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The Distribution of Trawl Catches of Cod and American Plaice from
Research Vessel Surveys in NAFO Divisions 3L, 3M and 3N

by

W. B. Brodie and R. Wells

Fisheries Research Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland A1C 5X1

INTRODUCTION

Since the mid-1970's, changes in fishing practices off the Canadian east coast have been substantial. Fishing effort by major fishing countries has been curtailed or diverted from one group of species to another. Time and area of various fisheries have been modified to conform with new fishing regulations by the coastal state and the abundance and population structure of many stocks have changed greatly. Adjustments and improvements to gear and vessels have continued. The effects of such changes upon commercial catch rates are not well understood. It is, therefore, a matter of concern that catch rates in recent years may not be easily comparable with the historical series.

To provide a more consistent measure of groundfish abundance - independent of the commercial fishery - research vessel surveys have been carried out since the early 1970's in eastern Canada and for a somewhat longer period off the eastern United States. The technique employed has been the stratified-random survey. Survey results provide a mean estimate of biomass for the area surveyed as well as confidence limits about that mean estimate.

The logistics of surveying fish stocks in the northwest Atlantic are daunting. Areas to be surveyed may be large. The area of Subarea 2 is, for example, about 60,000 square nautical miles from the coast to the 400 fath contour while that of Subarea 3 is about 150,000. In practice, the number of fishing sets per unit of area to be surveyed is perhaps rather low. In Div. 3L the average number of fishing sets employed during the annual abundance survey for American plaice (and other groundfish) was 105 over the period 1977-82 (Brodie 1985). With 29 strata and an area of 36,777 square nautical miles covered, there was an average of 3.6 sets per stratum and 1 set per 350 square nautical miles. About 84% of the tows were employed at the rate of 2-6 sets per stratum. Only once was a frequency of as many as 10 tows in a single stratum in one survey achieved.

A common problem in assessing the abundance estimate from such a survey has been the occurrence of occasional very large catch numbers, much greater than the mean or modal value otherwise present in the distribution of catch numbers. The inclusion of the very high value or several very high values may greatly increase the estimated mean and variance of the estimate. The deletion of the value(s) may be considered capricious by some since the values are real observations. A satisfactory method of dealing with these values has not been forthcoming but a widely used solution has been the use of the logarithmic transformation of the catch values increased individually by 1 so as to avoid mathematical unpleasantness with zero values.

The form of the distribution of catches has not been widely agreed upon and may, in fact, comprise a group of distributions. The distribution of a fish species during a time of wide dispersal may be quite different from those at the times of spawning, feeding, or environmentally-induced concentrations.

Since the number of tows per stratum in Div. 3L and other areas is usually so low as to defy analysis of the form of distribution, several strata have been selected where the number of tows was higher than usual. In addition, the area of Div. 3M as a whole was considered as one stratum on the basis that the whole of the local stocks of cod and American plaice were encompassed and that the intensity of sampling had been rather high (1 set per 80 square nautical miles) and proportional to the individual stratum areas surveyed.

MATERIALS AND METHODS

The catch per tow of cod and American plaice was obtained from several surveys from 1978-85. Data from Div. 3M were available for each year over this period from 3-week surveys conducted in January or February by the research vessel GADUS ATLANTICA using a lined otter trawl. The survey design was stratified random, with the number of sets chosen in all 19 strata being approximately proportional to the stratum areas (Table 1, Fig. 1). For the purpose of this paper, only sets in strata 501-515 were used, these being the strata which encompass all the fishable area down to a depth of 300 fath (549 m) in Div. 3M. At depths greater than 300 fath, catches of cod and American plaice were negligible. In this analysis, all sets from the 15 strata combined were used for the purpose of calculating the yearly mean numbers per tow and associated statistics.

Data for cod and American plaice were also available for strata 505 and 508, Div. 3M, 1984, stratum 362, Div. 3N, 1985, and stratum 364, Div. 3L, 1984 (Fig. 1 and 2). These strata have a considerably higher number of sets per 100 square nautical miles at these particular times than is usual in other surveys of these areas. Strata 505 and 508 were selected for further sampling after the 1984 stratified random survey of Div. 3M because these were the strata with the highest catch per tow of cod during this survey. Consequently, an additional 20 sets in stratum 505 and 19 in stratum 508 were chosen at random and completed immediately following the completion of the regular survey. For this analysis these additional sets have been combined with the sets (8 in each stratum) completed during the survey. Strata 362 in Div. 3N and 364 in Div. 3L were chosen for intensive sampling because of the consistently high abundance of American plaice observed in these strata in previous surveys. Totals of 73 randomly chosen sets in stratum 362 and 68 in stratum 364 were completed in February 1985 and November 1984 respectively by the research vessel WILFRED TEMPLEMAN, using a lined otter trawl. These strata were not surveyed in conjunction with a survey of a larger area.

In all cases, only 30-minute tows which resulted in no serious net damage were selected. Catches from sets of less than 30 minutes in duration were not used in the analysis, although such sets are often adjusted to 30 minutes and the adjusted catches used in standard abundance estimation procedures. In virtually all cases, all cod and American plaice in the catch were measured. Where catches were too large to permit measuring all individuals, the number caught in the set was determined from the ratio of the number of baskets of species A caught to the number of baskets of species A measured, a ratio known exactly in all cases.

No parameters of net operation were monitored in any of the surveys. It was assumed that 30-minute tows covered exactly the same distance each time, with vessel speed measured at 3.5 knots from the ship's speed log. In all cases, sets were randomly chosen within strata and appeared to be reasonably dispersed.

For both cod and American plaice in all surveys, the mean number per 30-minute tow was calculated along with the variance and range. Arbitrary groupings were used in plotting the catch frequency data (Fig. 3-9). The distribution of the catches was tested against specified distributions using the nonparametric Kolmogorov-Smirnov goodness-of-fit test (Afifi and Azen, 1979). The ungrouped frequency data was tested to see if it fit normal, Poisson, or lognormal [$\log_{10}(\text{catch} + 1)$] distributions. No tests for fits to any other distributions were attempted. Mean and variance of the specified distributions tested for were estimated from the samples, and no corrections were available for the resultant Kolmogorov-Smirnov D statistics. The 95th and 99th quantile values of the D statistic were taken from Afifi and Azen, 1979.

