UPDATED AGE-SPECIFIC CPUE FOR CANADIAN SWORDFISH LONGLINE, 1988-1994*

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SUMMARY

An updated age-specific index of relative abundance is calculated for north Atlantic swordfish caught by longline in the Canadian fishery from 1988 to 1994. Standardized catch rates for ages ranging from 2 to 3+ were estimated using a multiplicative model. The variability in predicted CPUE explained by the model ranged from 37 to 43%, higher than reported in the previous analysis.

RESUMÉ

Un indice de l'abondance relative spécifique de l'âge est calculé pour l'espadon de l'Atlantique Nord capturé à la palangre dans la pêche canadienne de 1988 à 1994. Le taux de capture standardisé des âges 2 à 5+ a été estimé au moyen d'un modèle multiplicatif. La variabilité de la CPUE prévue expliquée par le modèle allait de 37 % à 43 %, plus que dans l'analyse antérieure.

RESUMEN

Se calcula un índice actualizado de abundancia relativa específico de la edad para el pez espada del Atlántico norte, capturado con palangre en la pesquería canadiense, de 1988 a 1994. Se estimaron tasas estandarizadas de captura para las edades entre 2 y 5+, usando un modelo multiplicador. La variabilidad en la CPUE predicha, explicada por el modelo, estaba entre 37 y 43%, mas alta que la presentada en el análisis anterior.

Introduction

The purpose of this analysis is to provide age-specific indices of abundance for swordfish from the Canadian longline fishery from 1988 to 1994 for use by the SCRS in stock assessments. Age-specific, standardized CPUE indices for north Atlantic swordfish from Spanish (Mejuto and de la Serna 1995), Japanese (Nakano 1995) and U.S. (Scott and Bertolino 1995) commercial longline fisheries have been used by ICCAT to calibrate age-structured sequential population analysis (VPA) (Anon. 1995). This manuscript updates previous standardized catch rates for the Canadian longline fishery for 1988 through 1993 developed by Stone and Porter (1995). A multiplicative model approach (Gavaris 1980, 1988) is used to standardize Canadian catch per unit effort data for ages 2, 3, 4, and 5+.

Description of the fishery

The Canadian longline fishery operates from Georges Bank to the Grand Banks of Newfoundland when swordfish migrate into Canadian waters (Fig. 1). Fishing effort generally progresses from west to east and back again, following swordfish movements associated with seasonal warming trends of surface water temperature.

In 1994, the fishery commenced in June, with sets occurring off Georges Bank, the western Scotian Shelf and in deeper waters along the edge of the Gulf stream (Fig. 2). Fishing spread eastward along the Shelf slope and off the western Grand Banks in July, becoming progressively more concentrated in a narrow band along the edge of the continental shelf in August and September. During October and November, the fishery occurred mainly on the central Scotian Shelf. Nominal CPUE (number of fish per 1000 hooks) in 1994 showed a pattern of increasing swordfish abundance from June to September, when it was highest throughout the Canadian fishing zone, followed by a subsequent decline in October and November (Fig. 3). This pattern of nominal catch rate likely reflects the seasonal warming and cooling trends of surface water temperature. As the water warms up, more swordfish move into the Canadian fishing zone to feed in areas of upwelling along the edge of the Scotian Shelf and Grand Banks.

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Materials and Methods

Catch and effort database

Stone and Porter (1995) describe the catch, effort and size data available for swordfish from the Canadian longline fishery. Set-by-set catch (number of swordfish) and effort (number of hooks) data were edited and condensed to the trip level to provide total number of fish and total number of hooks per trip. Two geographical areas of fishing were used for classification, defined as ICCAT Areas 2 (Georges Bank, western and central Scotian Shelf) and 14 (eastern Scotian Shelf, Grand Banks and Flemish Cap), falling west and east of the 60° W line of longitude, respectively (Fig. 1). A total of 985 trips with catch and effort information, cross-classified by year (1988-1994), area (2, 14) and month (May-November) were used in these analyses (Table 1). The 1994 data contributed 421of those observations, due to increased sampling (Tables 1 and 2). Coverage by the catch and effort data during 1988-93 generally represents less than 50% of the landings for these years, while 1994 coverage was 96% (Tables 1 and 2). While only 15% of the Canadian catch is from Area 14, nominal catch rates are consistently higher than for Area 2 (Table 1, Fig. 3). Months were combined at the beginning (i.e. May-June for Area 2; May-July for Area 14) and end (i.e. October-November, Areas 2 & 14) of the fishing season to increase the number of observations.

