Northwest Atlantic Fisheries Organization

Serial No. N1544 NAFO SCR Doc. 88/92

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1988

Changes in Redfish Distributions and Abundance with Reference to Changes in Bottom Temperatures in the Gulf of St. Lawrence from 1983 to 1987

by

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Abstract

Marked changes in the distribution and abundance of redfish have occurred in the Gulf of St. Lawrence during the 1980's. A reduction in the catch-per-unit-effort (CPUE) was noted with the standardized commercial CPUE, research vessel CPUE and with logbook data. Weight per tow data from summer reseerch vessel surveys was analyzed by means of Duncans Range tests and with a four factor Analysis of Variance. The treatment factors were 5 Temperature Classes, 3 Areas, 4 Years, and 4 Depth Classes. Temperature was found to be a highly significant factor in explaining redfish abundance. Weight per tow was significantly higher at 6-8 °C from Duncan's Range test. Temperature was the most significant factor in the ANOVA. There was also a weak significance for Depth Class. A second order interaction Depth Class* Years and Duncan's tests by Depth Class indicate that redfish changed their depth distributions in response to a contraction and then an expansion of the warm bottom water layer. Area was not significant indicating that redfish exhibited little exchange between areas. A significant third order interaction TClass*DClass*Years appears to have resulted from changes in temperature between years. A cooling trend in 1984 caused the redfish to move into deeper water and may have caused a significant proportion of the biomass to become pelagic. A warming trend which peaked in 1986 allowed redfish to expand their distributions and helped increase their availability to bottom trawling.

SPECIAL SESSION ON ENVIRONMENTAL CONDITIONS

Introduction

In 1983, fishermen and processors based in the Gulf of St. Lawrence expressed concern about declining commercial catch rates of NAFO Divs. 4RST redfish. This fishery has been directed at deepwater redfish (<u>Sebastes mentella</u>) in the Esquiman Channel (CAFSAC 1984). An analysis if the geographic distribution of commercial fishing effort for redfish by Gulf and non-Gulf based vessels revealed marked differences in fishing patterns (Rubec et al. 1986). Gulf based vessels fished throughout the summer and fall months, while non-Gulf based vessels fished in the fall and winter. Non-Gulf based vessels concentrated their fishing effort off St. George's Bay, Newfoundland and east of Beauge Bank in 1984 and 1985. Gulf-based vessels fished over a wider area. The fishery by Quebec-based vessels was localized between the east end of Anticosti Island and the Port au Port Peninsula, Newfoundland from 1979-1982. From 1983-1985, the area fished by Gulf based vessels expanded. Analyses of both commercial and research vessel (R/V) catch-per-unit-effort (CPUE) indicated that the deepwater redfish had declined in abundance in the traditional fishing area. The decline was not predicted through stock assessments. Despite considerble analyses of the data, it was difficult to explain the changes. It was proposed that the decline in commercial catches might be related to changes in environmental conditions. Changes in the distribution of preferred temperature zones could have caused the redfish to change their geographic and depth distributions making them less vulnerable to the commercial fishery.

The population biomass of redfish spp. in Divs. 4RST is estimated to be in excess of 500,000t (Laberge et al. 1987; Laberge 1988). The annual quota was 33,000t in 1983 and ranged between 50,000-55,600t from 1984-1987. Commercial landings ranged from 24,000-35,000t during these years. A multiplicative regression model shows the standardized catch rate declining since 1981. Calculations derived from a non-linear Schaefer production model indicates that the catchability coefficient has been below average from 1985 to 1987. The standardized commercial catch rate is lower than predicted at equilibrium. The value of the residuals was large for 1985, suggesting that the sudden decline in the standardized catch rate for 1985 cannot be explained by the dynamics of the stock as described by the production model (Rivard and Gavaris 1986). Hence, it is considered likely that changing environmental conditions may have influenced the availability of redfish to the commercial fishery.

Commercial vessels generally do not collect environmental data such as the water temperatures where the fish were caught. Research vessels can be used to make inferences about the factors determining fish distributions because water temperature and other environmental data is collected. Atkinson (1984) summarized R/V data from 1976 to 1981 for Gulf redfish. In the autumn and winter months redfish were found to be concentrated off St. George's Bay and off Port aux Basques in the Cabot Strait. Both small and large redfish preferred temperatures higher than 4° C with the greatest abundance where temperatures exceeded 6° C. This pattern was even more pronounced in winter when about 70% of both small and large redfish were taken in areas where temperatures exceeded 6° C. Summer R/V data did not appear to be as directly related to bottom temperature. Atkinson cited Templeman (1959) who reported on summer redfish surveys in the Gulf during the 1950's. During that time redfish were found mainly in areas where temperatures were between 3° and 5° C and temperatures of the deepwater bottom layer were usually not higher than 5.5° C. Atkinson noted that the temperatures noted in summer, fall and winter surveys were somewhat higher from 1976-1981 than during the 1950's. Temperatures below 170m in the Gulf remain quite constant and warm throughout the year (Trites 1972). Bugden (1981) noted that the warm deepwater layer below 100m has no resolvable seasonal cycle in the Gulf. However, Bugden (pers. comm 1988) has found a warming trend in the Laurentian Channel using a time series from 1953 to 1984. The bottom temperature shows an increase above 5° C during the 1970's and generally exceeds 5.5° C from 1980-1984. The eastern end of the Laurentian Channel has the most elevated temperatures. Hence, the area where redfish are concentrated has experienced the most elevated bottom temperatures.

Summer R/V data was summarized for 1984 and 1985 in an attempt to relate the catch per tow to bottom temperatures (Rubec et al. 1986). For 1984, there was noted to be a shrinkage of the area with bottom temperatures of 5° C or higher in comparison to temperature data plotted on maps from 1979-1983 (Rubec unpubl.). In 1985, there appeared to be an expansion of the area with bottom temperatures greater than 5° C. Redfish weight per tow data indicated the highest catches occurred in the southeast corner of the Gulf in the Laurentian Channel during 1984 (Rubec et al. 1986). During 1985, high weights per tow were taken further west in the Laurentian Channel and northwards in the Esquiman Channel.

The redfish distributions determined from the 1984 and 1985 summer R/V surveys, and from three dimensional plots of weight per tow versus depth and bottom temperature suggested that redfish abundances were related to bottom temperatures (Rubec et al. 1986). The plots suggested that redfish were found in deeper water (> 274m) in August 1985 in comparison with 1984. Mean catches per standardized tow were highest at 5.5-7.0° C for both 1984 and 1985. It was proposed that by moving into deeper water, and possibly off the bottom, redfish would be less vulnerable to commercial bottom trawling. The situation was complex with respect to the effect of temperature on redfish distributions and further statistical analysis was needed. The present paper presents a quantitative analysis of summer R/V weight per tow data in relation to bottom temperature classes, depth classes, areas and years from 1983 to 1987.

Materials and Methods

Several different stratification schemes were used on R/V surveys to assess redfish abundance in the Gulf during the 1970's (Pitt et al. 1981). A 91.5m (50 fathom) interval scheme was used with the A.T. Cameron in the fall and with the Gadus Atlantica survey in winter. During the summer, the

Beothic Venture was used for a joint shrimp-redfish survey using a 73.2m (40f) interval stratification. In 1983, the Lady Hammond was used to conduct a shrimp-redfish survey during September-October using the 73.2m interval stratification. Starting in 1984, the Lady Hammond was used to conduct a separate redfish survey during the summer (July-August) using the 91.5m stratification.

Using a random stratified survey design with 41 strata, the northern Gulf was surveyed for redfish each year from 1983 to 1987. There were 824 sets (200 in 1983, 102 in 1984, 180 in 1985, 176 in 1986, and 166 in 1987). An efforts was made to obtain a Sippican XBT temperature profile at each station. But, for various reasons not all stations could be sampled, resulting in missing temperature data. Some temperature data for depths less than 200m were obtained with a Guildline CTD in 1987.