RESULTS AND DISCUSSION

Sample size for the surveys in Div. 3M ranged from 79-122 with the average being 110 sets (Table 1). The sampling intensity ranged from 1.2 to 1.3 sets per 100 square nautical miles with the exception of 1979 when it was 0.9. The sampling intensity was relatively constant between strata within each year, particularly for the years 1980-85 (Table 1). Stratum 515 in 1982 was the only stratum with no sets.

For the intensively sampled strata, the sampling intensity ranged from 2.4 to 4.2 sets per 100 square nautical miles and the sample size in these strata ranged from 27-73 sets (Table 4).

Table 2 shows the sample size, mean, variance, and range for the 24 samples. Of particular interest are the values of the largest catches, which show that in many samples there are some extreme values, often several times larger than the next highest catch. The catch frequencies are shown as histograms in Fig. 3-9 and, in most cases, are highly skewed to the right.

Results from the Kolmogorov-Smirnov goodness-of-fit test for the samples from Div. 3M, 1978-85 are given in Table 3. These show that the distributions of cod and American plaice catches in all cases were significantly different from a normal or Poisson distribution, with

$p < 0.01$. For all samples, with the exception of American plaice in 1984, the distributions of catches were not significantly different from lognormal distributions. In the case of the 1984 American plaice sample, Fig. 7 shows that there are two adjacent peaks in the distribution, and that the major peak occurs at the 11-20 range, while the peak for the other 7 comparable samples occurs at the 1-10 range (Fig. 6 and 7).

Table 4 contains the results of the Kolmogorov-Smirnov goodness-of-fit test for the intensively sampled strata in Div. 3M, 3N, and 3L. For cod, the distributions of all 4 samples were significantly different from Poisson distributions, with $p < 0.01$. The sample from stratum 505, had a distribution not significantly different from a normal, and significantly different from a lognormal, with $0.01 < p < 0.05$. The distribution of the cod catches in stratum 508 was not statistically different from either a normal or lognormal distribution. For the samples from strata 362 and 364, the distribution of cod catches was significantly different from a normal ($p < 0.01$ for stratum 362, $0.01 < p < 0.05$ for stratum 364) and not significantly different from a lognormal. These results indicate that for cod, it may not be possible to distinguish between types of distributions where sample sizes are small ($n = 28$, 27 for strata 505, 508 respectively). For the larger samples from strata 362 and 364, the results are in agreement with those from the samples from Div. 3M as a whole.

Results for American plaice from the 4 intensively sampled strata are also in agreement with those from Div. 3M as a whole. In stratum 508, the largest catch was only 11 fish and since these small numbers appear to represent only a fringe of the distribution, results for this sample will not be considered further. The distributions of the other 3 samples are significantly different from Poisson ($p < 0.01$) and normal distributions ($p < 0.01$ for stratum 362, $0.01 < p < 0.05$ for strata 505, 364). All are not significantly different from lognormal distributions.

Overall, the results for both cod and American plaice indicate that, in most cases, the distribution of catches is not normal or Poisson and may be lognormal. Obviously, these results are not conclusive in that not all types of distributions were tested, nor were samples available at different times of the year, under different conditions, etc. Factors such as prespawning concentration of fish and changing hydrographic conditions would undoubtedly have significant effects on the distribution of fish, and thus trawl catches. Moreover, the distribution of a species of fish would be affected by its behaviour, which for example, may range from densely schooling to territorial. However, the results do show that the distribution of catches within a stratum may not be different from the distribution of catches over an entire stock area. The results also indicate that even at very high levels of sampling intensity, a large number of sets may be required before any meaningful conclusions about the distribution of catches can be drawn.

REFERENCES

- Afifi, A. A. and S. P. Azen. 1979. Statistical Analysis. A Computer Oriented Approach. Academic Press, Inc., New York, 442 p.
- Brodie, W. B. 1985. An assessment update of the American plaice stock in NAFO Divisions 3LNØ. NAFO SCR Doc. 85/51. Ser. No. N1000, 24 p.

Table 1. Sampling intensity during stratified random surveys on the Flemish Cap (Division 3M), 1978-85. Intensity defined as the number of 30-minute tows per 100 square nautical miles.

Stratum	1978	1979	1980	1981	1982	1983	1984	1985	Stratum area (sq. n. mi.)
501	0.88	0.88	1.17	1.46	1.46	1.46	1.17	1.17	342
502	1.31	0.72	1.31	1.31	1.31	1.31	1.19	1.19	838
503	1.59	0.96	1.27	1.27	1.27	1.27	1.27	1.27	628
504	1.72	1.15	1.15	1.44	1.44	1.44	1.15	1.15	348
505	1.42	0.85	1.14	1.28	1.28	1.28	1.14	1.14	703
506	1.61	1.21	1.21	1.41	1.41	1.41	1.21	1.21	496
507	0.97	0.73	1.22	1.34	1.34	1.34	1.22	1.22	822
508	1.39	0.93	1.24	1.39	1.39	1.39	1.24	1.24	646
509	0.64	1.27	1.27	1.27	1.27	1.27	1.27	1.27	314
510	1.47	0.63	1.26	1.37	1.37	1.37	1.16	1.26	951
511	1.36	0.74	1.24	1.36	1.36	1.36	1.24	1.24	806
512	0.75	0.90	1.19	1.34	0.60	1.34	1.19	1.19	670
513	1.61	1.61	1.20	1.20	1.20	1.20	1.20	1.20	249
514	1.33	1.00	1.16	1.33	1.33	1.33	1.16	1.00	602
515	1.05	0.60	1.20	1.35	0.00	1.35	1.20	1.20	666
Total	1.28	0.87	1.22	1.34	1.19	1.34	1.20	1.20	9,081
Total no. of tows	116	79	111	122	108	122	109	109	

Table 2. Sample size, mean, variance, and range for cod and American plaice catches in Divisions 3L, 3M and 3N.