Individual dressed weights of swordfish were converted to lower-jaw-fork-length and aggregated by 2 cm intervals into length frequencies for each year, area and month (similar to ICCAT Task II procedures). Length frequencies were converted to age frequencies (ages 1, 2, 3, 4 and 5+) for each analytical stratum (i.e. year, area and month) using age-length keys developed from the ICCAT Gompertz growth model and age slicing method used by the 1994 SCRS Swordfish Species Group (Anon. 1995). Data substitutions were made for strata with missing age frequency samples. Since there were very few age 1 fish in the samples for area 14, this age group was not included in the analysis. The proportions at age for each analytical stratum were then used to partition the trip data set to obtain age-specific catches for use in the multiplicative model.

Model and specifications

The multiplicative model (Gavaris 1980, 1988) used to standardize the catch rates of swordfish (ages 2, 3, 4 and 5+) was solved using standard linear regression techniques after ln transformation of nominal CPUE data (number of fish per 1000 hooks). Estimated mean CPUE values and associated standard errors were then retransformed to arithmetic scale, with logarithmic bias correction. The model required a standard for each main effect upon which all other mean CPUE values were scaled. To minimize the standard error of the CPUE estimate, standards were defined as area=2 (Scotian Shelf) and month=8 (August), when sample sizes (number of trips) were highest. Observations with CPUE=0 were omitted by excluding the age 1 group from the analysis. All analyses were conducted using the APL workspace "STNDR_V2".

Initially, a model based on three main effects (Year, Area, Month) and an interaction term (Area*Month) was examined, since previous experience has shown that these factors account for most of the variation in CPUE in swordfish longline fisheries:

$$\ln(CPUE_{ijk}) = \mu + Year_i + Area_j + Month_k + Area_k * Month_j + \varepsilon_{ijk} \quad (1)$$

Since an interaction term used in such a model is difficult to interpret, a composite term for area and month was used. In this case, instead of an interaction term, a single composite main effect was modelled which combined Area and Month main effects, and Area*Month interaction into one term:

$$\ln(CPUE_{ijk}) = \mu + Year_i + [\ Area_j \ \&\ Month_k\ ] + \varepsilon_{ijk} \quad (2)$$

where: $[\ Area_k \ \&\ Month_j\ ]$ = composite effect of Area, Month and Area*Month.

The Area & Month composite variable contained codes representing each area-month combination. This treatment gives the same r^2 as when equation (1) is applied, but the sources of variation from the ANOVA are more easily interpreted. For each age group, residual patterns were examined for outliers and partial probability plots of residuals were examined for normality.

Results and Discussion

Analysis of variance (ANOVA) results for the Composite Model are given by age group in Tables 3-6. In all cases, the overall regression and individual main effects were significant ($P < 0.05$) and the model explained between 37 and 43% (multiple r^2) of the variability in the data, depending on the age group modelled. This represents a substantial improvement over the Stone and Porter (1995) analysis using the 1988-93 time series, for which the model explained between 16 and 36% of the variability. For each age group, no trends were apparent in the pattern of residuals and partial probability plots indicated that residuals were normally distributed.

The updated CPUE series for the Canadian longline fishery showed that relative abundance continued to decline in 1994, reaching the lowest point in the 7-year time series for all age groups except age 5+ (Fig. 4). Trends in CPUE for age 2 swordfish were quite variable, reaching peaks in 1990 and 1992, followed by a continuous decline to 1994. The age 3, 4 and 5+ fish all had similar patterns in CPUE, showing a general increase in abundance from 1988 to 1990, followed by a gradual decline to 1992. For ages 4 and 5+, this decline continued through to 1994; in contrast, CPUE increased slightly in 1993 for age 3 fish, dropping off sharply in 1994.

As recommended by the 1994 Swordfish Working Group (Anon. 1995), future analyses will include the following:

1) Modification of Area Specification: Split the areas at 55° W to separate the Canadian fishing zone into Scotian Shelf and Georges Bank vs the Grand Banks. The present split at 60° W (using ICCAT boundaries) includes some Scotian Shelf fish with the Grand Banks fish. The latter are known to be larger than Scotian Shelf fish. The proposed split should improve the matching of size and effort information.

