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Spatial Variation in Distribution and Abundance of Yellowtail Flounder in NAFO Divisions 3LNO Using Geostatistics

by

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Introduction

Yellowtail flounder inhabits the continental shelf of the Northwestern Atlantic Ocean from Labrador to Chesapeake Bay at depths of 10-100m (Bigelow and Schroeder 1953). This species has reached its northern limit in commercial concentrations on the Grand Bank off the coast of Newfoundland. Brodie et al. (1998) showed that the area occupied by the yellowtail flounder stock in Div. 3LNO was positively correlated with stock abundance from surveys, but not with bottom water temperatures from these same surveys. During the years of highest abundance in the late 1970's and early 1980's, the stock was distributed widely over the Grand Bank within the 100 meter depth contour. However, as the stock declined from the mid 1980's onward, the remaining fish appear to aggregate in the area of the Southeast Shoal and to the area west of the shoal. Brodie et al. (1998) concluded that the contraction in the area of distribution for this stock to the preferred habitat around the Southeast Shoal was primarily a function of low stock size, which resulted from increased fishing activity in the mid to late 1980's. Most of these analyses have been presented in various NAFO SCR docs. and reviewed at recent STACFIS meeting from 1994-1997. Examination of data from surveys conducted from 1995-1998 suggest that some expansion of the range may be occurring.

In 1994, a fishing moratorium for Yellowtail flounder, American plaice and cod was declared from the Grand Bank area, NAFO division 3LNO. In 1998 the fishery for yellowtail flounder was reopened (Walsh et al. 1999). A major concern for the yellowtail flounder fishery on the southern Grand Bank is devising a strategy that will reduce the by-catch of American plaice, which is still under moratorium. Achieving this strategy requires understanding the spatial dynamics of yellowtail flounder and American plaice. Previously, analyses of the spatial distribution of yellowtail flounder and American plaice on the southern Grand Bank, based on the FPI/DFO seasonal cooperative surveys (Simpson et al. 1999) and DFO annual surveys (Morgan et al. 1999; Walsh et al 1999), have been mainly qualitative in nature.

Quantitative analysis of fish populations is problematic since many sampling techniques such as the stratified random sampling used in fisheries surveys assume that samples are spatially independent. However, since samples are likely spatially correlated, adjacent samples are similar, and therefore this assumption is often violated. Recently, geostatistics have been applied to fisheries data in order to obtain a more accurate understanding of spatial variation while accounting for spatial autocorrelation. In this paper, we present a preliminary analysis of variation in the abundance and distribution of yellowtail flounder and American plaice on the southern Grand Bank using geostatistics.

Material and Methods

Datasets:

FPI/DFO Co-operative surveys:

Quarterly surveys have been conducted since July, 1996 over an area of approximately 9500 square nautical miles, corresponding to the area where the yellowtail stock is mainly distributed (See Simpson et al. 1999). The surveys are carried out by the vessel Atlantic Lindsey, a 44 m commercial stern trawler using a Engel 145 Hi-Lift otter trawl (See Brodie et al. 1997, Brodie et al.1998 for more detailed description). Each fishing set was one hour in duration at a speed of 3.0 knots. Catch numbers and weights of all yellowtail in the catch of each set were recorded. By-catch data on other species such as American plaice were also collected.

Canadian spring groundfish surveys

Annual stratified-random trawl surveys have been conducted by Canada in Div. 3LNO since 1971. Because of varying coverage in the surveys from 1971-74, we chose to examine the time period 1975-98 with the exception of 1983 when the survey was cancelled due to vessel problems. Stratification is based on depth and the survey covered depths to the 731m contour. Strata deeper than 731 m were fished for the first time in this time series in 1994, however, mechanical problems with the survey vessel did not permit these strata to be fished in 1995 and there was insufficient survey time in 1996 and 1997 to cover these depth zones. From 1975-82 the converted time series is based on Engel 145 high lift otter trawl survey catches. From 1984-1998 the converted data base is based upon the Campelen 1800 shrimp trawl survey catches (See Walsh and Orr 1998).