Species	Div.	Year/ Stratum	Sample size	Mean catch per tow	Variance	Smallest catch	Largest Catches		
							Largest catch	Second largest	Third largest
Cod	3M	1978	116	105.5	9673.6	0	554	425	406
		1979	79	39.7	6743.7	0	594	424	134
		1980	111	46.9	35896.3	0	1947	411	186
		1981	122	39.2	19839.2	0	1412	515	296
		1982	108	9.4	155.2	0	70	66	45
		1983	122	119.9	814696.0	0	9901	1349	533
		1984	109	30.3	1494.3	0	196	176	150
		1985	109	40.8	3369.5	0	371	235	201
Cod	3M	1984/505	28	33.5	1633.9	1	187	114	75
	3M	1984/508	27	58.9	2641.7	0	196	150	145
	3N	1985/362	73	159.0	117190.0	0	2011	1419	1327
	3L	1984/364	68	14.5	185.8	0	78	56	52
A. plaice	3M	1978	116	19.3	4123.5	0	638	278	63
		1979	79	9.7	996.7	0	276	51	48
		1980	111	14.4	8091.0	0	951	41	28
		1981	122	8.0	869.7	0	320	56	30
		1982	107	7.3	133.9	0	81	64	47
		1983	122	24.4	2935.2	0	412	349	211
		1984	109	18.7	396.0	0	156	68	63
		1985	109	16.9	513.9	0	99	98	98
A. plaice	3M	1984/505	28	37.8	2433.6	4	210	168	121
	3M	1984/508	27	3.7	8.5	0	11	9	8
	3N	1985/362	73	144.0	35125.7	1	912	851	696
	3L	1984/364	68	444.3	193277.0	0	1879	1846	1710

Table 3. Results of the Kolmogorov-Smirnov goodness-of-fit test for cod and American plaice catches from surveys in Division 3M, 1978-85.

Species	Year	Sample size	Critical value		D Statistic		
			.05	.01	Arith. Normal	Poisson	Log normal N+1
Cod	1978	116	.126	.151	.176	.542	.056
	1979	79	.153	.183	.314	.637	.072
	1980	111	.129	.155	.402	.763	.059
	1981	122	.123	.148	.390	.784	.092
	1982	108	.131	.157	.235	.432	.090
	1983	122	.123	.148	.457	.926	.086
	1984	109	.130	.156	.217	.513	.098
	1985	109	.130	.156	.241	.591	.070
American plaice	1978	116	.126	.151	.382	.610	.067
	1979	79	.153	.183	.380	.591	.117
	1980	111	.129	.155	.444	.706	.080
	1981	122	.123	.148	.393	.542	.102
	1982	107	.131	.158	.281	.389	.104
	1983	122	.123	.148	.334	.608	.076
	1984	109	.130	.156	.174	.412	.158
	1985	109	.130	.156	.240	.510	.056

Table 4. Results of the Kolmogorov-Smirnov goodness-of-fit test for cod and American plaice catches from surveys in Divs. 3L, 3M and 3N in 1984 and 1985.

Species	Div.	Stratum	Sample Size	Critical Value		D. Statistic			Sampling Intensity (sets/100 sq.n.mi)	Stratum area (sq.n.mi)
				.05	.01	Arith Normal	Poisson	Log normal		
Cod	3M	505	28	.254	.302	.211	.571 ^b	.287 ^a	3.98	703
	3M	508	27	.255	.308	.160	.505 ^b	.118	4.18	646
	3N	362	73	.157	.187	.333 ^b	.767 ^b	.131	2.90	2520
	3L	364	68	.162	.194	.164 ^a	.349 ^b	.098	2.41	2817
American plaice	3M	505	28	.254	.302	.293 ^a	.655 ^b	.132	3.98	703
	3M	508	27	.255	.308	.198	.190	.138	4.18	646
	3N	362	73	.157	.187	.224 ^b	.650 ^b	.075	2.90	2520
	3L	364	68	.162	.194	.182 ^a	.628 ^b	.099	2.41	2817