2) Vessel-Specific Size and Effort Data: Since 1994, size and effort data are available at the trip level for the Canadian fishery and the proportion of the catch by age group can be obtained for individual trips rather than by area/month strata. Comparisons between these two methods of partitioning the trip data set (i.e. ageing size distributions for each trip vs ageing size distributions for area/month strata) need to be carried out. Since the growth template used for age slicing is based on monthly increments, there may be no differences in the final aged catches used in the model.

3) Correlated pattern (i.e. a year effect) over ages : While there are no distinct cohort trends in the data, the peak in 1990 was thought to be a correlated pattern among year classes. Further analyses are necesary to determine if this is an artifact of poor sampling in 1988 and 1989 or the influence of environmental conditions in 1990. The latter could be examined by including surface water temperature as a main effect in the model.

Acknowledgements

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Table 1. Summary statistics for Canadian swordfish longline trips by year, ICCAT Area, and month. (Nominal CPUE= (number of fish per trip/number of hooks per trip) x 1000).

Year	ICCAT area	Month	No.of Trips	No.of fish	Biomass (t)	Nominal CPUE	Landings (t)
1988	2	7	2	84	5.6	6	
1988	2	8	9	869	42.5	11	
1988	2	9	9	739	33.5	10	
1988	2	10	6	347	19.2	7	
1988	2	11	1	77	3.8	11	
1988	**2**	**all**	**27**	**2116**	**104.6**	**9**	**811.3**
1988	14	7	1	61	4.2	4	
1988	14	8	2	487	26.8	22	
1988	14	9	6	936	46.9	17	
1988	**14**	**all**	**9**	**1484**	**77.8**	**16**	**62.6**
1989	2	7	8	318	19.7	6	
1989	2	8	17	1172	61.9	10	
1989	2	9	6	552	32.9	10	
1989	2	10	5	276	15.5	8	
1989	2	11	1	3	0.1	5	
1989	**2**	**all**	**37**	**2321**	**130.1**	**9**	**942.0**
1989	14	8	4	785	41.5	11	
1989	14	9	2	710	36.2	19	
1989	14	10	1	268	15.4	12	
1989	**14**	**all**	**7**	**1763**	**93.1**	**13**	**155.0**
1990	2	7	5	250	13.0	9	
1990	2	8	18	2039	120.3	14	
1990	2	9	9	1403	82.2	19	
1990	2	10	4	411	30.2	16	
1990	**2**	**all**	**36**	**4103**	**245.7**	**15**	**618.5**
1990	14	7	2	84	3.1	12	
1990	14	8	1	218	14.0	19	
1990	14	9	4	964	64.5	21	
1990	14	10	1	181	16.8	14	
1990	14	11	1	53	3.1	11	
1990	**14**	**all**	**9**	**1500**	**101.4**	**18**	**200.7**
1991	2	6	8	688	42.5	12	
1991	2	7	21	1241	77.0	8	
1991	2	8	33	2438	155.0	9	
1991	2	9	34	2704	183.2	9	
1991	2	10	14	1105	79.8	10	
1991	2	11	1	27	1.2	14	
1991	**2**	**all**	**111**	**8203**	**538.8**	**9**	**881.2**
1991	14	8	4	745	35.5	8	
1991	14	9	2	241	14.8	4	
1991	**14**	**all**	**6**	**986**	**50.3**	**7**	**72.2**
1992	2	6	15	767	46.0	9	
1992	2	7	23	1207	78.0	7	
1992	2	8	28	1935	108.7	8	
1992	2	9	19	2189	134.6	16	
1992	2	10	8	544	36.4	10	
1992	**2**	**all**	**93**	**6642**	**403.7**	**10**	**1430.3**
1992	14	8	2	544	30.9	15	
1992	14	9	7	1336	71.1	15	
1992	14	10	2	438	29.0	14	
1992	**14**	**all**	**11**	**2318**	**131.0**	**15**	**55.6**
1993	2	5	4	114	6.1	6	
1993	2	6	22	630	33.4	5	
1993	2	7	51	2619	145.0	6	
1993	2	8	53	4553	258.2	9	
1993	2	9	31	2869	178.1	11	
1993	2	10	18	1148	77.7	8	
1993	2	11	2	137	18.1	7	
1993	**2**	**all**	**181**	**12070**	**716.7**	**8**	**2051.1**
1993	14	6	2	154	6.3	9	
1993	14	7	5	866	39.9	8	
1993	14	8	11	1450	86.8	10	
1993	14	9	8	947	68.6	10	
1993	14	10	8	1045	65.3	11	
1993	14	11	2	159	6.9	10	
1993	**14**	**all**	**36**	**4621**	**273.8**	**10**	**154.4**
1994	2	6	28	815	50.6	4	
1994	2	7	82	2612	161.2	4	
1994	2	8	78	3917	232.5	6	
1994	2	9	85	5439	375.9	8	
1994	2	10	59	2134	181.7	5	
1994	2	11	8	387	35.5	6	
1994	**2**	**all**	**340**	**15304**	**1037.4**	**6**	**1002.5**
1994	14	7	14	1349	65.6	7	
1994	14	8	35	4390	251.1	11	
1994	14	9	29	3217	200.3	10	
1994	14	10	3	325	25.2	8	
1994	**14**	**all**	**81**	**9281**	**542.2**	**10**	**635.6**

