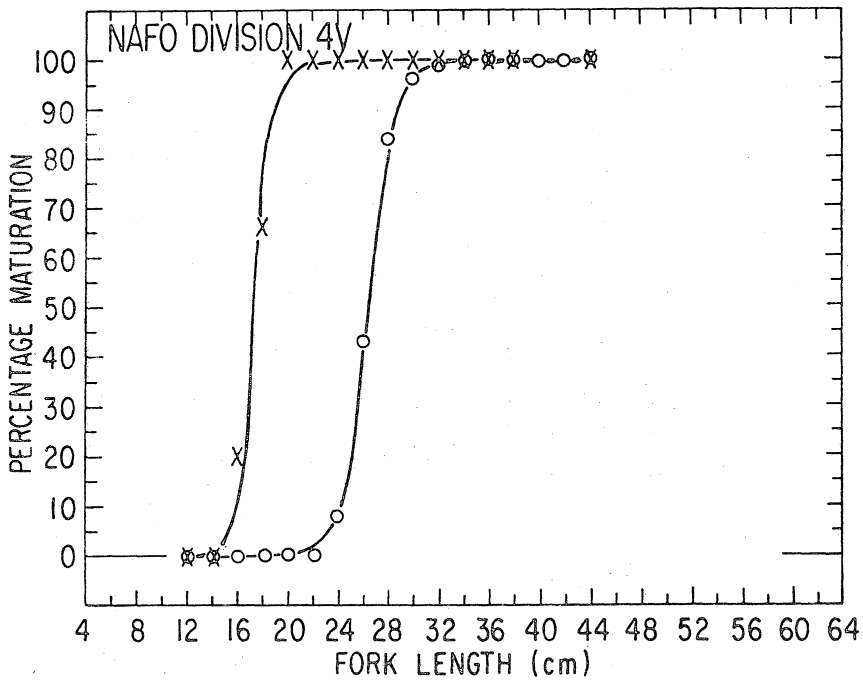
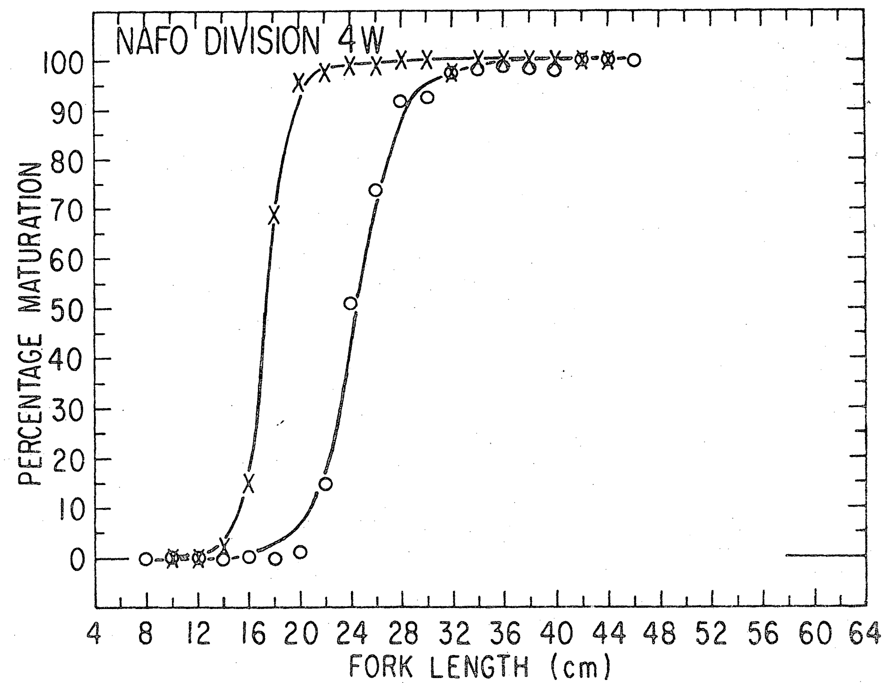

NAFO DIVISION 3L
NAFO DIVISION 3O
NAFO DIVISION 3N
NAFO DIVISION 3P
NAFO DIVISION 4R
NAFO DIVISION 4T
NAFO DIVISION 4S
PERCENTAGE MATURATION
FORK LENGTH (cm)
0 10 20 30 40 50 60 70 80 90 100
4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64

Fig. 3 - 2


NAFO DIVISION 4V
PERCENTAGE MATURATION
FORK LENGTH (cm)


NAFO DIVISION 4W
PERCENTAGE MATURATION
FORK LENGTH (cm)