^a -significant at the 0.05 level

^b -significant at the 0.01 level

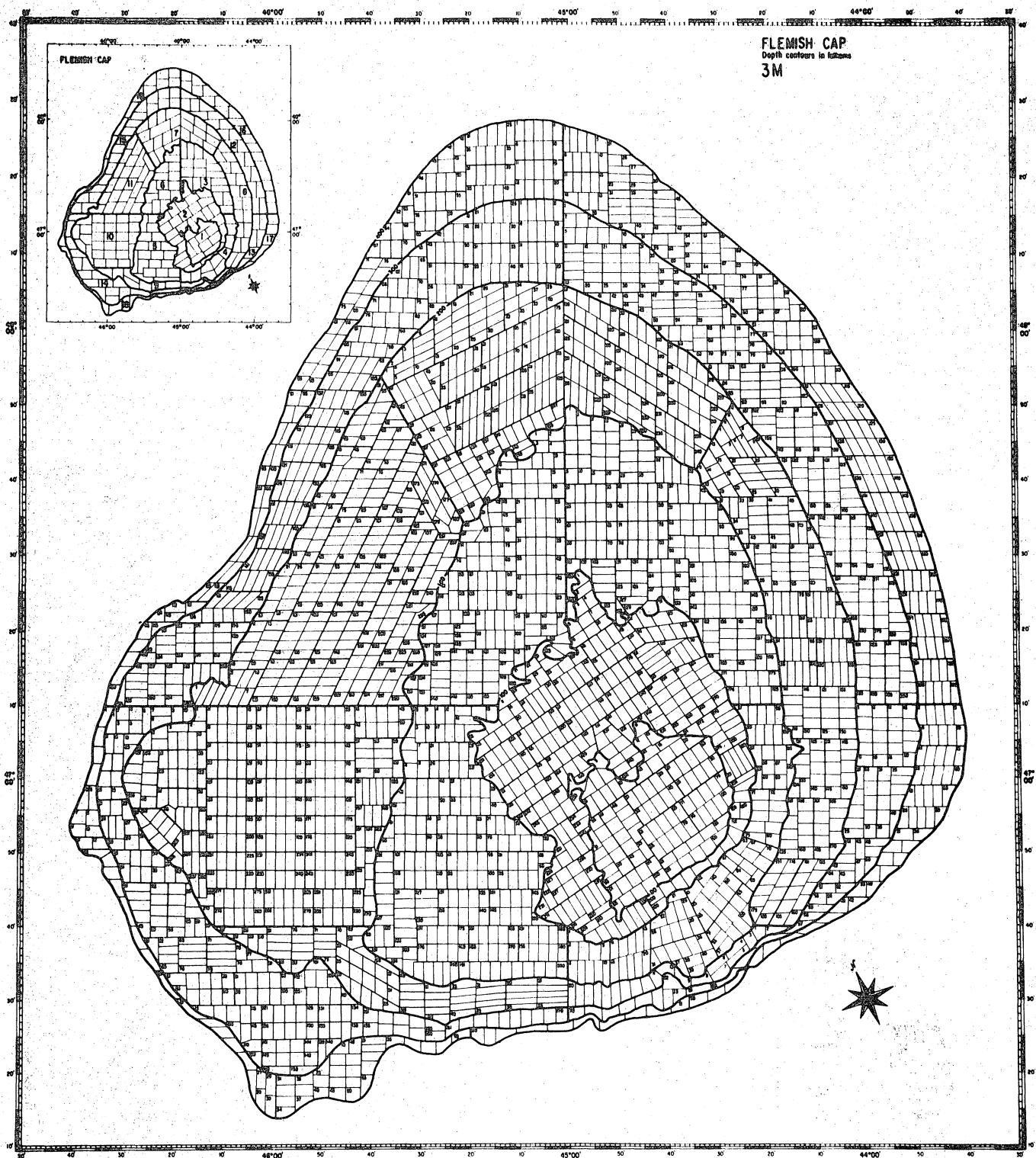


Figure 1. Stratification scheme for NAFO Division 3M.

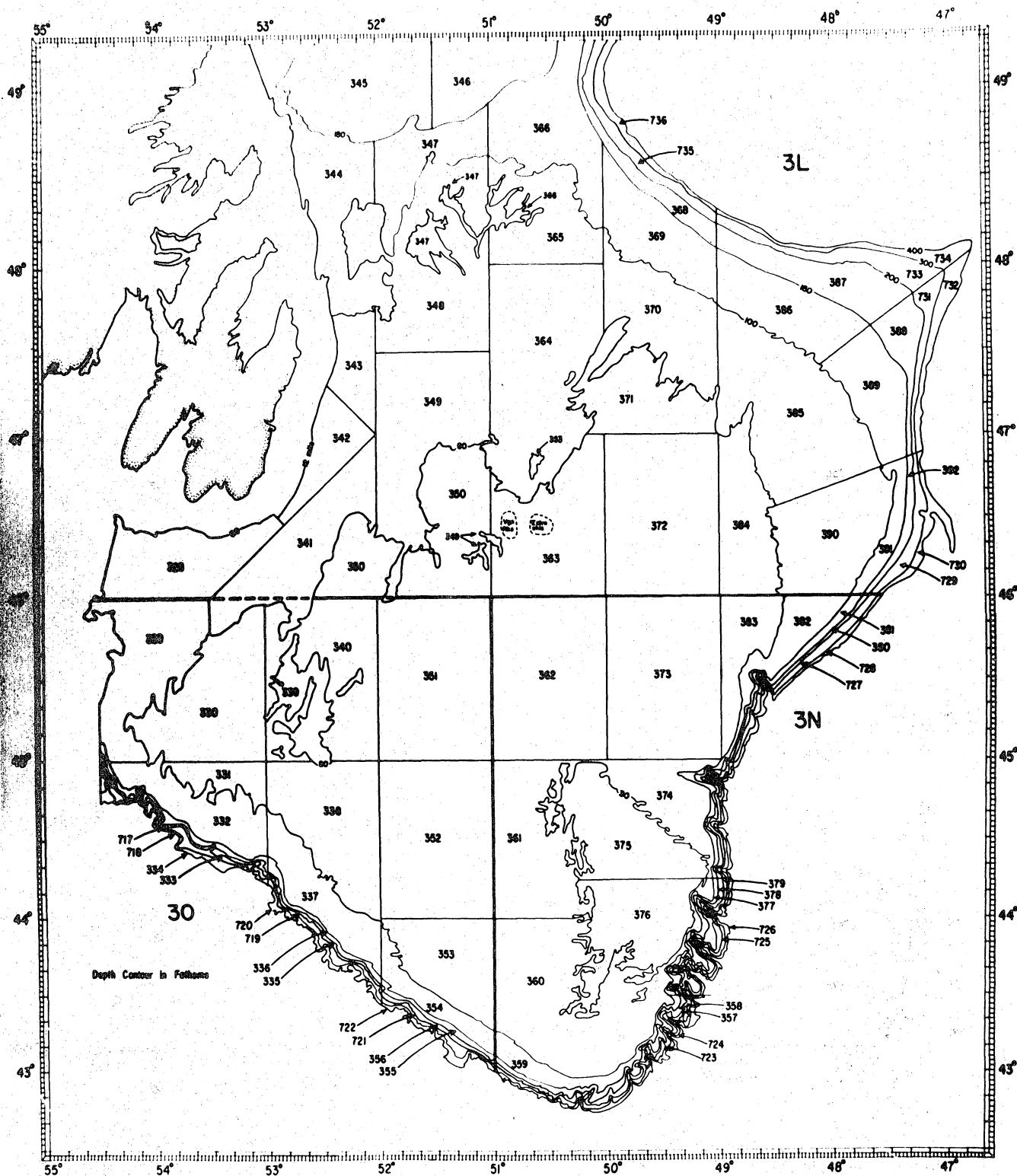


Figure 2. Stratification scheme for NAFO Divisions 3L, 3N, 30.