Table 2. Summary statistics for Canadian swordfish landings (Task I), total catch reported from log records and total weight of fish sampled for size from 1988 to 1994.

		Log records		Size samples	
Year	Total landings (MT)	Catch (MT) represented	% of total landings	Biomass (MT) sampled	% of total landings
1988	873.9	182.4	20.9	68.7	7.9
1989	1097.0	223.3	20.3	197.6	18.0
1990	819.2	347.1	47.4	632.7	77.2
1991	953.4	589.1	61.8	484.4	50.8
1992	1485.9	534.7	36.0	339.3	22.8
1993	2205.5	990.5	44.9	1083.8	49.1
1994	1638.1	1579.6	96.4	1600.7	97.7

Table 3. ANOVA results from Composite Model for Canadian swordfish longline CPUE, age 2.

REGRESSION OF MULTIPLICATIVE MODEL

MULTIPLE R............ 0.622
MULTIPLE R SQUARED..... 0.387

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F-VALUE
INTERCEPT	1	2.767E2	2.767E2	
REGRESSION	14	1.685E2	1.203E1	43.719
YEAR	6	8.771E1	1.462E1	53.114
AREA&MONTH	8	8.305E1	1.038E1	37.718
RESIDUALS	970	2.670E2	2.752E-1	
TOTAL	985	7.121E2		

REGRESSION COEFFICIENTS

CATEGORY	VARIABLE	COEFFICIENT	STD. ERROR	NO. OBS.
88	INTERCEPT	0.751	0.093	985
3				
89	1	0.009	0.119	44
90	2	0.458	0.118	45
91	3	-0.348	0.101	117
92	4	0.348	0.103	104
93	5	-0.105	0.096	218
94	6	-0.474	0.092	421
2	7	-0.425	0.051	193
4	8	0.285	0.051	193
5	9	-0.168	0.058	127
6	10	0.286	0.113	24
7	11	0.525	0.077	59
8	12	0.347	0.078	58
9	13	-0.038	0.129	18
1	14	-0.264	0.070	77

PREDICTED CATCH RATE

	LN TRANSFORM		RETRANSFORMED			
YEAR	MEAN	S.E.	MEAN	S.E.	CATCH	EFFORT
88	0.7509	0.0087	2.421	0.225	873900	360934
89	0.7594	0.0069	2.444	0.202	1097000	448840
90	1.2089	0.0067	3.832	0.314	819200	213800
91	0.4030	0.0032	1.715	0.097	953400	556036
92	1.0993	0.0035	3.439	0.204	1485900	432047
93	0.6457	0.0022	2.187	0.102	2205500	1008677
94	0.2764	0.0017	1.512	0.062	1638100	1083556

Table 4. ANOVA results from Composite Model for Canadian swordfish longline CPUE, age 3.