From 1983 to 1987, the Lady Hammond used a standard Western IIA trawl to conduct 0.5h tows at a speed of 6.48 km/h (3.5 N mi/h). The weight per tow from these surveys can be compared after they are standardized to a distance of 3.24 km (1.75 N mi). For the purpose of the present study, the 1983 stations were reassigned to strata within the 91.5m interval stratification.

The standardized weight per tow data from the surveys from 1983 to 1987 was evaluated using SAS statistical software (version 6 running on microcomputer). Means and standard deviations were calculated. Initially mean weights per tow and mean temperatures by strata were examined. Then it was decided to partition the data into depth classes, temperature classes, years and areas. Depth classes follow the Newfoundland 91.5m stratification scheme. Temperatures were divided into about 2° C intervals based on examination of the range of that data, and areas were initially chosen to correspond with NAFO Divisions (Div. 4R, northern Div. 4T, northern Div. 4S and southern Div. 4S). But in order to make the data more robust in terms of variance and to balance the number of depth classes between areas, southern 4S and northern 4T in the Laurentian Channel were combined. This gave an area north and west of Anticosti Island designated 'N', an area south of Anticosti Island in the Laurentian Channel designated 'Z' and an area in the Esquiman Channel designated 'R' (Figure 1). The class designations are summarized in Table 1.

Means and standard deviations within classes were calculated. Plots of of mean weight per tow versus the standard deviations within blocks of temperature classes, depth classes, areas and years were made to determine whether the standard deviations were normally distributed (Figure 2).

Duncan's Range tests were used to evaluate mean weights per tow and mean temperatures respectively between depth classes, between temperature classes between areas and between years. The comparisons between the Depth, Temperature and Area Classes were conducted within years and for all years combined.

A four factor factorial Analysis of Variance (ANOVA) was used to determine the relationship of weight per tow to the factors Depth Class, Temperature Class, Area and Year and interactions between the factors in a randomized incomplete block design assuming all factors are fixed. The PROC GLM procedure (SAS version 5) was used running on a VAX-11 780 mainframe computer. The analysis was initially conducted using 4 Depth Classes, 5 Temperature Classes, 3 Areas and 5 Years. It was then repeated dropping 1983 and using only 4 years of data.

Results and Discussion

Table 1 summarizes the definitions of Depth Classes, Temperature Classes and Areas used in the analyses.

The mean weights per tow and mean temperatures by Years, Areas and Depth Classes are given in Table 2. Generally, it can be seen that weights per tow were generally highest in DClasses 2 and 3. In Areas N and Z the highest CPUE fluctuates between DClass 2 and 3 by year. In Area R the high CPUE is consistently in DClass 3. A very high CPUE was noted in 1987 (775 kg). The mean water temperature by DClass is lowest in DClass 1 and increases in deeper water. A warming trend is discernable with mean temperatures occurring above 6° C in Areas R and Z during 1986. The temperature declines slightly in 1987, but is still warmer than in 1983 and 1984.

The distribution of the bottom water temperatures in the Gulf are shown in maps for 1983 to 1987 (Figures 3-7). Water temperatures were linked by eye with isopleths for 1° C intervals to map common temperature zones. Warm water above 6° C was not prevalent and was found in the western end of the Laurentian Channel, in the Anticosti Channel and a small patch in the northern part of the Esquiman Channel during the September-October survey in 1983 (Figure 3). In contrast, 6° and 7° C water was distributed near the mouth of the Laurentian Channel in the southeastern part of the Gulf in 1984 (Figure 4). During 1985, there is an expansion of warm bottom water above 6° C northwards and westwards in both the Laurentian and Esquiman Channels (Figure 5). The warming trend intensifies in 1986 with an increase in the area of water above 7° C (Figure 6). The distribution of warm water in 1987 is more similar to 1985 with a fairly large area of 6° C water, but almost no area above 7° C.

Table 3 quantifies the number and relative frequency of temperature data according to Area, TClass and Years. In each area, the warming trend is evident through the increase in the relative frequency of water in TClass 4 and 5 from one year to the next. Area N seems to have gotten cooler in 1984 in comparison to 1983, before warming in 1985 and 1986. Area Z was warmer in 1984 in comparison to Areas N and R. This is indicated by the prevalence of TClasses 4 an 5 in Area Z. The overall warming trend is summarized for all areas combined in Table 4. 1986 is definitely the warmest year with the highest relative occurrences of bottom temperatures in TClasses 4 and 5. In 1987, water temperatures in TClasses 4 and 5 decrease and there is an increase in the the prevalence of bottom tempertures of 4-6° C (TClass 3).

Table 5 summarizes mean weights per tow by Year, Area and TClass. The highest CPUE were generally in TClass 4 for most years, except 1983, for areas N, R and Z. It can been seen that mean temperatures for TClass 4 are closer to 6 than to 7° C. Mean temperatures within TClasses are similar between the three areas. The higher CPUE's in TClass 4 for most years and areas may be indicative of a water temperature preference for 6-8° C water. For the three areas combined from 1984 to 1987, the highest CPUE is consistently in TClass 4 (Table 7). The 1983 data does not fit this pattern, with the highest CPUE occuring in TClass 1.

Table 6 examines the mean CPUE in relation to Year and DClass for all areas combined. There appears to be a trend with the highest CPUE occurring in progressively deeper water (DClass 2 to 4) from 1983 to 1985. The highest CPUE is then in shallower depth zones, being in DClass 2 in 1986 and DClass 3 in 1987. It is not clear from the mean temperature data whether water temperature influenced changes in CPUE by DClass from one year to the next.

Duncans Range Tests

Duncan's Range tests allow statistical comparisons of multiple means and rank the data from high to low. It allows one to group similar means and to determine which are significantly different. The relative ranking of means from high to low can also help discern trends in the data.

Comparisons between mean CPUE's by TClass are presented in Table 8. For most years, except 1983 and 1984, TClass 4 has the highest weight per tow. The Pr>F values confirm that weight per tow is related to TClass. The 1983 data appears anomolous since the Pr>F value is non-significant. The ranking is completely reversed, with the highest CPUE at the lowest TClass. It should be noted that higher water temperatures were infrequent during 1983 and this may have biased the Duncan's test. The 1984 data is non-significant, but the PR>F is close to 0.05 and the ranking is similar to the other years from 1985-1987. The mean weight per tow is significantly different at TClass 4 from other CPUE's at higher and lower TClasses when the Duncan's Range test is conducted with all the data from 1983 to 1987.

The trends in ranking of mean CPUE's by DClass described in Table 6 are evaluated with Duncan's Range test in Table 9. It is not surprising that there are higher catches in deeper water in light of the temperature preference for water of 6-8° C noted in Table 8. Shallower water being cooler has lower catch rates. Table 9 indicates that there are changes in the DClasses having the highest CPUE's from one year to the next. The data strongly suggests that redfish moved into deeper water in 1984 and 1985. This would make them less vulnerable to Gulf-based vessels which cannot fish in deeper water. The differences between DClasses 2, 3, and 4 are not significant in 1984 and 1985, but there is a change in the ranking between years. In 1986, DClass 2 and 3 have significantly higher CPUE's than DClasses 4 and 1. In 1987, the CPUE is significantly higher in DClass 3 in comparison to the CPUE's in the other DClasses.

Comparisons of mean CPUE's by Duncan's Range test between Areas within each DClass were generally non-significant (Table 10). There were some significant differences in mean CPUE's between Areas in DClass 3. Areas R and Z are not significantly different from one another from 1983 to 1985. But, the change in ranking in 1984 may indicate that there was some movement from other areas to Area Z, associated with the shrinkage of the deep warmwater zone during 1984. High CPUE's were predominantly in the southeast corner of the Gulf in Area 'Z' during the 1984 R/V survey. This is quite apparent when CPUE's were plotted on distribution maps (Rubec et al 1986, Laberge 1988). At the same time, most of the commercial fishing effort was further north in the mouth of the Esquiman Channel.

There is a significant difference in the mean CPUE for Area R in comparison to other areas for 1986 and 1987. This is not believed to be due to a movement between areas. Length frequencies would indicate that large numbers of juvenile redfish (20-24 cm) are concentrated in Area R.

