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Estimates of Mortality From Cod Tagged in NAFO Divisions 2J+3KL During the Winter-Spring of 1978-82

by

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INTRODUCTION

During February-March 1978-82, about 31,400 Atlantic cod (≥45 cm) were tagged from the prespawning concentrations on Hamilton Bank, Belle Isle Bank, Funk Island Bank, and the northern slopes of the Grand Bank. On the basis of tagging during February-March 1981 of about 25,000 cod in the above areas, Lear (1984) demonstrated that each overwintering component contributed to the summer inshore fishery in specific, although widely overlapping, areas of the Labrador and eastern Newfoundland coasts. The migrations of cod of the 2J3KL stock complex are characterized by an inshore movement of a proportion of each component to the coast during the summer and an offshore migration to outer continental slopes in autumn. They form overwintering concentrations on the outer slopes of the continental shelf in depths of 200 to 600 m and in bottom water temperatures of 2.5-4°C (Akenhead et al., 1982). Thus over the course of a year the mature, adult cod of a particular stock component would have completely distributed themselves throughout the whole winter and summer range of the area generally inhabited by that stock component.

The purpose of this paper is to provide estimates of total instantaneous mortality rates (Z) and hence fishing mortality rates (F) assuming a constant annual natural mortality rate (M = .20) (Pinhorn 1975).

METHODS

During February-March 1978-82 about 31,400 adult cod (45 cm and larger) were tagged using a variety of tag types (Tables 1 and 2) from the pre-spawning concentrations on Hamilton Bank, Belle Isle Bank, Funk Island Bank, and the northern areas of the Grand Bank (Fig. 1).

The cod which were tagged were obtained by an Engel High Rise otter trawl. The net was not lined with a fine mesh liner except during the 1978 tagging. The sets were generally short (10-20 minute duration), depending on the concentration of cod as indicated from the echo sounder. The net was taken back very slowly (8-10 m/minute) to allow the cod to acclimate to the changing pressure somewhat and to prevent drowning from crowding in the codend. Only fish classed in excellent condition were tagged. Any fish showing signs of bruising, scale loss, injuries to fins or gills, bleeding and "pop eye" condition were routinely culled out during the tagging procedures. Any fish with distended swim bladders were culled out rather than attempt to squeeze the gas out of the swim bladder. The cod were held in holding tanks filled with running sea water, dipped out with dipnets, measured, tagged, and placed in recovery tanks filled with running sea water until they fully recovered and actively swam in the tank. They were released through the rock hatch at the level of the water line of the ship. Thus the cod were placed, not dropped, into the sea. The tag recaptures are reported here by tag type (Table 3) and are standardized by effort on the basis of tags reported per 100,000 hours fished in NAFO Div. 2J, 3K, and 3L (Table 4). The effort figures used are those provided by Baird and Bishop (1985) based on the catch rate index series for cod in Div. 2J3KL for 1962-79 and 1979-84 using 1979 as a reference.

Only tagging experiments No. 1 for the year 1978, No. 7 for the year 1979, and Nos. 13 and 14 for the year 1980 were used in the calculations of total mortalities. Experiment No. 8 (1979) and Nos. 19 and 20 (1981) were excluded because recaptures were such that only two estimates of Z could be obtained and given the high variability in such estimates (Tables 5

and 6) these were not considered sufficient to provide a reliable average. Similarly experiments 28-31 (1982) were excluded because the recaptures provided only one estimate of Z.

The numbers of tags reported per 100,000 hours of fishing were transformed using the natural logarithm of the numbers reported. The differences in the natural logarithmic values of tags recaptured by standardized effort were then used as estimates of total instantaneous mortality (Z) (Table 5). The overall average of the years was then obtained to give an average Z over time for the years after tagging excluding the tagging year. Based upon an assumed constant natural mortality (M = .20), (Pinhorn 1975) the fishing mortality rates (F) were calculated for the different tag types and the various combined cohorts beginning for example in 1979 for the 1978 tagging and including years to 1984.