REGRESSION OF MULTIPLICATIVE MODEL

MULTIPLE R............ 0.653
MULTIPLE R SQUARED..... 0.426

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F-VALUE
INTERCEPT	1	2.296E2	2.296E2	
REGRESSION	14	1.966E2	1.405E1	51.500
YEAR	6	1.118E2	1.864E1	68.340
AREA&MONTH	8	8.709E1	1.089E1	39.918
RESIDUALS	970	2.645E2	2.727E-1	
TOTAL	985	6.908E2		

REGRESSION COEFFICIENTS

CATEGORY	VARIABLE	COEFFICIENT	STD. ERROR	NO. OBS.
88	INTERCEPT	0.695	0.093	985
3				
89	1	0.071	0.118	44
90	2	0.349	0.117	45
91	3	0.239	0.100	117
92	4	0.070	0.102	104
93	5	0.087	0.095	218
94	6	-0.547	0.091	421
2	7	-0.275	0.051	193
4	8	0.039	0.051	193
5	9	-0.508	0.058	127
6	10	0.347	0.113	24
7	11	0.664	0.077	59
8	12	0.444	0.077	58
9	13	-0.145	0.129	18
1	14	-0.160	0.069	77

PREDICTED CATCH RATE

	LN TRANSFORM		RETRANSFORMED			
YEAR	MEAN	S.E.	MEAN	S.E.	CATCH	EFFORT
88	0.6952	0.0086	2.287	0.212	873900	382035
89	0.7663	0.0068	2.458	0.203	1097000	446282
90	1.0444	0.0067	3.247	0.265	819200	252326
91	0.9338	0.0032	2.912	0.164	953400	327452
92	0.7656	0.0035	2.460	0.145	1485900	603904
93	0.7824	0.0022	2.504	0.117	2205500	880840
94	0.1479	0.0017	1.328	0.055	1638100	1233630

Table 5. ANOVA results from Composite Model for Canadian swordfish longline CPUE, age 4.

REGRESSION OF MULTIPLICATIVE MODEL

MULTIPLE R............	0.653
MULTIPLE R SQUARED.....	0.426

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F-VALUE
INTERCEPT	1	4.743E0	4.743E0	
REGRESSION	14	1.945E2	1.390E1	51.519
YEAR	6	1.089E2	1.815E1	67.304
AREA&MONTH	8	8.505E1	1.063E1	39.414
RESIDUALS	970	2.616E2	2.697E-1	
TOTAL	985	4.609E2		

REGRESSION COEFFICIENTS

CATEGORY	VARIABLE	COEFFICIENT	STD. ERROR	NO. OBS.
88	INTERCEPT	0.527	0.092	985
3				
89	1	-0.303	0.117	44
90	2	0.205	0.117	45
91	3	0.038	0.100	117
92	4	-0.106	0.102	104
93	5	-0.400	0.095	218
94	6	-0.774	0.091	421
2	7	-0.222	0.051	193
4	8	0.071	0.051	193
5	9	-0.473	0.058	127
6	10	0.191	0.112	24
7	11	0.667	0.076	59
8	12	0.552	0.077	58
9	13	0.046	0.128	18
1	14	-0.188	0.069	77

PREDICTED CATCH RATE

YEAR	LN TRANSFORM MEAN	LN TRANSFORM S.E.	RETRANSFORMED MEAN	RETRANSFORMED S.E.	CATCH	EFFORT
88	0.5269	0.0085	1.930	0.177	873900	452732
89	0.2234	0.0067	1.426	0.117	1097000	769135
90	0.7320	0.0066	2.372	0.192	819200	345366
91	0.5645	0.0031	2.010	0.112	953400	474402
92	0.4212	0.0034	1.741	0.102	1485900	853428
93	0.1266	0.0021	1.298	0.060	2205500	1699585
94	-0.2468	0.0017	0.893	0.036	1638100	1833423

Table 6. ANOVA results from Composite Model for Canadian swordfish longline CPUE, age 5+.

REGRESSION OF MULTIPLICATIVE MODEL

MULTIPLE R............	0.604
MULTIPLE R SQUARED.....	0.365

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F-VALUE
INTERCEPT	1	4.134E2	4.134E2	
REGRESSION	14	1.552E2	1.108E1	39.842
YEAR	6	4.269E1	7.114E0	25.573
AREA&MONTH	8	1.073E2	1.341E1	48.193
RESIDUALS	970	2.699E2	2.782E-1	
TOTAL	985	8.385E2		