Comparisons of mean Temperature data ranked by DClass according to Year are presented in Table 11. The mean temperatures were highest in DClass 4 for 1984, 1985 and 1986. The mean Temperature data are similar for DClasses 3 and 4 in 1983 and 1984. These are warmer and significantly different from the shallower depth zones. During 1985, 1986 and 1987 DClasses 2,3 and 4 are not significantly different. This appears to be the result of a warming of DClass 2 bringing that depth zone's temperatures closer to the deeper zones. This may have allowed redfish, which were in DClass 3 and 4 and to migrate up in the water column into DClass 2. As previously noted in discussing Table 6, mean CPUE's were highest in DClass 4 in 1985 and highest in DClass 2 in 1986, and in DClass 3 in 1987.

The differences described by DClass in terms of mean Temperature and mean CPUE are rather subtle and difficult to visualize. The data seems to imply that redfish moved into deeper water in 1984 associated with a shrinkage of the warm deepwater layer. As the deepwater layer warmed and expanded in it's geographic extent during 1985 and 1986, one can infer that that the vertical thickness of the warm body of water expanded upwards into DClass 2. This also seems to be associated with a redistribution of redfish upwards in the water column.

Table 12 presents mean depths by TClass and Year. Since redfish prefer TClass 4 it is possible to examine the table to determine at what depth this range of temperatures (6-8 $^{\circ}$ C) was most prevalent by year. In 1984, TClass 4 was prevalent at a deeper depth (364 m) than in the other years. It follows from this that redfish would have sought deeper water during 1984. The picture is not clear cut, partly because the three areas differ in temperature conditions. Consequently, the depth zones occupied and the movements of the redfish in the water column into the various DClasses differ between Areas.

Tables 13 and 14 test the previous ideas by subjecting the CPUE data to a factorial Analysis of Variance. Table 13 uses the entire data set from 1983 to 1987. Temperature is the most significant factor with a Pr>F of 0.0068. Depth is close to being a significant factor (Pr>F = 0.0507). There is a significant two factor interaction DClass*Year (Pr>F = 0.0168). The third order interaction TClass*DClass*Year is close to being significant at the 0.05 level.

From the previous discussion of Table 8, it is apparent that the 1983 data displayed no relationship between mean CPUE and TClass. It is not apparent why this should be the case. It may be because the survey was conducted in September-October. Redfish may prefer a different temperature at that time. But, this supposition is contradicted by the data of Atkinson (1984), which also found a preference for water above 6 ^{o} C for autumn R/V surveys. Another possibility is that the CPUE data was biased by the use of 950 kg trawl doors in 1983, which differed from the 950 kg Portugese Oval trawl doors used in the other years. Because of the possible bias in the data, the 1983 data was omitted in the final factorial Analysis of Variance.

Table 14 summarizes the four factor factorial ANOVA and the interactions. The results are similar to the preceding analysis, TClass is highly significant (Pr>F = 0.0001). DClass becomes significant. The third order interaction TClass*DClass*Year also becomes significant.

It is apparent that TClass alone is a highly significant factor determining mean wtpertow. DClass is only mildly significant, probably because of the occurence of increasing temperatures with increasing depth, rather than some other characteristic of depth such as hydostatic pressure influencing redfish abundance. The highly significant DClass*Year interaction (Pr>F = 0.0044) indicates that redfish were changing their depth distributions from year to year. The third order interaction TClass*DClass*Year appears to be indicative of the effect warming temperatures had on redfish abundance by TClass and DClass between years. The Duncan's Range tests appear to indicate that temperture became a more significant factor, when the preferred temperatures (TClass 4) became more prevalent, associated with the warming trend.

Table 15 summarizes calculations of R/V minimal trawlable population biomass derived from STRAP calculations (Laberge 1988). There is a substantial biomass in DClass 3 in Area Z for 1984 which may be related with the shrinkage of the warm bottom layer for that year. Most of the biomass is in DClasses 2 and 3 for all three areas. The relative abundances indicated by weight per tow by DClass and Year (Table 2) is reflected in the biomass estimates. But, the biomass estimates are also affected by the total area.

Table 16 summarizes total biomass estimates from 1984 to 1987 calculated from STRAP by Laberge (1988). There is a marked decline in total trawlable population biomass from 1984 to 1986. At the same time the estimated population biomass from a non-linear production model is relatively constant around 480,000t. The present analysis (Table 15) indicates that redfish changed their depth distributions in response to changes in the distribution of zones of preferred temperature. This was more important than changes in area. The decline in trawlable biomass from the R/V surveys could very likely be because the redfish moved up in the water column off the bottom. The redfish most probably became pelagic in response to changing water temperatures. This could help account for the decline in catch rates experienced by Gulf based bottom trawlers. The increase in the landings of redfish taken by midwater trawls, from 3% in 1986 to 29% in 1987 (Laberge 1988), appears to be a response by the commercial fishery to these changing conditions.

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Table 1. Definition of depth classes, temperature classes, and areas in terms of strata by depth class.

Depth Classes

DClass	fathoms	meters
1	50- 99.9	91.5-182.8
2	100-149.9	182.9-274.3
3	150-199.9	274.4-365.7
4	200-300.0	365.8-548.7

Temperature Classes (° C)

TClass		
1	< 2	
2	> = 2	< 4
3	> = 4	< 6
4	> = 6	< 8
5	> = 8	

Area Classes

Strata Within Areas By DClass

DClass	Area = 'N'	Area = 'R'	Area = 'Z'
1	825, 827, 828 829, 831, 832	820, 821, 822 823, 824	830
2	814, 815, 816 817	811, 812, 813	401, 402, 403 409, 818, 819
3	805	801, 809, 810	404, 405, 406 410, 806, 807, 808
4		802	407, 408, 803, 804

Table 2. Mean weight per tow and mean temperature by years, areas, and depth class.

	Mean Weight Per Tow (kg)					Mean Temperature (° C)				
	Years					Years				
	83	84	85	86	87	83	84	85	86	87
DClass	Area - N					Area - N				
1	71	---	56	10	75	2.56	----	3.13	2.01	1.58
2	163	123	256	268	173	4.47	4.15	4.78	5.57	5.13
3	63	147	65	156	198	5.43	4.96	4.83	5.90	5.73
4	20	---	---	---	---	5.60	----	----	----	----
	Area - R					Area - R				
1	172	26	27	2	4	3.35	2.19	3.74	3.81	1.53
2	238	319	176	243	228	4.63	4.16	4.28	6.08	5.53
3	256	449	302	382	775	5.36	5.34	4.27	6.33	6.03
4	75	51	323	72	237	5.06	5.55	4.33	6.23	5.75
	Area - Z					Area - Z				
1	---	284	10	48	2	----	2.57	2.16	2.13	1.07
2	141	461	233	325	239	4.40	4.56	5.60	5.09	5.75
3	154	454	207	176	386	5.09	5.51	6.03	5.96	5.96
4	92	286	216	101	191	5.33	5.90	5.62	6.22	5.84

Table 3. Number and relative frequency of temperature classes, by area and year.

Area = N

TClass

Year	1	2	3	4	5	Total No.
83	12 11.8	16 15.7	68 66.7	5 4.9	1 1.0	102
84	2 12.5	2 12.5	12 75.0			16
85	9 20.5	9 20.5	19 43.2	6 13.6	1 2.3	44
86	12 16.4	21 28.8	21 28.8	12 16.4	7 9.6	73
87	18 29.5	8 13.1	18 29.5	17 27.9		61

Area = R

TClass

Year	1	2	3	4	5	
83	14 25.0	8 14.3	32 57.1	2 3.6		56
84	10 26.3	6 15.0	17 44.7	5 13.2		38
85	18 31.0	12 20.7	13 22.4	12 20.7	3 5.2	58
86	6 12.5	6 12.5	7 14.6	27 56.3	2 4.2	48
87	11 26.2	3 7.1	15 35.7	13 31.0		42

Table 3 (cont'd). Number and relative frequency of temperature classes by area and year.