Juvenile Fall groundfish surveys

Annual stratified-random surveys of the Grand Bank were conducted by the 50 m *FRV WILFRED TEMPLEMAN* using a Yankee 41 shrimp trawl from 1985-94. From 1985 to 1988, the survey covered depths inside the 91 meter contour and since 1989 the coverage increased to 274m (See Walsh et al. 1995 for details). Beginning in the fall of 1995, the Yankee trawl was replaced with the Campelen trawl. No conversions were applied to the Yankee trawl database.

Analysis:

Exploratory analysis of spatial distribution of FPI/DFO co-operative survey trawls, DFO Spring Research Vessel trawls and DFO Juvenile survey trawl were made with visual inspection of ACON point (expanding symbol) plots (Black 1993) of the standardized number per tow for yellowtail flounder and American Plaice in NAFO divisions 3LNO. To further examine variation in yellowtail density, we used a measure of the spatial autocorrelation between points, the semi-variogram. The semi-variogram is half the expected value of the squared difference between two points a distance 'h' apart. This analysis was followed by point kriging which uses the known covariance structure from the semi-variogram to weight the observations taken over the region to obtain a spatially interpolated estimate of abundance at unsampled points in the region. All semivariance and kriging analysis were conducted using GS+ software.

Since non-random patterns of distribution and abundance usually identify the scale of processes influencing these patterns we further analysed the spatial pattern of yellowtail flounder in relation to temperature and depth using generalized additive models (GAM) using S-Plus. GAM analysis, with a Poisson error distribution, are useful in quantifying the relationship between spatial trends in abundance and environmental factors. Initially, we used a step-wise GAM to determine the best fitting model based on the Akaike Information Criterion statistic (O'Brien and Rago 1996), which revealed that a spline smooth function provided a better fit than a loess smooth function. Further GAM models were run based on the formula.

Catch number ~ s(depth) +s(temperature) + latitude + longitude,

where s is the smooth function.

This paper explores various geostatistical methods to look at spatial variation in the distribution and abundance of yellowtail flounder and to a lesser extent, American plaice. The results are preliminary.

Results and Discussion

Geographic distribution

ACON plots of FPI/DFO cooperative trawl data for yellowtail flounder (Fig. 1) display large catches distributed throughout the region in the May/June, July, and November. During March, the number of large catches of yellowtail are smaller (Simpson et al 1999). In general, yellowtail flounder catches were distributed throughout the survey area, with the largest catches generally being taken in NAFO Division 3N. Low catches during the three March surveys were also observed for American Plaice (Fig. 2) with the largest catches occurring in the southwest portion of the grid in NAFO Division 3O. During other survey periods, American Plaice catches were distributed throughout the grid survey area.

ACON plots of juvenile fall survey data from year 1985 to 1997 for both yellowtail flounder and American plaice are shown in Fig.'s 3 and 4. Yellowtail flounder were found mainly in Divisions 3N and 3O in all years, with the largest catches occurring in Division 3N. From 1993 to 1996, the distribution of large catches was more discrete, with large catches clustered mainly on the Southeast Shoal, and partly outside the 200 mile limit. For American plaice, large catches were located in Divisions 3LNO in all years from 1989. In 1995, 1996 and 1997 fewer large catches of American plaice were located in Division 3N where larger catches of yellowtail flounder were concentrated. Overall, catches of yellowtail in the juvenile fall survey appear to be concentrated in Division 3N, especially on and around the Southeast Shoal and straddling the NAFO 200 mile limit, while American plaice are generally dispersed over the Grand Banks.

Large catches of yellowtail flounder in the DFO spring surveys (Fig. 5) were distributed mainly in Divisions 3NO after 1987. Prior to 1987, large catches of yellowtail flounder were infrequently located in southern Division 3L inside the 91m depth contour. From 1994 to 1997, large catches of yellowtail flounder were concentrated in Division 3N on and around the Southeast Shoal and straddling the NAFO 200 mile limit. Large catches of American plaice were distributed throughout the Grand Bank from 1975 to 1990 in NAFO 3LNO (Fig 6). After 1990, with the exception of 1996, large catches of American plaice appear to be generally confined to Division 3O and on the slope of the Grand Bank in Divisions 3N and 3L. In 1996, large catches of American plaice occurred through out Divisions 3LNO, with the largest catches concentrated on the slope of the Grand Bank in all 3 Divisions.