REGRESSION COEFFICIENTS

CATEGORY	VARIABLE	COEFFICIENT	STD. ERROR	NO. OBS.
88	INTERCEPT	0.479	0.094	985
3				
89	1	0.111	0.119	44
90	2	0.801	0.118	45
91	3	0.483	0.101	117
92	4	0.371	0.103	104
93	5	0.133	0.096	218
94	6	0.026	0.092	421
2	7	-0.460	0.052	193
4	8	0.332	0.052	193
5	9	0.163	0.059	127
6	10	-0.465	0.114	24
7	11	0.205	0.077	59
8	12	0.497	0.078	58
9	13	0.296	0.130	18
1	14	-0.528	0.070	77

PREDICTED CATCH RATE

YEAR	LN TRANSFORM MEAN	LN TRANSFORM S.E.	RETRANSFORMED MEAN	RETRANSFORMED S.E.	CATCH	EFFORT
88	0.4789	0.0087	1.847	0.173	873900	473054
89	0.5899	0.0070	2.066	0.172	1097000	530948
90	1.2800	0.0068	4.120	0.339	819200	198847
91	0.9622	0.0032	3.004	0.171	953400	317417
92	0.8495	0.0036	2.683	0.160	1485900	553819
93	0.6119	0.0022	2.117	0.100	2205500	1041752
94	0.5049	0.0017	1.903	0.079	1638100	860911

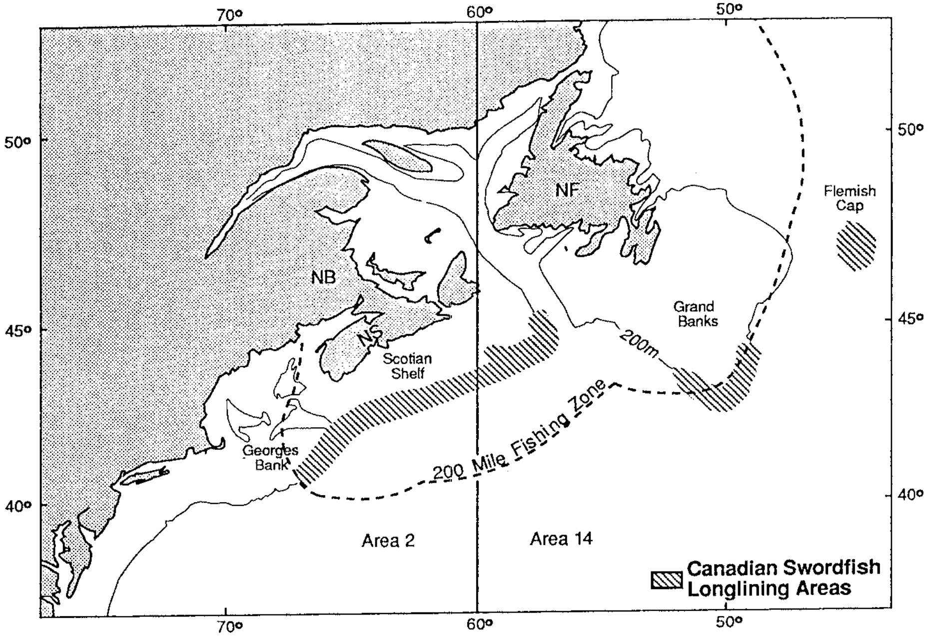

Figure 1. Geographic distribution of Canadian swordfish longlining areas within ICCAT Areas 2 and 14.