Area = Z

TClass

Year	1	2	3	4	5	Total No.
83	2 4.7	4 9.3	36 83.7	1 2.3		43
84	1 2.1	7 14.9	23 48.9	14 29.8	2 4.3	47
85	3 3.8	4 5.1	50 63.3	20 25.3	2 2.5	79
86	4 5.5	4 5.5	30 41.1	33 45.2	2 2.7	73
87	6 10.3	0	41 70.7	10 17.2	1 1.7	58

Table 4. Number and relative frequency of temperature classes by years for all areas combined.

Years	TClass 1	2	3	4	5	Total No.
83	26	29	136	8	1	200
	13.0	14.5	68.0	4.0	0.5	
84	13	16	52	19	2	102
	12.7	15.7	51.0	18.6	2.0	
85	30	25	82	38	6	181
	16.6	13.8	45.3	21.0	3.3	
86	17	22	58	72	5	174
	9.8	12.6	33.3	41.4	2.9	
87	6	4	94	28	1	133
	4.5	3.0	70.7	21.1	0.8	

Table 5. Mean weight per tow and mean temperature by years, areas, and temperature class.

	Mean Weight Per Tow (kg) Years					Mean Temperature(° C) Years				
TClass	83	84	85	86	87	83	84	85	86	87
	Area - N					Area - N				
1	141	268	50	7	26	1.10	----	0.88	-0.11	0.67
2	86	75	36	11	100	3.08	3.57	2.64	2.66	2.81
3	125	129	201	105	92	5.08	4.77	4.90	5.02	5.47
4	76	---	223	419	341	6.14	----	6.00	6.49	6.66
5	3	---	6	174	---	9.10	----	14.50	14.00	----
	Area - R					Area - R				
1	216	72	115	3	53	----	1.42	0.54	0.92	0.73
2	335	97	119	2	19	3.21	3.08	2.67	2.63	3.17
3	190	292	84	99	248	5.00	5.03	4.68	4.97	5.23
4	320	480	358	290	457	6.20	6.00	6.18	6.32	6.11
5	---	---	2	3	---	----	----	13.67	14.30	----
	Area - Z					Area - Z				
1	---	227	135	184	105	----	----	1.00	0.63	0.62
2	148	282	13	82	---	3.10	2.70	2.45	3.35	----
3	135	461	193	224	248	5.06	5.00	5.36	5.31	5.71
4	35	333	293	140	389	6.10	6.48	6.15	6.18	6.24
5	---	376	104	71	386	----	8.60	11.50	10.50	8.00

Table 6. Mean weight per tow and mean temperature by years and depth classes for all areas combined.

	Mean Weight Per Tow (kg)					Mean Temperature (° C)				
	Years					Years				
	83	84	85	86	87	83	84	85	86	87
DClass										
1	110	74	37	13	43	2.82	2.26	3.31	2.68	1.51
2	183	308	221	277	210	4.50	4.29	4.95	5.60	5.41
3	119	382	205	214	375	5.34	5.35	5.38	6.02	5.87
4	82	239	234	98	190	5.26	5.83	5.45	6.22	5.83

Table 7. Mean weight per tow and mean temperature by years, and temperature classes for all areas combined.

	Mean Weight Per Tow (kg)					Mean Temperature (° C)				
	Years					Years				
	83	84	85	86	87	83	84	85	86	87
TClass										
1	181	114	97	47	56	1.10	1.42	0.74	0.92	0.59
2	165	174	72	22	78	3.12	3.01	2.62	2.78	2.91
3	143	329	178	166	210	5.05	4.96	5.15	5.16	5.55
4	132	371	303	243	391	6.15	6.35	6.13	6.28	6.23
5	3	376	37	64	386	9.10	8.60	13.08	12.72	8.00

Table 8. Duncan's Range test of mean weight per tow ranked by temperature class according to years and for all years combined. Means underlined are not significantly different from one another (P=0.05).

Years							Pr > F
83	Mean	181	165	143	132	3	
	TCl	1	2	3	4	5	0.9115
	N	26	29	136	8	1	
84	Mean	376	371	329	174	114	
	TCl	5	4	3	2	1	0.0715
	N	2	19	52	16	13	
85	Mean	303	178	97	72	37	
	TCl	4	3	1	2	5	0.0001
	N	38	82	30	25	6	
86	Mean	243	166	64	47	22	
	TCl	4	3	5	1	2	0.0002
	N	72	58	5	17	22	
87	Mean	391	386	210	78	56	
	TCl	4	5	3	2	1	0.0001
	N	40	1	74	11	41	
83-87	Mean	298	190	112	104	96	
	TCl	4	3	5	2	1	0.0001
	N	177	402	15	103	127	

Table 9. Duncan's Range test for mean weight per tow ranked by depth class, according to year for all areas. Means underlined are not significantly different from one another (P=0.05).

Year						Pr > F
83	Mean	183	119	110	82	
	DCl	2	3	1	4	0.2341
		———	———	———	———	
	N	107	64	13	16	
84	Mean	382	308	239	74	
	DCl	3	2	4	1	0.0075
		———	———	———		
				———	———	
	N	39	27	20	16	
85	Mean	233	221	205	37	
	DCl	4	2	3	1	0.0001
		———	———	———	———	
	N	32	58	44	47	
86	Mean	277	214	98	13	
	DCl	2	3	4	1	0.0001
		———	———	———	———	
	N	58	42	31	43	
87	Mean	375	210	190	43	
		3	2	4	1	0.0001
		———	———	———	———	
	N	42	55	30	40	

Table 10. Duncan's Range test of mean weight per tow ranked by areas according to year for depth class 3. Means underlined are not significantly different (P = 0.05).

Year					Pr > F
83	Mean	256	154	63	
	Area	R	Z	N	0.0054
	N	12	14	38	
84	Mean	454	449	147	
	Area	Z	R	N	0.0745
	N	19	11	9	
85	Mean	302	207	65	
	Area	R	Z	N	0.0477
	N	11	25	8	
86	Mean	382	176	156	
	Area	R	Z	N	0.0047
	N	9	20	13	
87	Mean	775	386	198	
	Area	R	Z	N	0.0282
	N	7	8	17	

Table 11. Duncan's Range tests of mean temperatures ranked by depth class, according to year for all areas combined. Means underlined are not significantly different (P=0.05).

Year						Pr > F
83	Mean	5.34	5.26	4.50	2.80	
	DCl	3	4	2	1	0.0001
	N	57	16	93	12	
84	Mean	5.83	5.35	4.29	2.26	
	DCl	4	3	2	1	0.0001
	N	19	37	26	16	
85	Mean	5.45	5.38	4.96	3.31	
	DCl	4	3	2	1	0.0001
	N	30	42	55	46	
86	Mean	6.22	6.02	5.60	2.68	
	DCl	4	3	2	1	0.0001
		31	42	58	42	
87	Mean	5.87	5.83	5.41	1.51	
	DCl	3	4	2	1	0.0001
	N	40	27	50	40	

Table 12. Mean depth according to temperature class, depth class and year.