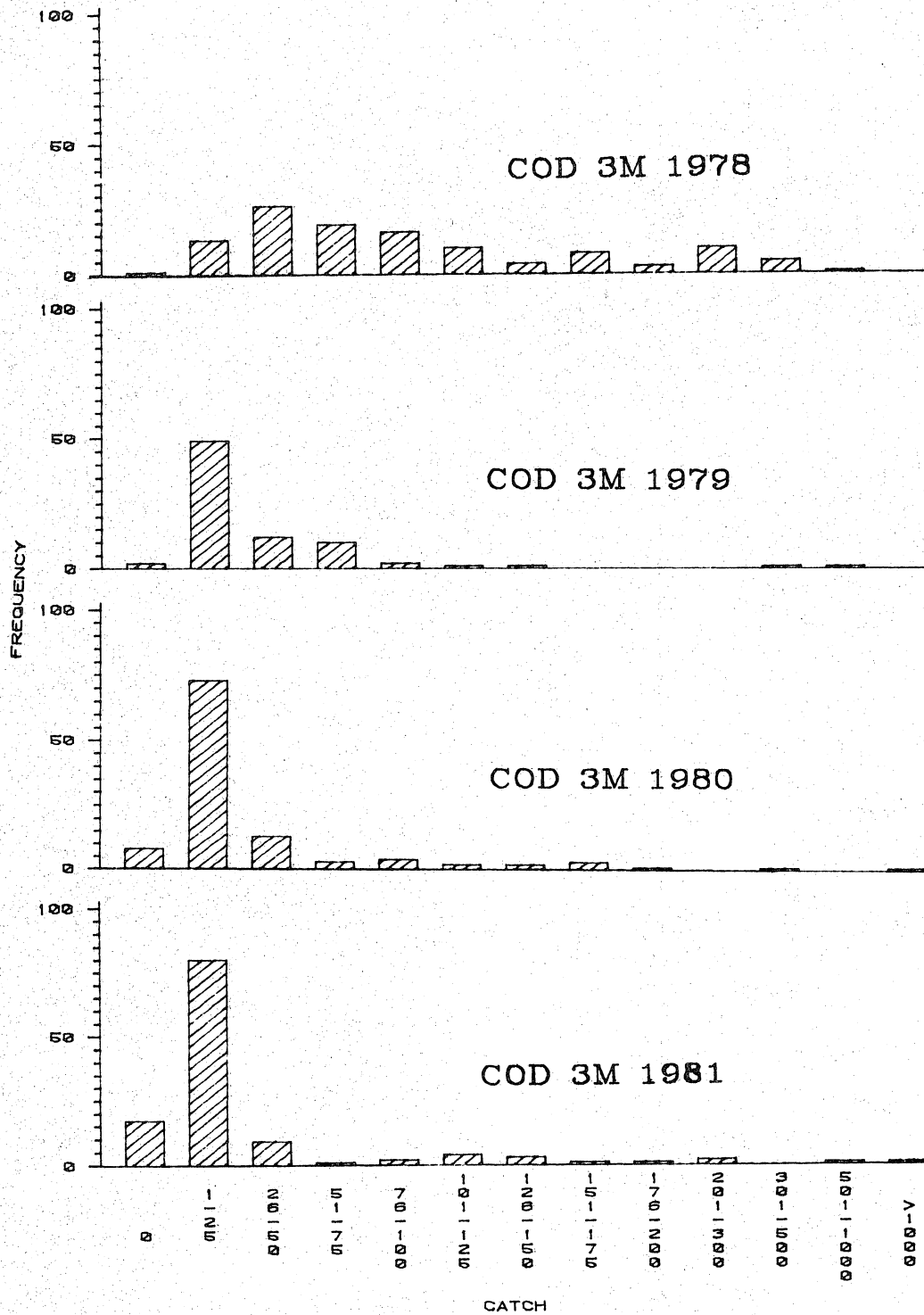


Figure 3. Catch per tow of cod from research vessel surveys in Division 3M, 1978-81.

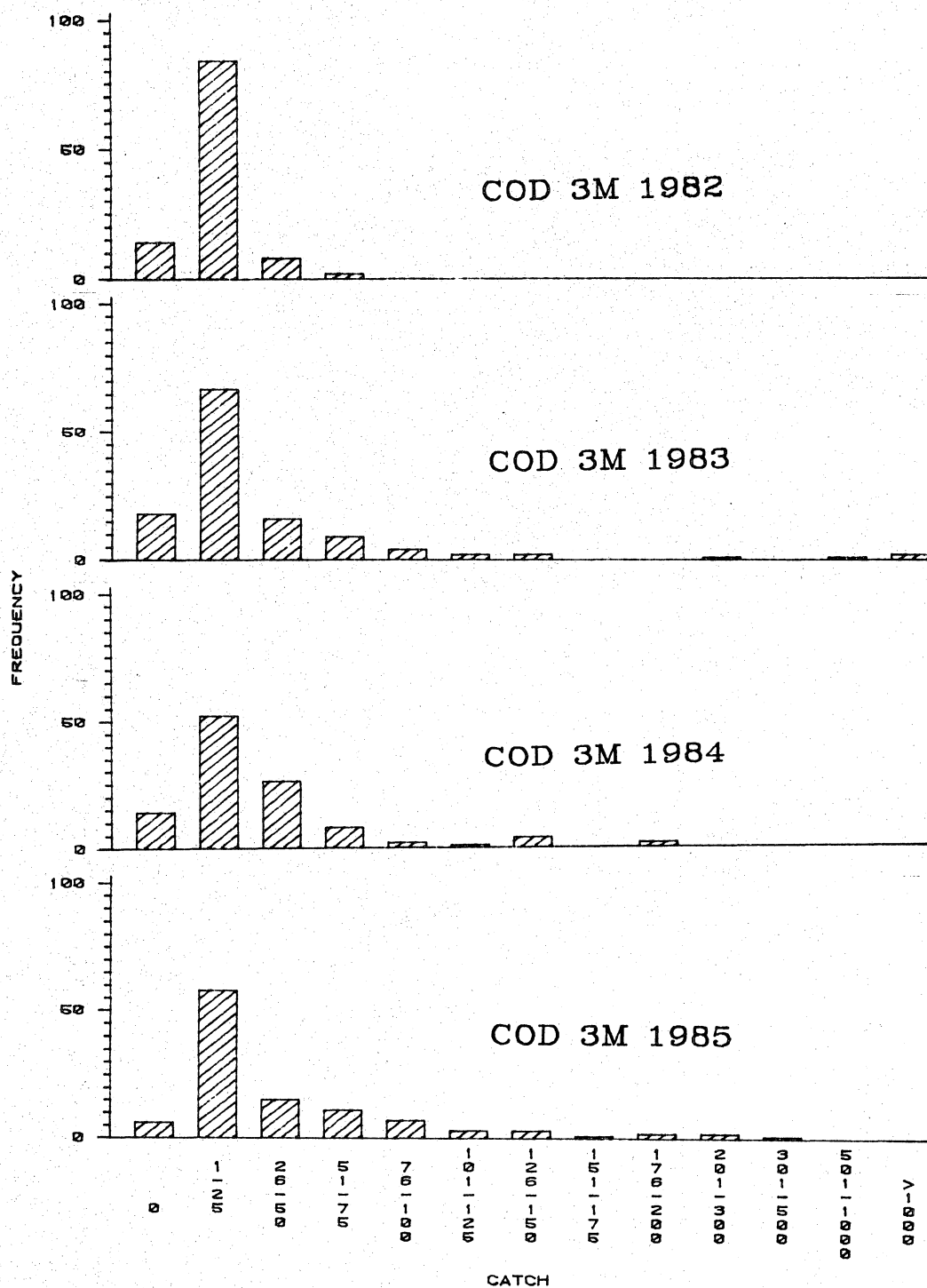


Figure 4. Catch per tow of cod from research vessel surveys in Division 3M, 1982-85.