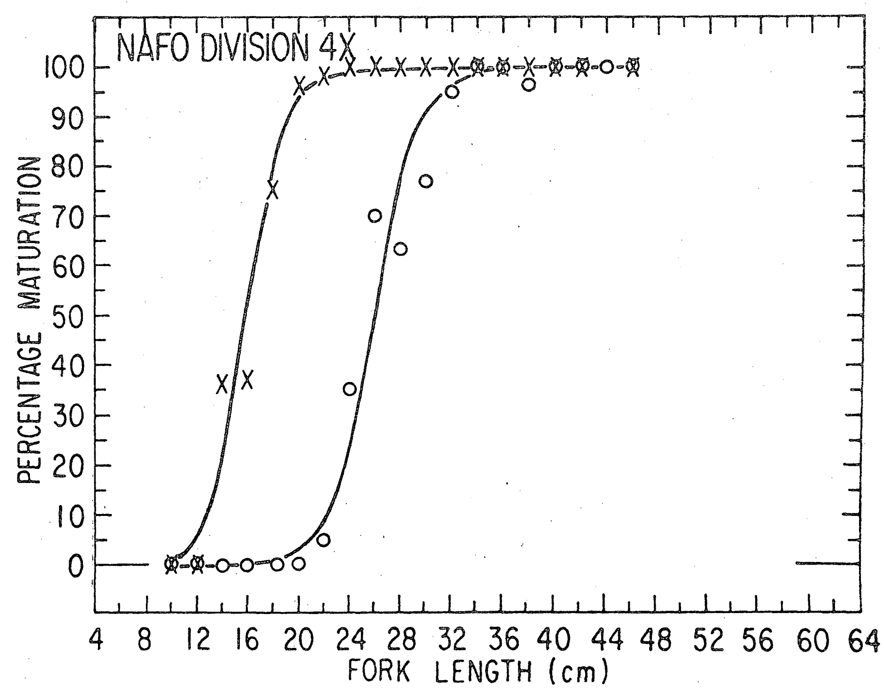

NAFO DIVISION 4X
PERCENTAGE MATURATION
FORK LENGTH (cm)

Fig. 3 - 3

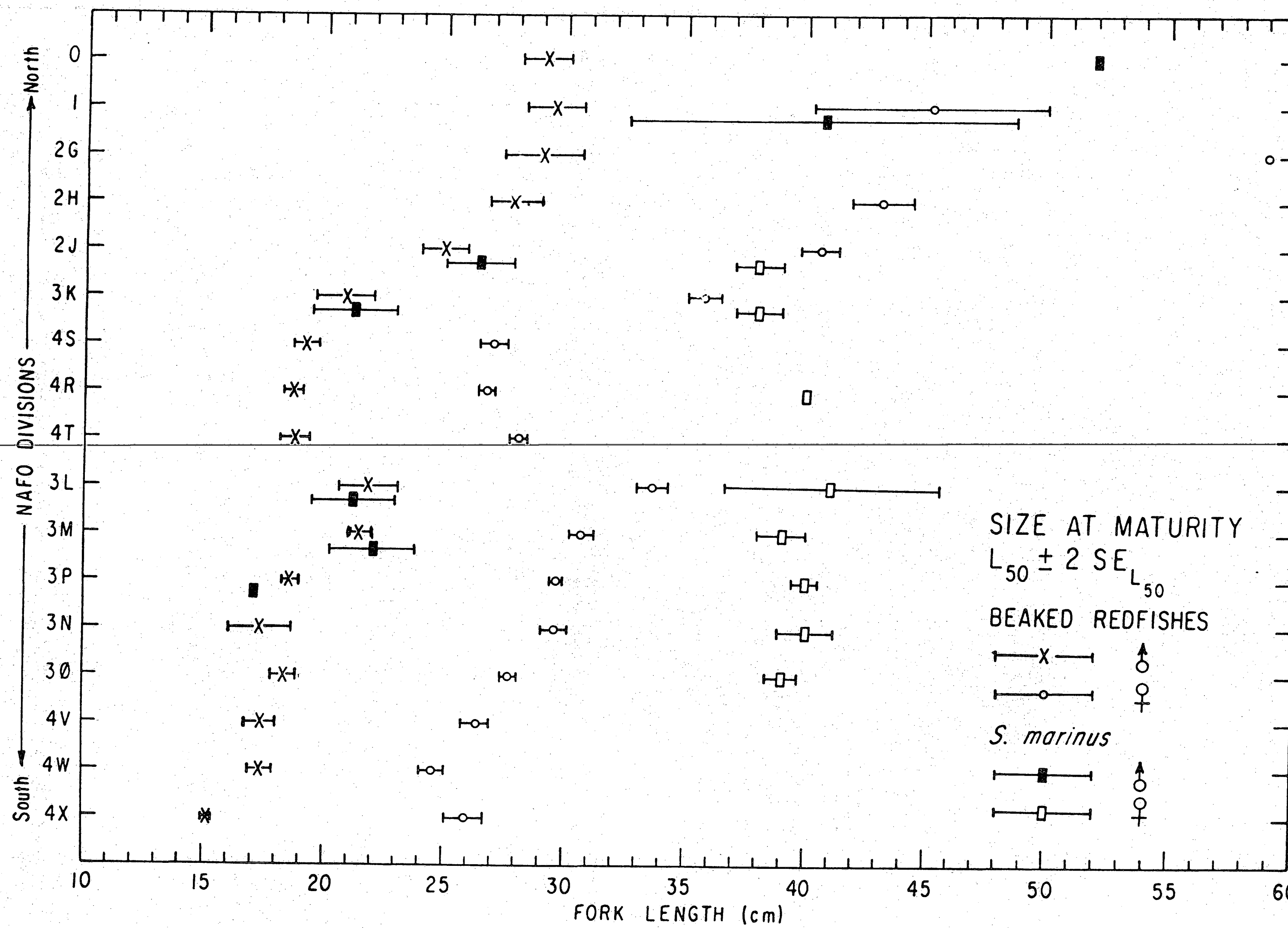


Fig. 4. Geographic variation of size at maturity for beaked redfishes and S. marinus in the Northwest Atlantic.