	Year				
	83	84	85	86	87
	Mean depth (m) and DClass				
TClass					
1	240	183	203	144	177
	2	2	2	1	1
2	203	185	172	144	163
	2	2	1	1	1
3	287	311	302	282	313
	3	3	3	3	3
4	285	364	285	322	285
	3	3	3	3	3
5	291	364	216	262	391
	3	3	2	3	4

Table 13. Factorial Analysis of Variance of weight per tow data of Gulf redfish for R/V surveys from 1983-1987.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	153	20,094,285.49	131,335.20	2.14	0.0001
Treatments		Type III SS			
Area	2	318,535.87		2.60	0.0751
TClass	4	876,192.05		3.58	0.0068 **
DClass	3	479,347.94		2.61	0.0507
Year	4	383,574.38		1.57	0.1819
Area*TClass	8	477,159.37		0.97	0.4555
Area*DClass	6	514,306.85		1.40	0.2124
Area*Year	8	687,725.19		1.40	0.1916
TClass*DClass	10	869,973.56		1.42	0.1669
TClass*Year	16	610,468.76		0.62	0.8670
DClass*Year	12	1,524,520.68		2.07	0.0168 *
Area*TClass*DClass	8	404,825.41		0.83	0.5798
Area*TClass*Year	16	512,404.81		0.52	0.9361
Area*DClass*Year	16	504,355.88		0.51	0.9405
TClass*DClass*Year	18	1,771,674.70		1.61	0.0529
Area*TClass*DClass*Year	11	172,938.36		0.26	0.9927
Error	670	41,049,547.46	61,267.98		
Corrected Total	823	61,143,832.96			

R^2 = 0.33 C.V. = 132.83 Root MSE = 247.52

Mean WTPERTOW = 186.35

Table 14. Factorial Analysis of Variance of weight per tow data of Gulf redfish for R/V surveys from 1984-1987.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	124	18,200,173.11	146,775.59	2.44	0.0001
Treatments		Type III SS			
Area	2	284,079.07		2.36	0.0951
TClass	4	1,391,257.37		5.79	0.0001 ***
DClass	3	518,368.61		2.88	0.0357 *
Year	3	331,959.28		1.84	0.1387
Area*TClass	8	463,798.59		0.96	0.4628
Area*DClass	6	549,203.64		1.52	0.1684
Area*Year	6	446,779.19		1.24	0.2846
TClass*DClass	10	897,598.75		1.49	0.1381
TClass*Year	12	281,197.14		0.39	0.9671
DClass*Year	9	1,462,714.43		2.70	0.0044 **
Area*TClass*DClass	8	421,244.19		0.88	0.5363
Area*TClass*Year	12	432,274.51		0.60	0.8432
Area*DClass*Year	12	360,584.67		0.50	0.9148
TClass*DClass*Year	14	1,499,511.10		1.78	0.0383 *
Area*TClass*DClass*Year	11	131,265.79		0.31	0.9485
Error	499	29,983,788.72	60,087.75		
Corrected Total	623	48,183,961.84			

R^2 = 0.38 C.V. = 123.76 Root MSE = 245.13

Mean WTPERTOW = 198.07

Table 15. Estimated R/V population biomass (t) for Divs. 4RST redfish by year, area, and depth class derived from Laberge (1988).

	Year			
DClass	1984	1985	1986	1987
		Area = 'N'		
1	________	38,946.1	4,086.9	24,530.7
2	43,369.7	77,952.1	77,938.2	71,849.9
3	15,545.2	9,813.3	22,533.3	11,944.9
		Area = 'R'		
1	3,489.4	2,526.7	424.0	905.9
2	70,765.3	46,040.3	54,256.7	62,113.1
3	38,428.3	27,480.8	35,578.8	76,636.4
4	1,669.9	4,618.7	2,357.0	7,797.5
		Area = 'Z'		
1	9,943.3	175.0	419.1	78.3
2	59,723.5	33,539.4	49,427.9	53,609.5
3	144,691.8	80,365.5	51,819.2	77,548.7
4	38,130.8	47,151.6	21,182.7	63,482.2

Table 16. Estimated R/V population biomass of Divs. 4RST redfish by year and depth classes compared with population biomass estimates from non-linear production model of Laberge (1988).

	Year			
DClass	1984	1985	1986	1987
1	13,432.7	41,647.8	4,930.0	25,514.9
2	173,858.4	157,531.9	181,622.8	187,572.6
3	198,665.3	117,659.6	109,931.3	166,130.0
4	39,800.8	51,770.3	25,539.7	71,279.7
Total R/V	426,095	368,608	318,998	450,507
Production Model	489,788	488,670	486,285	481,116

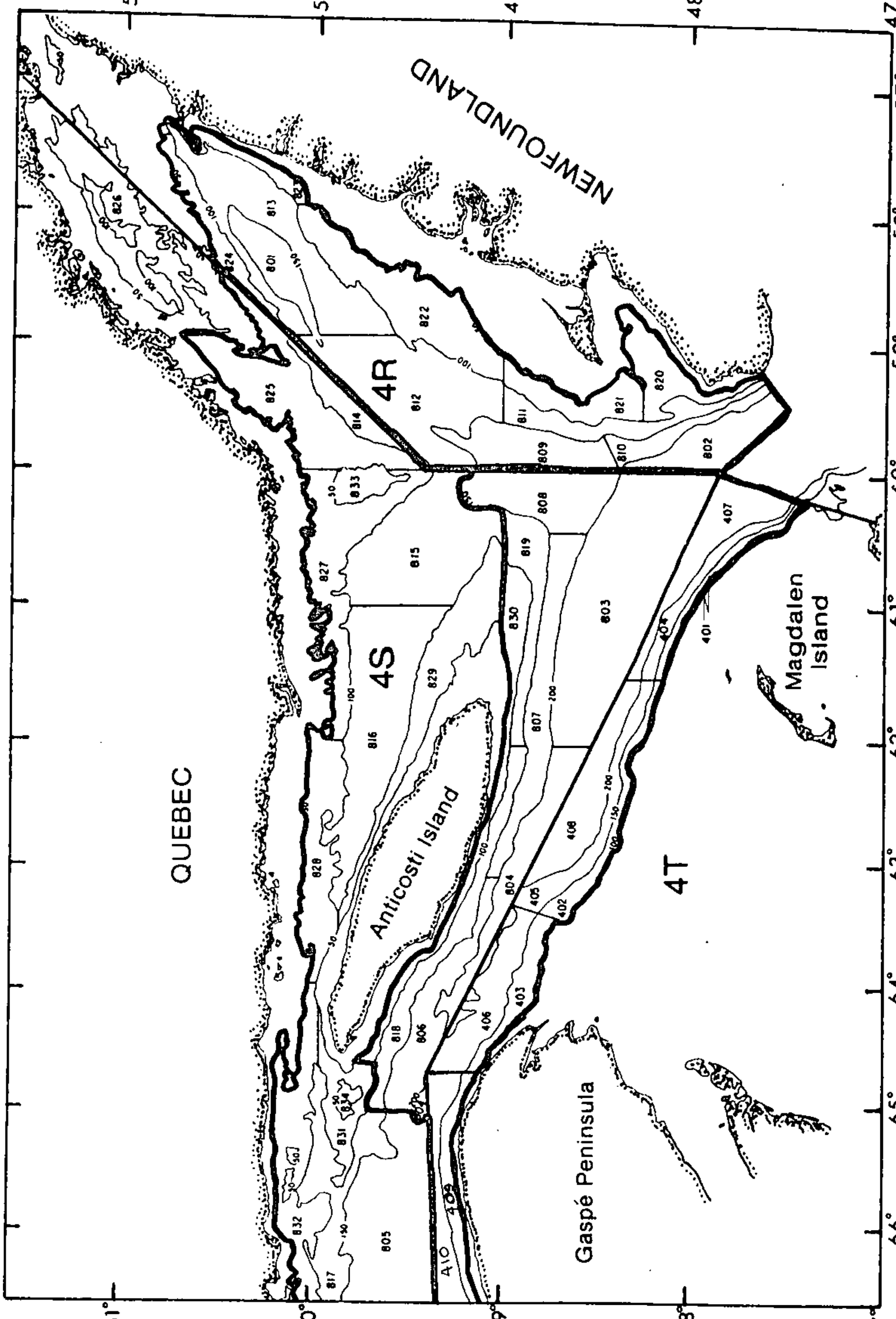
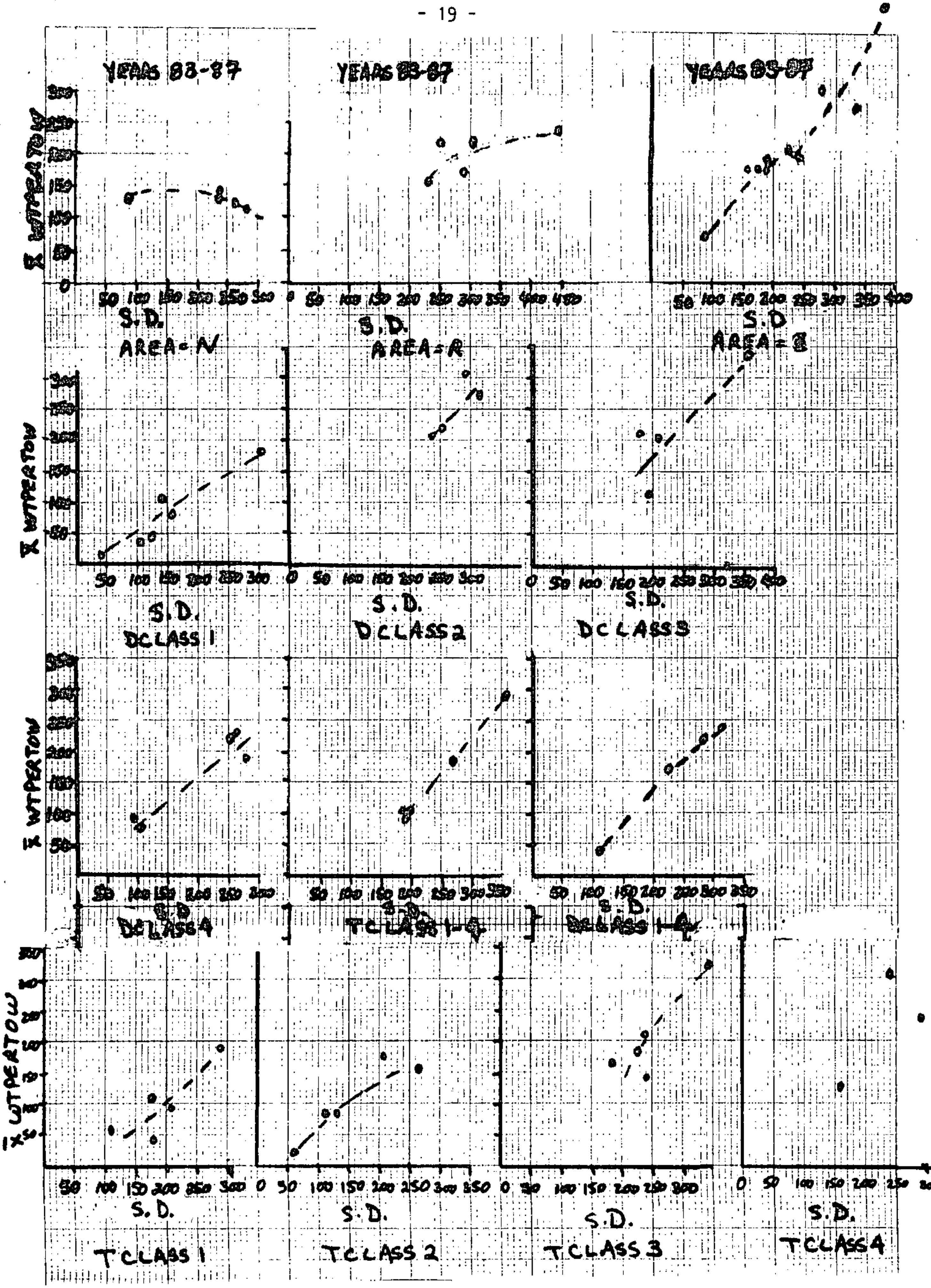