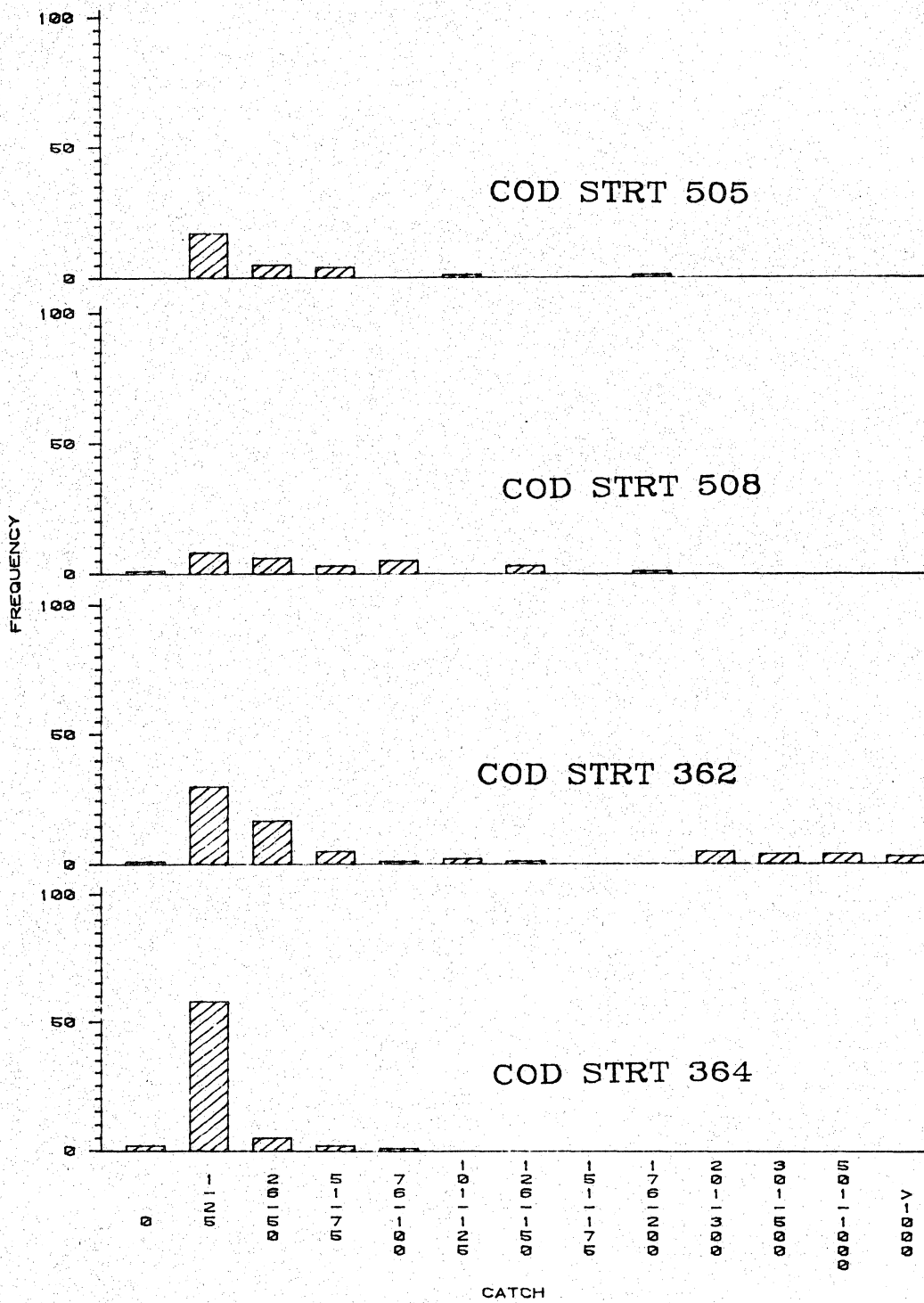


Figure 5. Catch per tow of cod from intensively sampled strata in Divisions 3M, 3N 3L.