Semivariance Analysis and Kriging

For both yellowtail flounder and American plaice survey catches were spatially correlated in the DFO Juvenile fall surveys using 1989-1998 data (Table 1 & 2), spring DFO research vessel surveys (Table 3 & 4) and FPI/DFO cooperative surveys. For yellowtail flounder the average spatial correlation extended from 113.92 n.m. in the spring DFO research vessel surveys to 170.98 n.m. in the DFO fall juvenile surveys. Spatial autocorrelation between catches for American plaice extended from 223.55 n.m. in the DFO fall juvenile survey to 278.65 n.m. in the DFO spring research vessel surveys. In both species, and surveys, the spherical autocorrelation model explained from 40% to over 90% of the spatial variation in trawl catch variation.

Maps of kriged estimates for yellowtail flounder (Fig. 7) display a pattern of abundance concentrated in Division 3NO on and around the Southeast Shoal. Consistent with the pattern revealed by DFO spring survey ACON point patterns, the distribution of yellowtail flounder was restricted in 1994 and 1995. In all years, the distribution of kriged values for yellowtail flounder appear to be concentrated in a single loose aggregation. In contrast, the distribution of American Plaice kriged estimates are diffusely distributed throughout the Grand Bank in all years from the DFO spring survey data (Fig. 8). Kriged estimates of yellowtail abundance from the FPI/DFO cooperative survey indicate that while yellowtail flounder is concentrated in Division 3N during March surveys, the distribution is relatively homogeneous throughout the survey area in many of the other sampling periods (Fig. 9). The spatial distribution of kriged estimates from the fall DFO juvenile survey from 1988 to 1997 indicate consistent pattern of concentration oriented on and around the Southeast Shoal and over the NAFO 200 mile limit (Fig. 10).

Comparisons of the pattern between years for yellowtail flounder indicated that the interpolated distribution from the fall DFO juvenile survey was generally highly correlated from year to year (Table 5). That is, the values interpolated from the semivariance and kriging tend to overlap from year to year with a fairly high repeatability. This is particularly true since 1990 when the population range contracted to the southern Grand Bank. For American Plaice, there was very little correlation between years (Table 6). Between species, the correlation of kriged estimates within years is very weak (Table 7) potentially as a result of differences in the preferred habitats of these species.

Generalized Additive Models

The abundance and distribution of yellowtail flounder are highly influenced by depth and temperature as indicated by the GAM analysis (Table 10). Together, these environmental variables explained 50-86% of the variation in yellowtail flounder abundance and distribution. The slight difference (Fig. 11) between the partial (depth and temperature) and full models (depth, temperature, latitude, and longitude) indicate that specific location had little influence upon the distribution and abundance of yellowtail flounder catch. Furthermore, the observed increase in the R^2 to values greater than 75% since 1991 compared with from 55-60% in 1988 suggests the significance of temperature and depth increased. In each of the years analysed, a large concentration of yellowtail flounder was present in Division 3N (Fig. 12). This concentration is consistent with the aggregations which were found in maps of kriged abundance.

Conclusions

Quantitative analysis of the spatial dynamics of yellowtail flounder and American Plaice indicate these species have very different patterns of abundance and distribution. American Plaice is generally distributed over the Grand Bank in a diffuse pattern (see Morgan et al. 1999) which is not consistent from year to year. However, yellowtail flounder appears to be consistently concentrated in Division 3NO on and around the Southeast Shoal from year to year. This pattern is highly correlated since 1991 indicating very little change in the spatial distribution of this species in recent years. While spatially yellowtail flounder appears to be geographically localized, the GAM analysis indicated that the pattern of temperature and depth appear to be significant factors affecting the distribution of this species.