Fig. 8. Strata in NAFO Divisions 4R and 4S. Strata areas are given in Table 2.

Figure 1.


YEARS 83-87
YEARS 83-87
S.D.
S.D.
S.D
AREA=N
AREA=R
X WTPERTOW
S.D.
S.D.
S.D.
DCLASS 1
DCLASS 2
DCLASS 3
X WTPERTOW
DCLASS 4
TCLASS 1-4
WTPERTOW
S.D.
S.D.
S.D.
S.D.
TCLASS 1
TCLASS 2
TCLASS 3
TCLASS 4

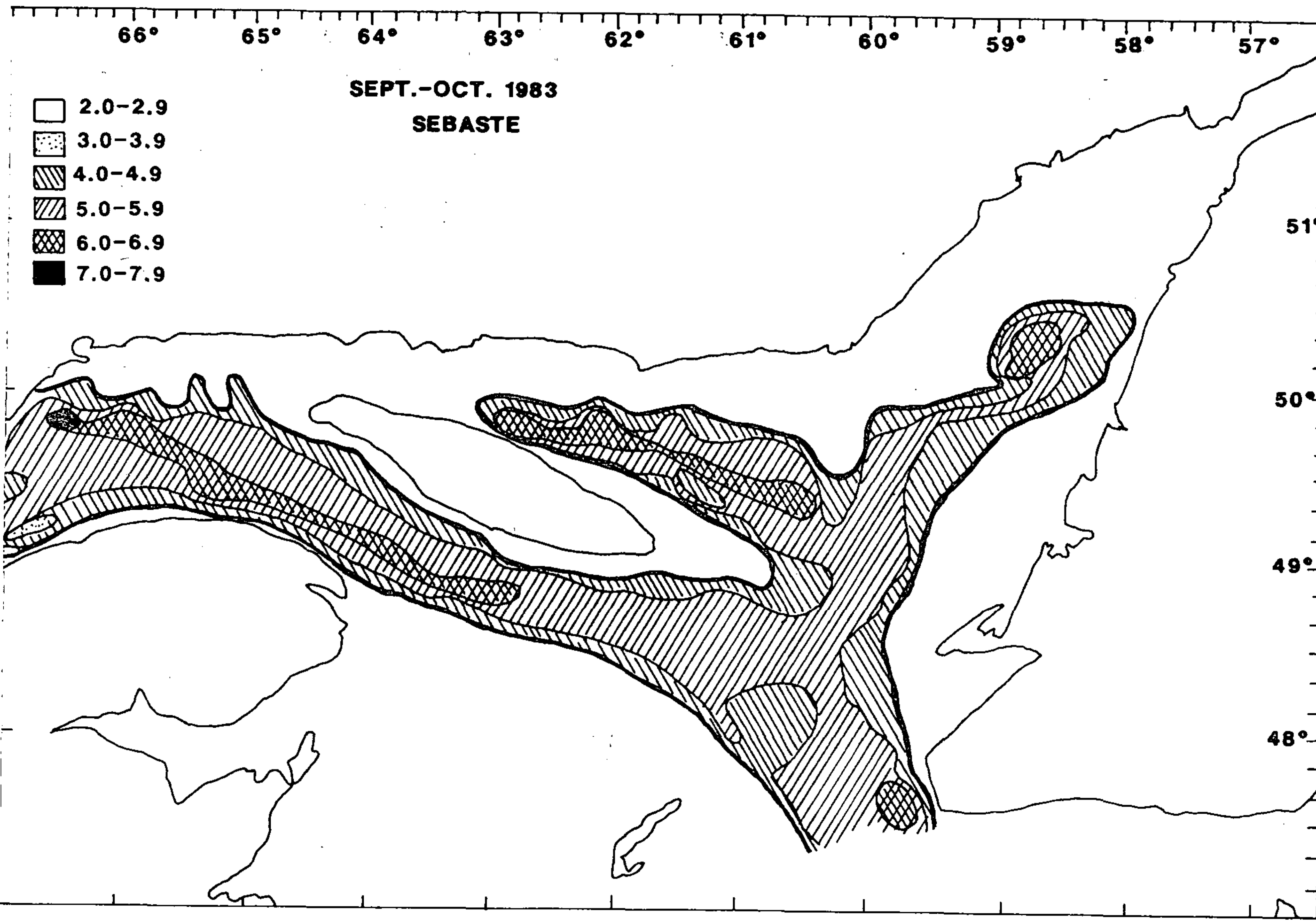

SEPT.-OCT. 1983
SEBASTE
2.0–2.9
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9
66°
65°
64°
63°
62°
61°
60°
59°
58°
57°
51°
50°
49°
48°

Figure 3.