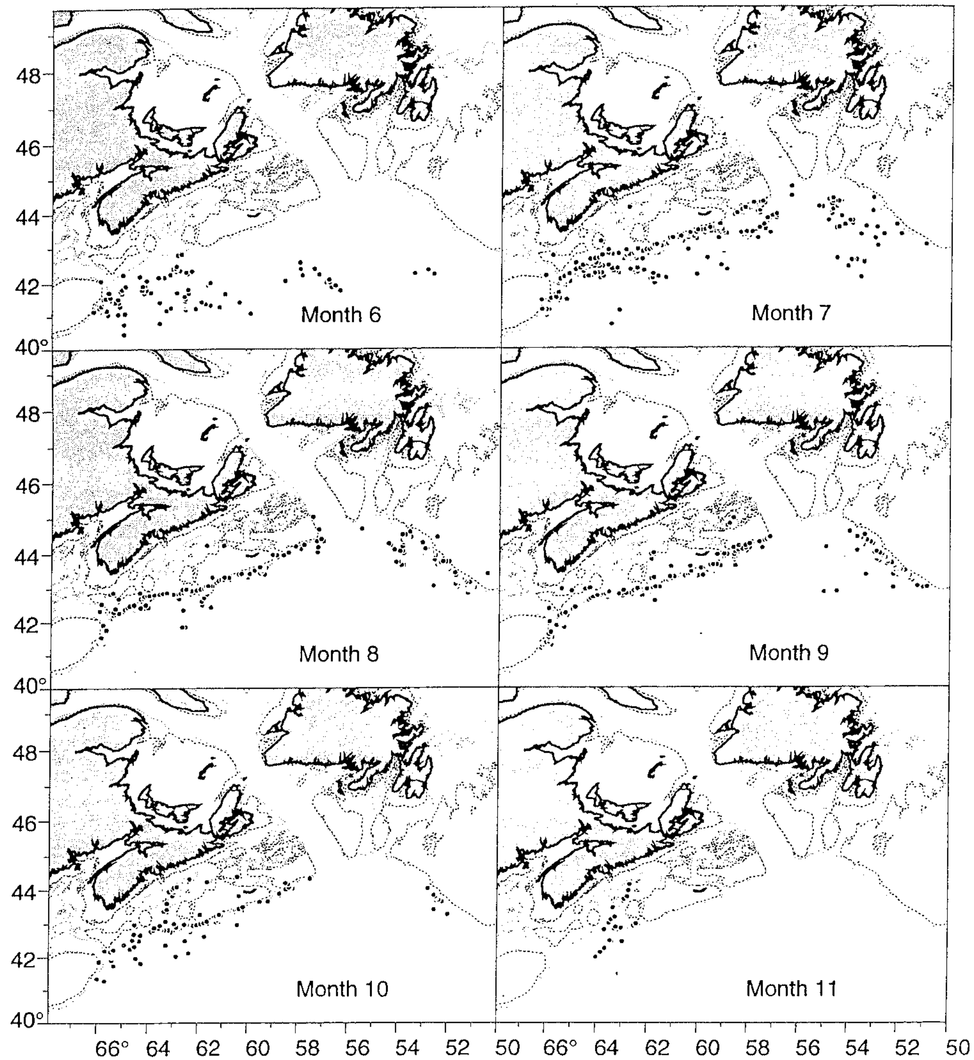

Figure 2. Set locations for Canadian swordfish longline, June-November, 1994.