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Table 1. Statistical parameters for semivariance analysis of Yellowtail Flounder from the DFO juvenile fall survey data.

Year	Nugget	Sill	Range	Proportion	r^2	RSS
1989	0.856	3.541	188.4	0.758	0.855	0.650
1990	0.784	3.197	166.2	0.755	0.858	0.502
1991	1.450	4.280	409.2	0.661	0.903	0.560
1992	0.648	2.830	116.1	0.771	0.276	6.139
1993	0.522	2.624	81.0	0.801	0.353	1.691
1994	0.684	2.867	152.1	0.761	0.769	0.759
1995	1.248	3.020	177.0	0.587	0.778	0.491
1996	1.669	3.375	164.8	0.505	0.830	0.520
1997	1.999	3.754	433.6	0.468	0.698	1.338
Average			209.82			

Table 2. Statistical parameters for semivariance analysis of plaice from DFO juvenile fall survey data.

Year	Nugget	Sill	Range	Proportion	r^2	RSS
1989	1.060	6.985	172.6	0.848	0.934	2.180
1990	0.780	8.220	178.2	0.905	0.939	1.947
1991	0.500	7.739	117.8	0.935	0.961	1.336
1992	1.340	6.758	278.4	0.802	0.780	9.560
1993	0.870	6.900	300.9	0.874	0.815	6.577
1994	0.430	7.885	210.0	0.945	0.865	5.592
1995	0.300	5.044	198.0	0.941	0.874	2.231
1996	0.620	4.476	406.2	0.861	0.662	6.782
1997	0.680	6.229	279.9	0.891	0.717	10.38
Average			238.0			

Table 3. Statistical parameters for semi-variance analysis of Yellowtail Flounder from the spring DFO research vessel surveys.

Year	Nugget	Sill	Range	Proportion	R^2	RSS
1975	0.076	1.232	196.7	0.938	0.944	0.0637
1976	0.084	1.093	139	0.923	0.859	0.0728
1977	0.001	1.076	138	0.999	0.841	0.134
1978	0.002	0.939	87.8	0.998	0.339	0.487
1979	0.038	1.056	111.4	0.964	0.795	0.133
1980	0.001	1.031	105.9	0.99	0.763	0.164
1981	0.001	1.088	109.5	0.999	0.761	0.112
1982	0.13	1.03	112.5	0.874	0.763	0.128
1984	0.1	1.09	105.2	0.908	0.861	0.0952
1985	0.136	1.138	170.3	0.88	0.976	0.0177
1986	0.095	1.046	120.5	0.909	0.731	0.178
1987	0.129	1.04	116.5	0.876	0.739	0.14
1988	0.091	1.042	105.7	0.913	0.674	0.203
1989	0.276	10.71	136.1	0.742	0.985	0.0502
1990	0.082	1.101	139.8	0.926	0.869	0.0471
1991	0.001	1.017	70.5	0.999	0.637	0.187
1992	0.001	1.055	86	0.999	0.946	0.0221
1993	0.029	1.081	100.4	0.973	0.899	0.523
1994	0.001	1.09	78.8	0.999	0.523	0.416
1995	0.01	1.047	69.7	0.999	0.712	0.182
1996	0.001	1.076	126.9	0.999	0.919	0.0593
1997	0.047	1.042	115.3	0.955	0.799	0.129
1998	0.001	1.222	77.6	0.999	0.976	0.042
Average			113.92			

Table 4. Statistical parameters for semi-variance analysis of American Plaice from spring DFO research vessel surveys.