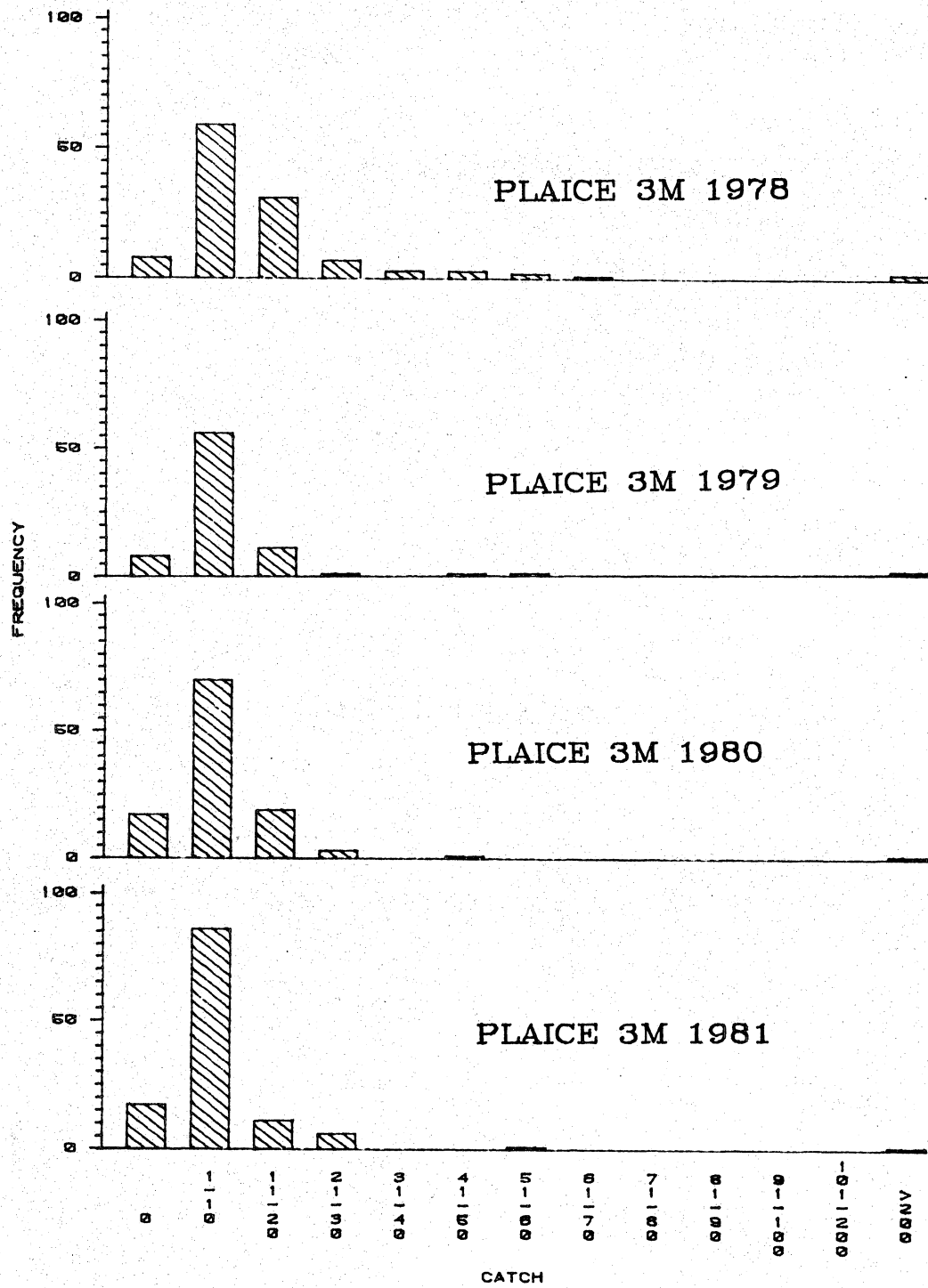


Figure 6. Catch per tow of American plaice from research vessel surveys in Division 3M, 1978-81.

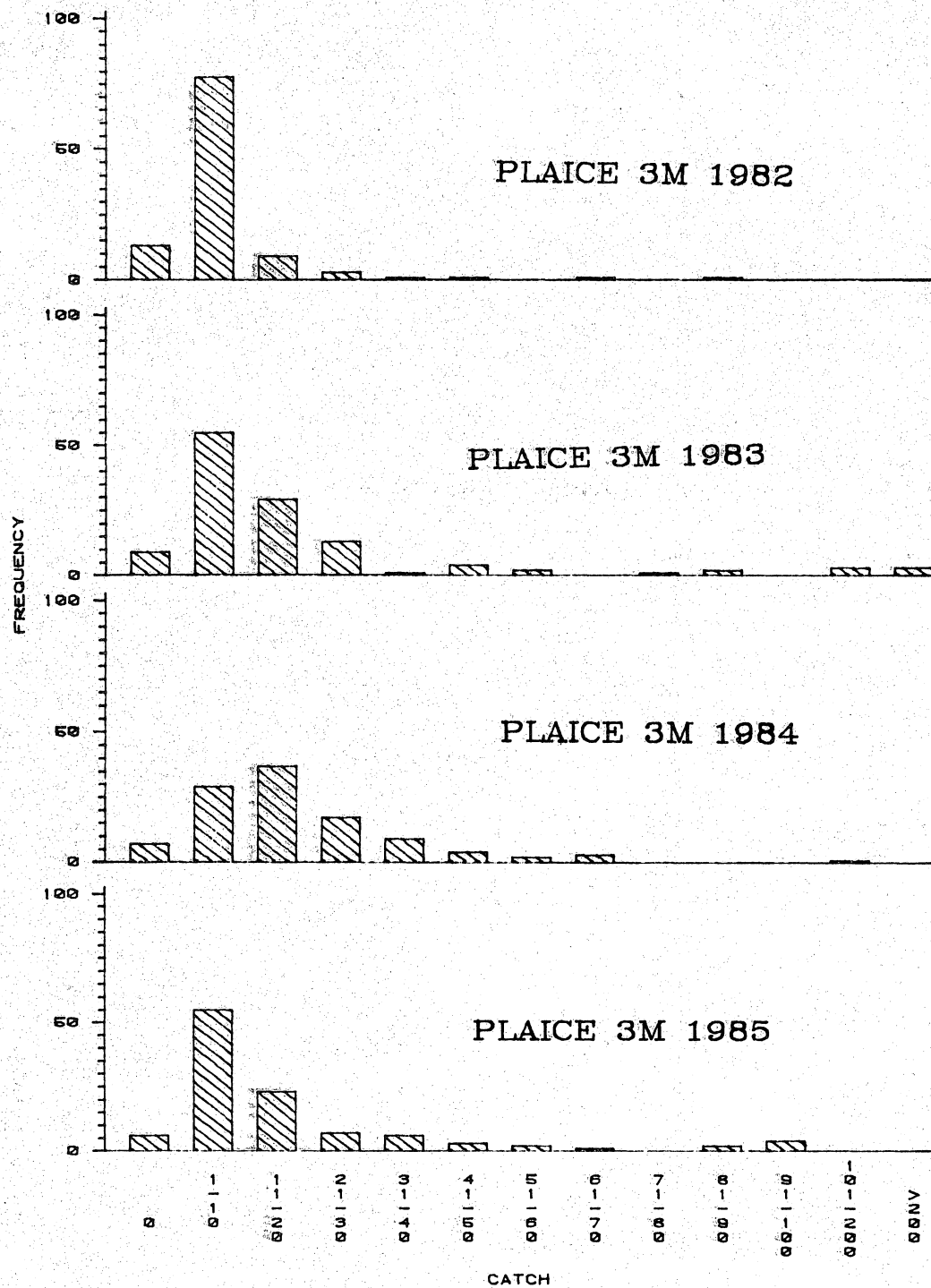


Figure 7. Catch per tow of American plaice from research vessel surveys in Division 3M, 1982-85.