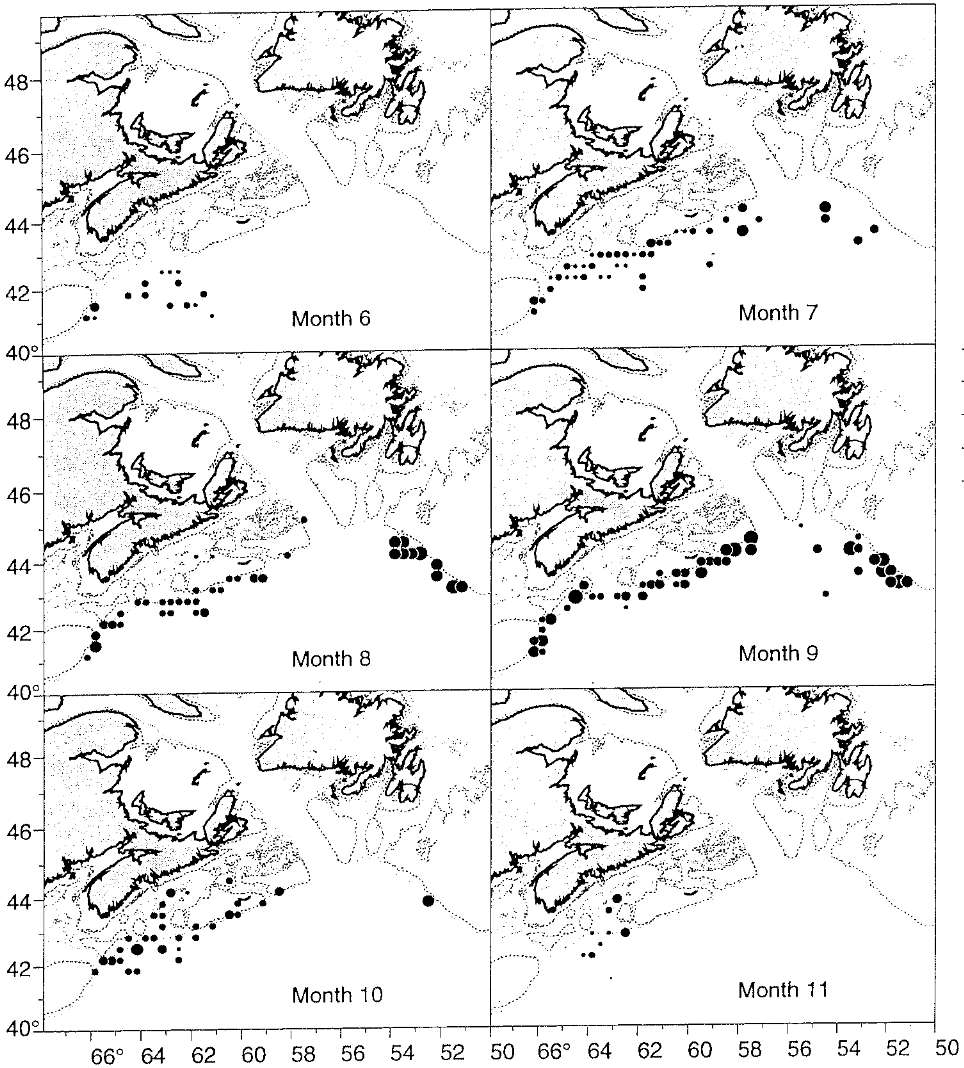

Figure 3. Nominal CPUE (number of fish per 1000 hooks) aggregated by 20 minute rectangles for Canadian swordfish longline, June-November, 1994.

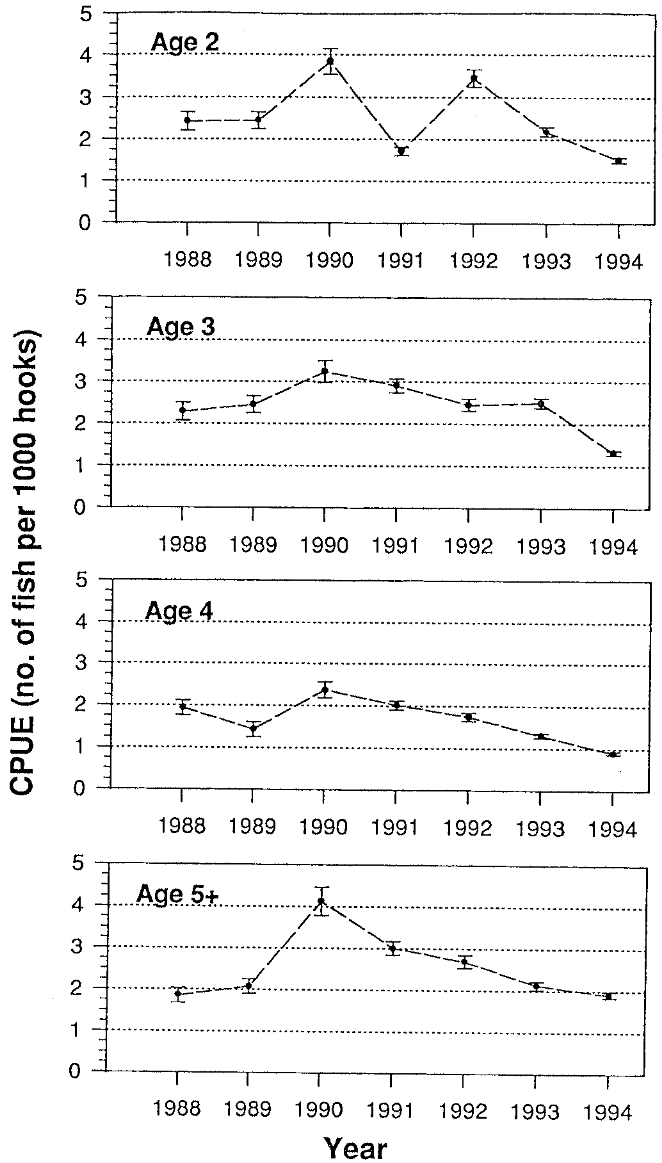

Figure 4. Standardized catch rates for swordfish (no. of fish per 1000 hooks) by age group for the Canadian longline fishery from 1988-94. Vertical bars represent ± 1 standard error.