Two methods of estimating total mortality from linear regression analysis are given in Table 6. These are the ordinary least squares (OLS) (Beverton and Holt 1956) and weighted least squares (WLS) as described by Farebrother (1985). The OLS method uses log (N_j) as the dependent variable where N_j = the number of tagged fish actually recaptured in the time interval j and j + 1 per 100,000 hours fished. The WLS method uses Log (N_j/N) as the dependent variable where N_j = the number of tagged fish actually recaptured per unit effort in the time interval j and j + 1, and N = the number of tagged fish in the population after allowing for 10% mortality from tagging and handling, based upon several years data from holding tagged cod in tanks on board ship for up to two weeks at a time. The time interval j, ranging from 0 to t-1 as the independent variable where 0 is defined as the year following tagging (i.e. the recaptures in the year of tagging were omitted to allow for homogeneous mixing of the tagged population). In the case of the WLS estimate the weight was equal to N_j.

Both OLS and WLS methods assume homogeneous mixing of tagged fish throughout the population and constant and equal rates of mortality for tagged and untagged fish (Farebrother 1985). This is assumed in the present analysis after the initial tagging and handling mortality. The OLS model has the error normally and independently distributed with $E(E_j) = 0$ and $Var(E_j) = \sigma^2$. The WLS model has error E_j^* approximately normally distributed having $E(E_j^*) = 0$ and $VAR(E_j^*) = (1-P_j)/N_jP$, where P_j = the proability that any individual tagged fish will be recaptured between time interval j and j+1.

Criteria for comparing estimators are:

1. ease with which a method can be employed;

2. bias (i.e. estimators are unbiased if the expected value of the parameters are equal to the true underlying parameters); and

3. efficiency, which means its variance is as small as can be allowed by an unbiased estimator (Sandland, 1982).

Both OLS and WLS can easily be carried out by package programs and both are unbiased estimators. Both, however, are not equally efficient. Work carried out by Sandland (1982) over a wide range of experimental situations compared OLS and WLS to the generalized least square estimator, which is known to be fully efficient if the errors E_j^* are indeed normally distributed and N is large. This work illustrated how constant and small is the loss of efficiency (<1%) in WLS while OLS had a rapid fall off in efficiency (see Sandland 1982; Table 1, p. 294).

The cod which were tagged were of length 45 cm or larger, except in an occasional instance. This would indicate that the tagged population was of ages 4 years and older (Baird and Bishop 1985). The mortality rates calculated in the year after tagging would relate to fish five years and older in that year. The mortality rates calculated from the regressions would reflect the mortality rates of cod 5 years and older of the particular cohort of year-classes tagged in a specific year.

RESULTS AND DISCUSSION

The estimates of instantaneous total mortality (Z) between successive years for the 1978 tagging on Belle Isle Bank (Div. 2J and 3K) were quite variable among years (Table 5) for both the Petersen disc (PD) and the small yellow T-bar tags (SYTB); on average, the Z values for the PD and SYTB were 0.51 and 0.43 respectively. On the assumption that natural mortality (M) = 0.20, then F = 0.31 and 0.23 respectively for an overall average value of 0.27 for both tag types for the years 1979 to 1984.

From the 1979 tagging on Funk Island Bank (3K) the average F values by tag type varied from .12 to .40 but were mainly around .25 to .40 with an overall average of 0.29.

The overall average fishing mortality(F) rates for Funk Island Bank and the North Cape of the Grand Bank during 1981-84 from cod tagged during 1980 were similar, 0.28 and 0.31 respectively for an overall average of 0.29 (Table 5).

The estimates of mortality based upon weighted and unweighted regressions of the natural logarithms of tags per 100,000 hours fished (Table 6) gave varying estimates. The weighted estimates for the period 1979-84 were 0.27 for PD and 0.13 for SYTB tags while the unweighted estimates were 0.31 and 0.21 for PD and SYTB respectively, comparable to the overall averages obtained by averaging successive years (Table 5). The overall averages of F by both regression methods from Funk Island Bank during 1980-84 were similar (0.29 and 0.31).

For 1981-84 for Funk Island Bank and north Cape of Grand Bank the overall average estimates of F were about 0.30.

Comparisons of the average F-values from the three methods used in this paper with those from the most recent cohort analysis (Baird and Bishop 1985) are shown in Table 7. The average F-values from the cohort were calculated from the F-values on the cohorts in the F-matrix that corresponded to the cohorts tagged in each year. For example the cohort value of F = 0.31 in Table 7 corresponding to the 1978 experiment was calculated by averaging the F-values in the F-matrix for ages 5 and older in 1979, ages 6 and older in 1980, ages 7 and older in 1981, ages 8 and older in 1982, ages 9 and older in 1983 and ages 10 and older in 1984. The agreement with the most recent cohort analyses, which used terminal F in 1984 = 0.23, is very good.