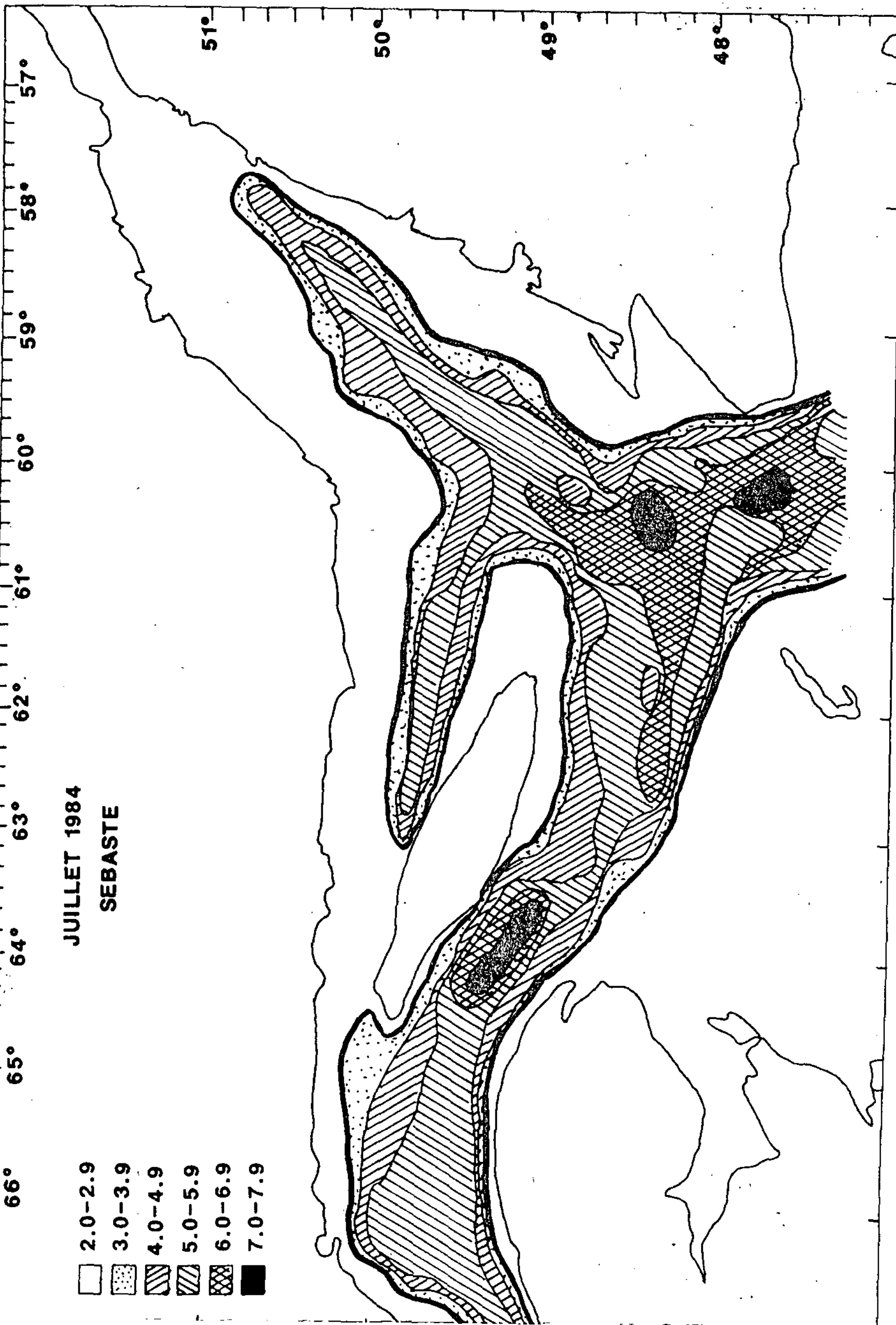

JUILLET 1984
SEBASTE
2.0–2.9
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9
66°
65°
64°
63°
62°
61°
60°
59°
58°
57°
51°
50°
49°
48°

Figure 4.

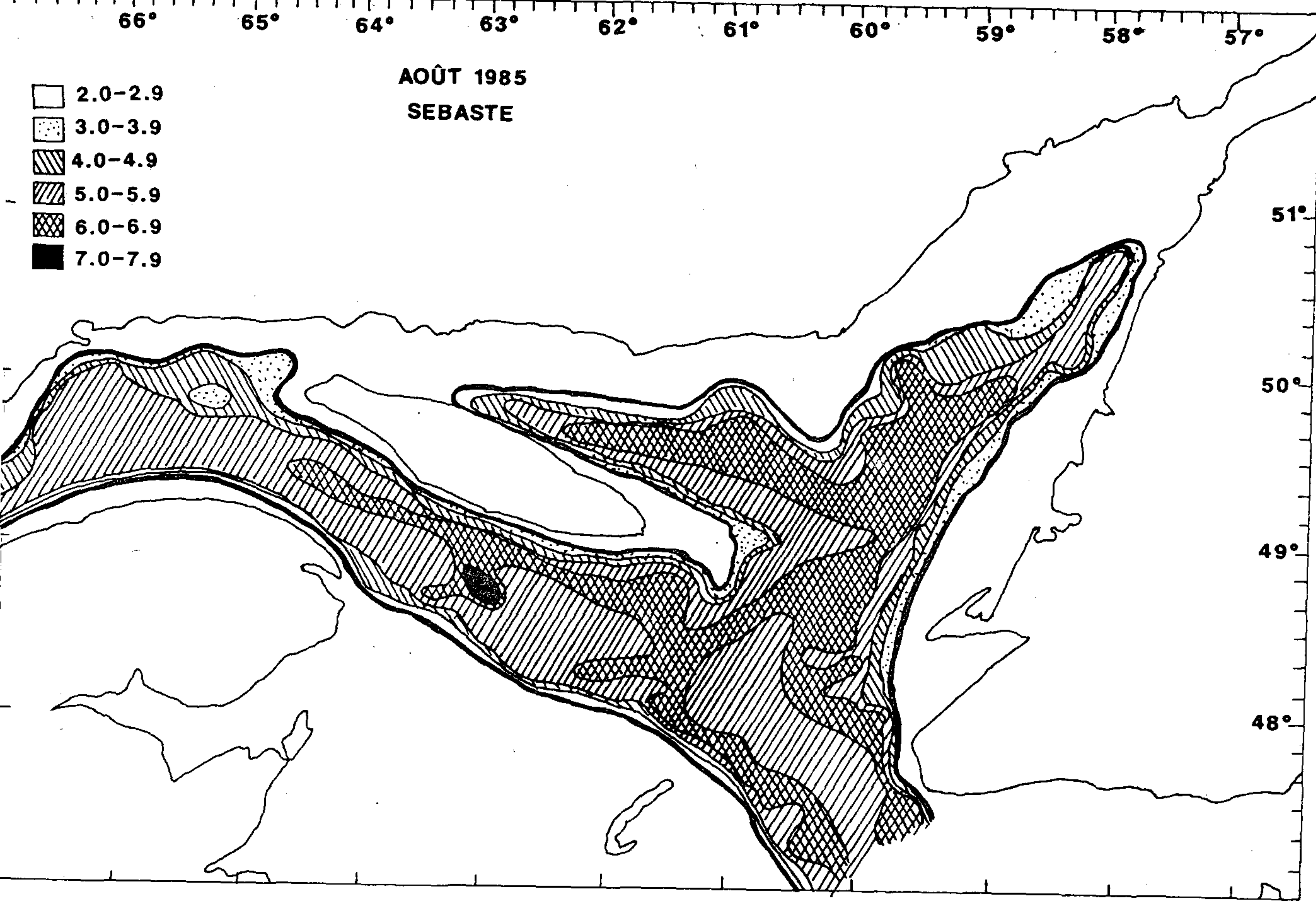
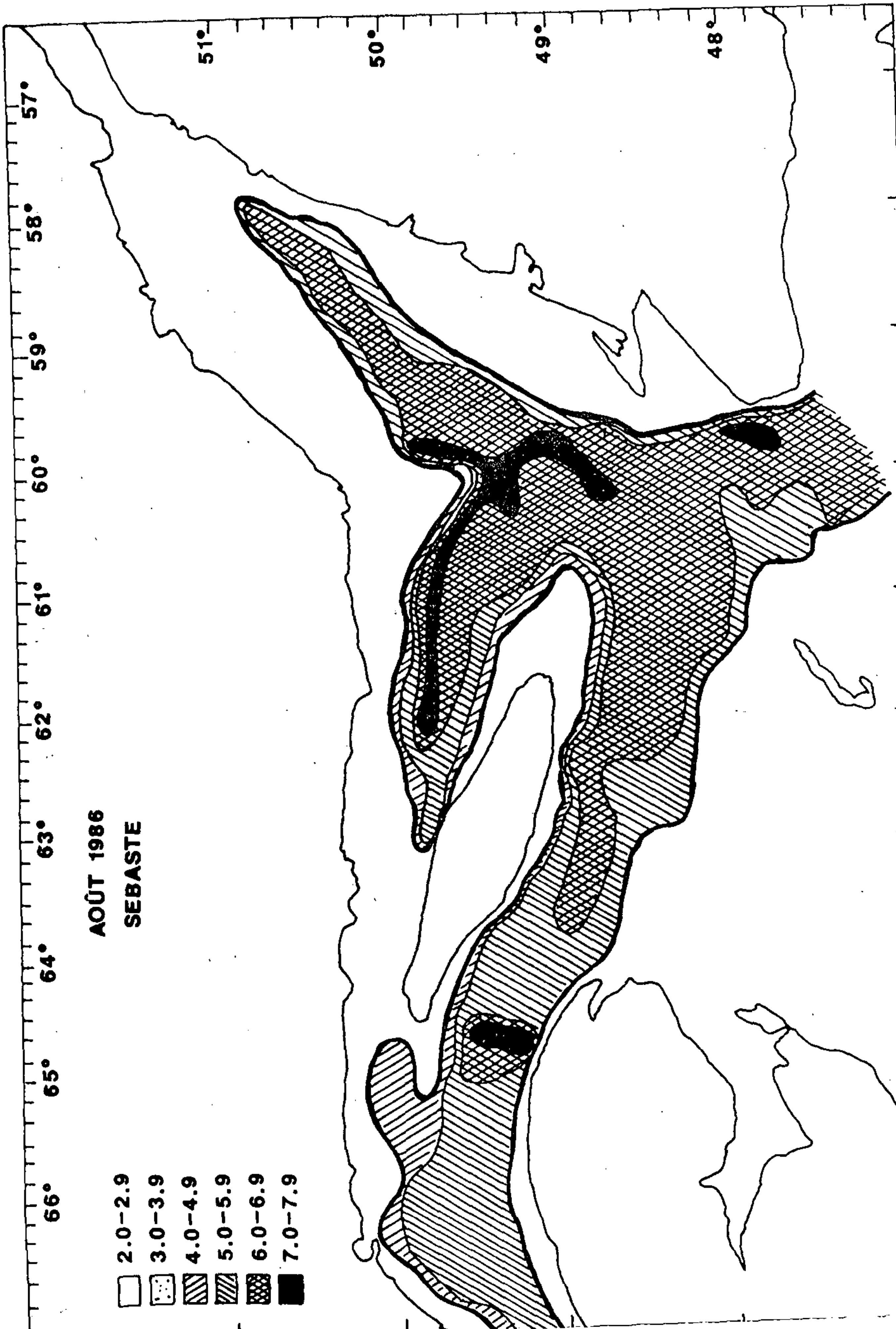