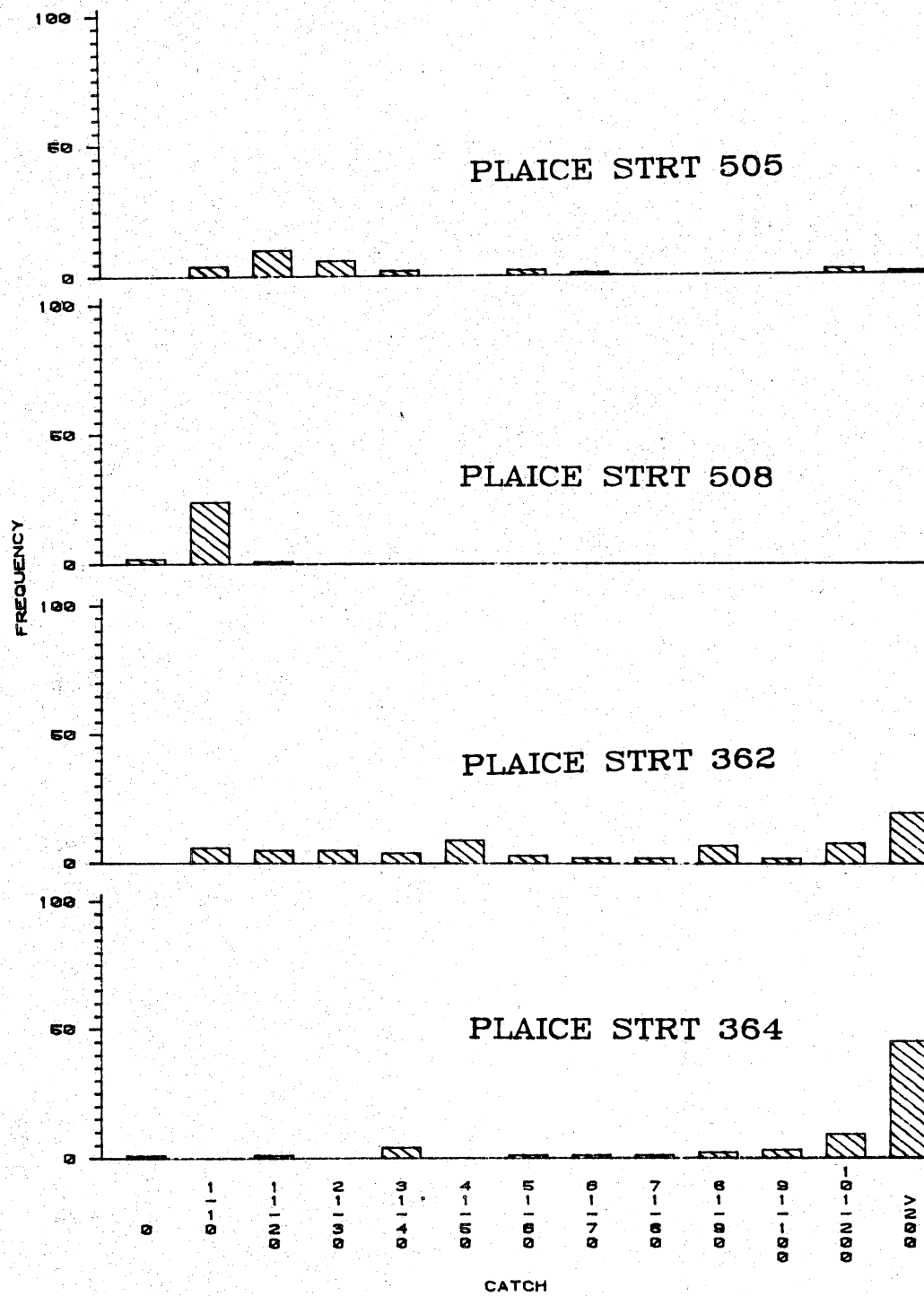


Figure 8. Catch per tow of American plaice from intensively sampled strata in Divisions 3M, 3N, 3L.

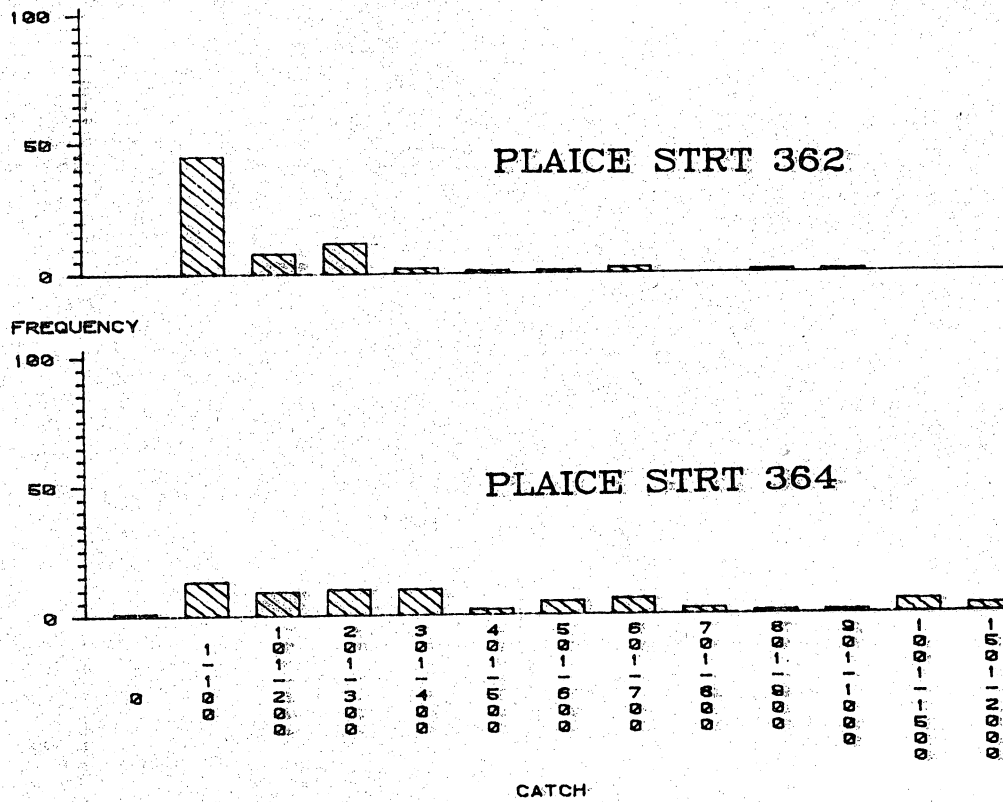


Figure 9. Catch per tow of American plaice, strata 362, 364. Catch groupings re-organized.