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Table 1. Descriptions of tag types applied to adult Atlantic cod during 1978-82 on Hamilton Bank, Belle Isle Bank, Funk Island Bank, and northern areas of the Grand Bank.

Tag type	Description
PD+B	13 mm diameter yellow Petersen disc and blank attached posterior to first dorsal fin by .032 soft stainless steel wire, 3 mm space allowed on each side of fish.
SYTB	7 cm yellow spaghetti T-Bar tag attached through base of the first dorsal fin.
YTB	8.25 cm yellow spaghetti T-Bar tag attached through base of the first dorsal fin.
OTB	8.25 cm orange spaghetti T-Bar attached through base of the first dorsal fin.
DD+PD+B	Combination tag composed of 13 mm diameter yellow Petersen disc and blank with a yellow dangler tag (5 cm long by 13 mm wide) attached to trail along each side of fish. The attachment is by .032 soft stainless steel wire posterior to the first dorsal fin with a spacing of 3 mm allowed on each side of the fish.
Double	These were combinations of 13 mm diameter yellow Petersen discs, 8.25 cm yellow or 8.25 orange spaghetti T-Bar tags attached in the area of the first and second dorsal fins. Each cod was tagged with two tags, either of the same type or two different types. The tags were attached in two positions around the first and second dorsal fins.

Table 2. Numbers of cod tagged by 3 cm length group in various areas during February-March, 1978-82.

Fork length (cm)	Experiment number (year)										
	1(1978)	7(1979)	8(1979)	13(1980)	14(1980)	19(1981)	20(1981)	22(1981)	28(1982)	30(1982)	31(1982)
37				1				1	3		
40		1							3		
43	11	5		1					10		
46	277	295	26	80	54	28	3	72	44	21	31
49	702	653	29	221	170	60	61	195	80	43	82
52	999	838	62	421	281	106	217	388	97	114	126
55	860	882	71	606	406	148	475	540	174	213	199
58	517	804	70	714	342	213	640	505	228	386	235
61	312	584	63	673	261	170	631	449	224	497	313
64	207	358	57	540	169	172	504	346	198	473	316
67	195	218	37	448	124	96	348	225	160	393	320
70	133	131	17	308	63	72	191	137	98	286	293
73	93	83	24	212	26	47	101	108	55	204	204
76	45	58	16	147	29	28	50	63	33	112	129
79	36	37	15	133	16	16	34	34	20	73	64
82	34	25	14	96	11	15	16	24	10	38	36
85	13	10	10	80	12	2	16	11	5	41	15
88	5	13	11	68	9	6	3	12	3	27	13
91	2	3	3	69	8	6	5	8	1	17	2
94	8	2	6	44	5		3	10	1	10	3
97		1	2	40	2	3	4	6		17	1
100	1	3	2	34		1	2	3		8	
103			1	14	3	1		1	2	7	1
106		1	3	8	1	2	1		1	6	
109				8	1				1	3	
112		1	2	2	1			1			
115			1	1		1				1	
118				2					1		
121			2	1		1					
124				2		1					
127											
130											
133											
136				1							
No length	5	2	1	2						2	
Total	4455	5008	545	4977	1994	1195	3305	3139	1452	2992	2383

Table 3. Numbers of cod tagged by tag type and area and total numbers of tags reported in years following the tagging. Recaptures in the year of tagging are omitted.