66°
65°
64°
63°
62°
61°
60°
59°
58°
57°
51°
50°
49°
48°
AOÛT 1985
SEBASTE
2.0–2.9
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9

Figure 5.


AOÛT 1986
SEBASTE
2.0–2.9
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9
57°
58°
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50°
49°
48°

Figure 6.

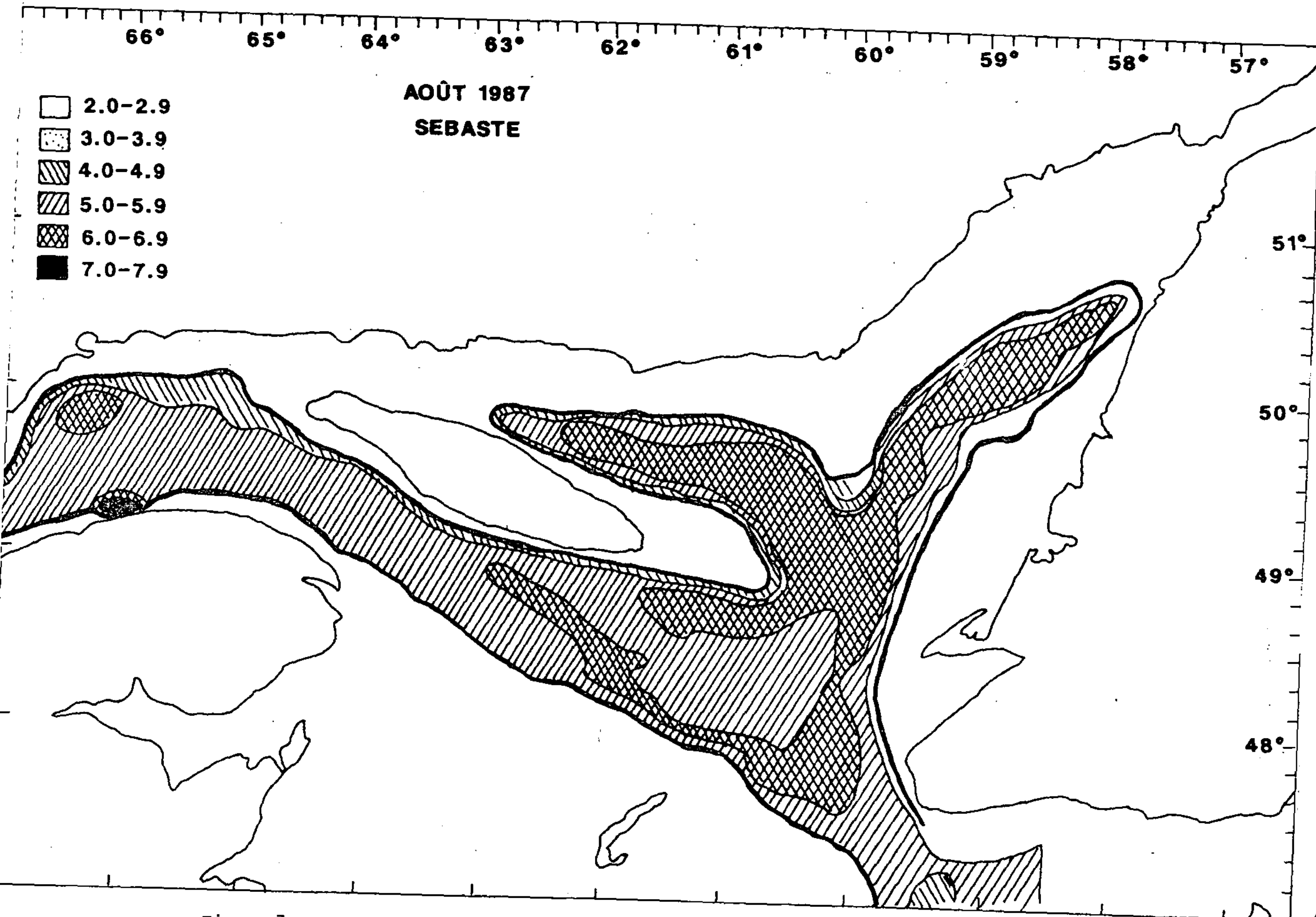
66°
65°
64°
63°
62°
61°
60°
59°
58°
57°
51°
50°
49°
48°
AOÛT 1987
SEBASTE
2.0–2.9
3.0–3.9
4.0–4.9
5.0–5.9
6.0–6.9
7.0–7.9

Figure 7.