Expt. no.	Area	Tagging year	Tag type	No. tagged	Tags reported						
					Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
1	Belle Isle Bank	1978	PD+B	3525	193	94	69	44	21	11	8
			SYTB	930	25	15	14	8	6	2	0
7	Funk Island Bank	1979	PD+B	1014	44	26	19	11	10	6	
			DD+PD+B	991	37	12	7	4	3	4	
			YTB	1003	27	21	18	5	2	1	
			OTB	1001	53	22	24	14	6	0	
			Double	999	51	29	24	11	7	3	
8	N. Grand Bank/ S. Funk Island Bank	1979	PD+B	200	8	4	1	0	1	1	
			YTB	195	5	3	1	0	0	0	
			OTB	150	5	2	2	0	1	0	
13	Funk Island Bank	1980	PD+B	1242	38	30	18	9	4		
			DD+PD+B	1287	30	14	9	9	3		
			YTB	1237	32	21	17	6	3		
			OTB	1211	32	23	16	9	5		
14	N. Cape of Grand Bank	1980	PD+B	500	9	11	7	3	1		
			DD+PD+B	498	12	4	5	3	1		
			YTB	574	14	7	4	2	3		
			OTB	422	11	12	2	0	2		
19	SW Funk Island Bank	1981	PD+B	299	13	2	2	1			
			DD+PD+B	310	20	10	3	0			
			YTB	287	16	10	3	4			
			OTB	299	14	5	2	3			
20	NE Hamilton Bank	1981	PD+B	832	57	20	10	4			
			DD+PD+B	845	35	15	9	4			
			YTB	822	53	20	11	6			
			OTB	806	44	10	12	6			
22	NE Funk Island Bank	1981	PD+B	849	46	22	14	8			
			DD+PD+B	487	31	13	5	3			
			YTB	905	54	30	10	8			
			OTB	898	46	28	20	10			
28	E. of Cape Bonavista	1982	PD+B	355	12	4	0				
			DD+PD+B	350	14	1	2				
			YTB	393	5	6	0				
			OTB	354	7	4	0				
30	SE Hamilton Bank	1982	PD+B	750	31	10	7				
			DD+PD+B	744	23	15	5				
			YTB	744	23	6	10				
			OTB	754	22	10	8				
31	N. Funk Island Bank	1982	PD+B	596	31	13	6				
			DD+PD+B	592	42	15	9				
			YTB	599	27	10	9				
			OTB	596	22	12	9				

Table 4. Numbers of cod tagged by tag type and area and total numbers of tags reported per 100,000 hours fished in NAFO Divisions 2J, 3K, and 3L in years following the tagging. Recaptures in the year of tagging are omitted.

Expt. no.	Area	Tagging year	Tag type	No. tagged	No. free	Tags reported/100,000 hours fished					
						Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1	Belle Isle Bank	1978	PD+B	3525	3173	115.6	63.7	60.9	26.3	14.8	9.1
			SYTB	930	837	15.0	10.2	12.3	4.8	4.2	1.7
7	Funk Island Bank	1979	PD+B	1014	913	29.8	22.9	11.4	7.8	8.3	
			DD+PD+B	991	892	25.1	10.6	4.2	2.8	2.5	
			YTB	1003	903	18.3	18.5	10.8	3.5	1.7	
			OTB	1001	901	35.9	19.4	14.3	9.9	5.0	
			Double	999	899	34.5	25.6	14.3	7.8	5.8	
8	N. Grand Bank/ S. Funk Island Bank	1979	PD+B	200	180	5.4	9.7	0.6	0.0	0.8	
			YTB	195	176	3.4	2.6	0.6	0.0	0.0	
			OTB	150	135	3.4	1.8	1.2	0.0	0.8	
13	Funk Island Bank	1980	PD+B	1242	1118	33.5	17.9	12.7	7.4		
			DD+PD+B	1287	1158	26.5	8.4	6.4	7.4		
			YTB	1237	1113	28.2	12.6	12.0	5.0		
			OTB	1211	1090	28.2	13.8	11.3	7.4		
14	N. Cape of Grand Bank	1980	PD+B	500	450	7.9	6.6	4.9	2.5		
			DD+PD+B	498	448	10.6	2.4	3.5	2.5		
			YTB	574	517	12.3	4.2	2.8	1.7		
			OTB	422	380	9.7	7.2	1.4	0.0		
19	SW Funk Island Bank	1981	PD+B	299	269	7.8	1.4	1.7			
			DD+PD+B	310	279	12.0	7.1	2.5			
			YTB	287	258	9.6	7.1	2.5			
			OTB	299	269	8.4	3.5	1.7			
20	NE Hamilton Bank	1981	PD+B	832	749	34.1	14.1	8.3			
			DD+PD+B	845	761	20.9	10.6	7.4			
			YTB	822	740	31.7	14.1	9.1			
			OTB	806	725	26.3	7.1	9.9			
22	NE Funk Island Bank	1981	PD+B	849	764	27.5	15.6	11.6			
			DD+PD+B	487	438	18.5	9.2	4.1			
			YTB	905	815	32.3	21.2	8.3			
			OTB	898	808	27.5	19.8	16.5			
28	E. of Cape Bonavista	1982	PD+B	355	320	8.5	3.3				
			DD+PD+B	350	315	9.9	0.8				
			YTB	393	354	3.5	5.0				
			OTB	354	319	4.9	3.3				
30	SE Hamilton Bank	1982	PD+B	750	675	21.9	8.3				
			DD+PD+B	744	670	16.3	12.4				
			YTB	744	670	16.3	5.0				
			OTB	754	679	15.6	8.3				
31	N. Funk Island Bank	1982	PD+B	596	536	21.9	10.7				
			DD+PD+B	592	533	29.7	12.4				
			YTB	599	539	19.1	8.3				
			OTB	596	536	15.6	9.9				

Table 5. Estimates of total mortality (Z) between successive years after tagging, based upon tags/100,000 hours fished. Recaptures in the year of tagging are omitted.

Expt. no.	Area	Tagging year	Tag type	No. tagged	No. free	Z Values Year 1-2	Year 2-3	Year 3-4	Year 4-5	Year 5-6	Av. Z	Av. F	
1	Belle Isle Bank	1978	PD+B	3525	3173	.60	.05	.84	.58	.49	.51	.31	.27
			SYTB	930	837	.39	-.19	.94	.13	.90	.43	.23	
7	Funk Island Bank	1979	PD+B	1014	913	.26	.70	.38	-.06		.32	.12	
			DD+PD+B	991	892	.86	.93	.41	.11		.58	.38	
			YTB	1003	903	-.01	.54	1.13	.72		.60	.40	.29
			OTB	1001	901	.62	.31	.37	.68		.50	.30	
			Double	999	899	.30	.58	.61	.30		.45	.25	
13	Funk Island Bank	1980	PD+B	1242	1118	.63	.34	.54			.50	.30	
			DD+PD+B	1287	1158	1.15	.27	-.15			.42	.22	.28
			YTB	1237	1113	.81	.05	.88			.58	.38	
			OTB	1211	1090	.71	.20	.42			.44	.22	.29
14	N. Cape Grand Bank	1980	PD+B	500	450	.18	.30	.67			.38	.18	
			DD+PD+B	498	448	1.49	-.38	.34			.48	.28	.31
			YTB	574	517	1.08	.41	.50			.66	.46	
			OTB	422	380	.30	1.64	—			—	—	

Table 6. Estimates of total mortality (Z) and fishing mortality (F) based on weighted and unweighted regressions of the natural logarithm of tags per 100,000 hours fished. Recaptures in the year of tagging are omitted.

Expt. no.	Area	Years	Tag type	No. free	Weighted Farebrother Method Bo (Z)	r^2	95% C.I.[1]	F		Unweighted Least Squares Z	r^2	95% C.I.[2]	F	
1	Belle Isle Bank	1979-84	PD+B	3173	0.47	.94	.36 to .58	.27		0.51	.97	.39 to .63	.31	.26
			SYTB	837	0.33	.79	.16 to .50	.13	.20	0.41	.89	.20 to .62	.21	
7	Funk Island Bank	1980-84	PD+B	913	0.38	.93	.26 to .50	.18		0.36	.90	.14 to .58	.16	
			DD+PD+B	892	0.67	.95	.50 to .84	.47		0.59	.92	.27 to .92	.39	
			YTB	903	0.48	.77	.18 to .78	.28	.29	0.64	.91	.27 to .97	.44	.31
			OTB	901	0.46	.98	.39 to .53	.26		0.46	.98	.34 to .58	.26	
			Double	899	0.46	.98	.38 to .54	.26		0.48	.98	.37 to .59	.28	
13	Funk Island Bank	1981-84	PD+B	1118	0.50	.99	.42 to .58	.30		0.49	.99	.33 to .65	.29	
			DD+PD+B	1158	-	-	-	-		-	-	-	-	
			YTB	1113	0.51	.91	.29 to .73	.31	.29	0.52	.92	.04 to 1.00	.32	.28
			OTB	1090	0.45	.95	.31 to .59	.25		0.42	.95	.12 to .72	.22	
14	N. Cape of Grand Bank	1981-84	PD+B	450	0.33	.90	.18 to .48	.13		0.37	.92	.03 to .71	.17	
			DD+PD+B	448	-	-	-		.32	-	-	-	-	.30
			YTB	517	0.71	.95	.49 to .93	.51		0.63	.95	.17 to 1.09	.43	
			OTB	380	-	-	-	-		-	-	-	-	

[1] 95% C.I. = Bo ± 1.96 $\sqrt{\text{Var Bo}}$

[2] 95% C.I. = Z ± t_{df} x S.E.

Table 7. Comparison of fishing mortalities from tagging experiments and cohort analyses.

Exp.	Year	Successive years	OLS	WLS	Cohort
1	1978	.27	.20	.26	.31
7	1979	.29	.31	.29	.28
13	1980	.28	.28	.29	.27
14	1980	.31	.30	.32	.27

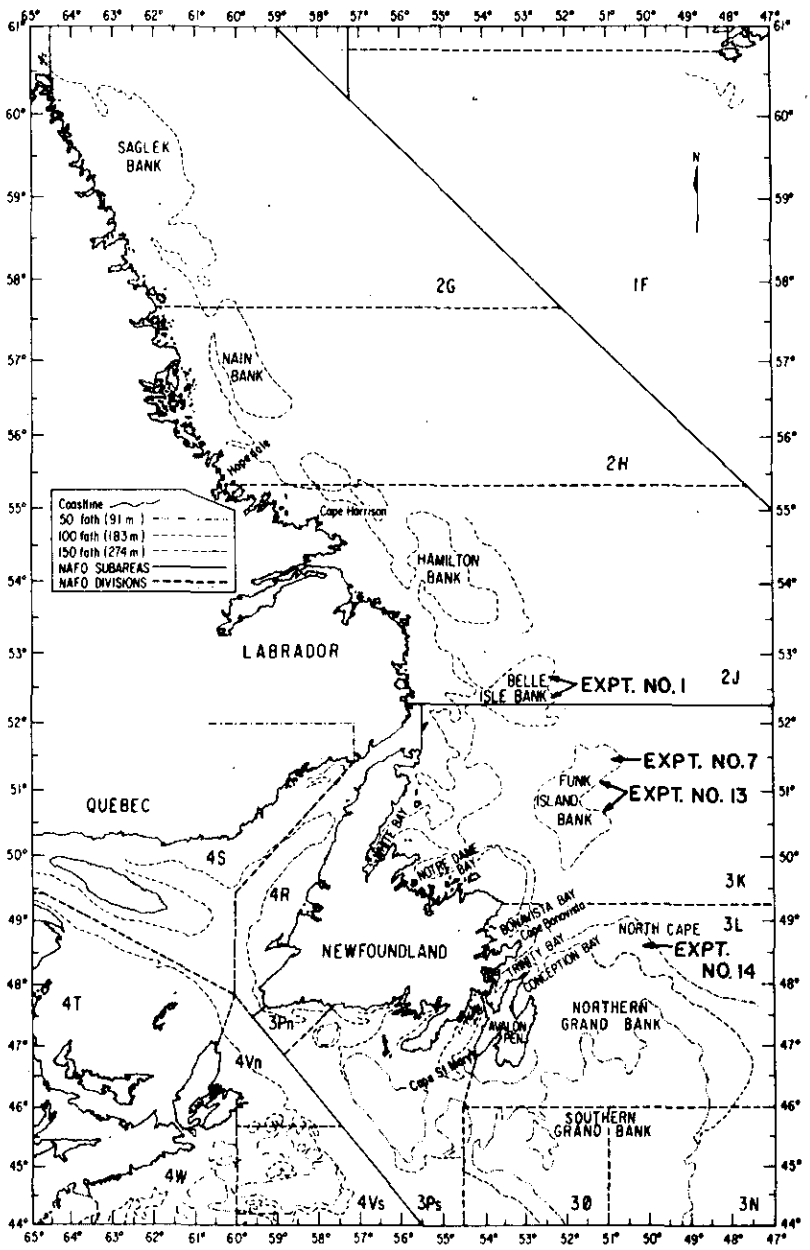

Fig. 1. Area map showing NAFO Divisions, offshore banks and locations of experiments 1, 7, 13 and 14.