Year	Nugget	Sill	Range	Proportion	R^2	RSS
1975	0.083	1.005	48	0.917	0.491	0.109
1976	0.605	1.47	422.68	0.588	0.641	0.325
1977	0.573	1.463	341.27	0.608	0.91	0.69
1978	0.607	1.215	397.8	0.5	0.401	0.283
1979	0.559	1.396	297.53	0.6	0.942	0.0341
1980	0.414	1.37	339	0.698	0.949	0.0448
1981	0.589	1.339	299.44	0.56	0.966	0.0157
1982	0.384	1.241	261.7	0.691	0.972	0.0172
1984	0.439	1.39	226.66	0.684	0.963	0.0281
1985	0.564	1.464	332.43	0.615	0.972	0.0208
1986	0.369	1.621	307.86	0.772	0.978	0.0277
1987	0.404	1.447	357.8	0.721	0.871	0.147
1988	0.39	1.509	400.4	0.742	0.975	0.022
1989	0.449	1.534	313.73	0.707	0.973	0.0258
1990	0.706	1.311	345.18	0.461	0.961	0.013
1991	0.786	1.177	291.86	0.332	0.723	0.0459
1992	0.323	1.019	71.4	0.683	0.899	0.006376
1993	0.521	1.043	137.4	0.5	0.878	0.0107
1994	0.498	1.052	164.4	0.527	0.917	0.0177
1995	0.48	1.104	199	0.565	0.959	0.012
1996	0.763	1.245	344.57	0.387	0.802	0.0503
1997	0.599	1.416	344.22	0.577	0.935	0.041
1998	0.781	1.139	164.64	0.314	0.645	0.0553
Average			278.65			

Table 5. Correlation between kriged values (Z) of Yellowtail Flounder between years from juvenile survey data.

Year	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**	**1989**	**1988**	**1987**	**1986**	**1985**
1997	0.90	0.94	0.90	0.92	0.93	0.85	0.75	0.86	0.66	0.45	0.30	0.32
1996		0.92	0.89	0.89	0.90	0.82	0.69	0.77	0.68	0.36	0.30	0.29
1995			0.94	0.93	0.92	0.88	0.76	0.86	0.69	0.44	0.30	0.29
1994				0.94	0.91	0.89	0.79	0.88	0.70	0.45	0.33	0.37
1993					0.94	0.87	0.78	0.88	0.71	0.45	0.32	0.32
1992						0.86	0.82	0.87	0.67	0.45	0.31	0.27
1991							0.82	0.89	0.65	0.42	0.31	0.31
1990								0.87	0.61	0.53	0.30	0.41
1989									0.62	0.50	0.29	0.34
1988										0.44	0.54	0.52
1987											0.39	0.42
1986												0.49

Table 6. Correlation between kriged values (Z) of plaice between years, for juvenile survey data

Year	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**	**1989**	**1988**
1997	0.67	0.79	-0.39	-0.24	-0.11	0.01	-0.27	-0.03	-0.43
1996		0.59	-0.19	-0.08	-0.16	-0.03	-0.13	0.05	-0.27
1995			-0.13	-0.03	0.19	0.29	-0.01	0.19	-0.35
1994				0.63	0.62	0.56	0.64	0.59	0.44
1993					0.51	0.48	0.52	0.49	0.34
1992						0.66	0.62	0.60	0.35
1991							0.73	0.89	0.27
1990								0.78	0.42
1989									0.32

Table 7. Correlations between kriged values (Z) of yellowtail flounder and plaice over years.

Yellowtail											
Plaice	Year	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988
	1997	0.07									
	1996		0.02								
	1995			-0.02							
	1994				-0.12						
	1993					-0.15					
	1992						-0.34				
	1991							-0.30			
	1990								-0.36		
	1989									-0.41	
	1988										0.22

Table 8. Generalized additive model results. The fit of the model is represented by the Pseudo-R^2.

YEAR	NULL DEVIANCE	DF	RESIDUAL DEVIANCE	DF	Pseudo R^2
1988	23186.79	94	9758.36	86.47	0.5791
1989	75195.74	122	36970.96	114.75	0.5083
1990	99454.81	141	32010.31	132.95	0.6781
1991	110139	133	29684.24	124.95	0.73
1992	60206	126	19254.74	118.49	0.5791
1993	84253.04	133	18452.06	125.03	0.781
1994	141810	101	19260.88	92.949	0.86
1995	70187.46	169	15067.28	161.11	0.7853
1996	60566.89	139	9901.525	130.98	0.83652
1997	76865.62	172	19026.85	164.22	0.7525
1998	100641.6	212	20953.17	204.23	0.792

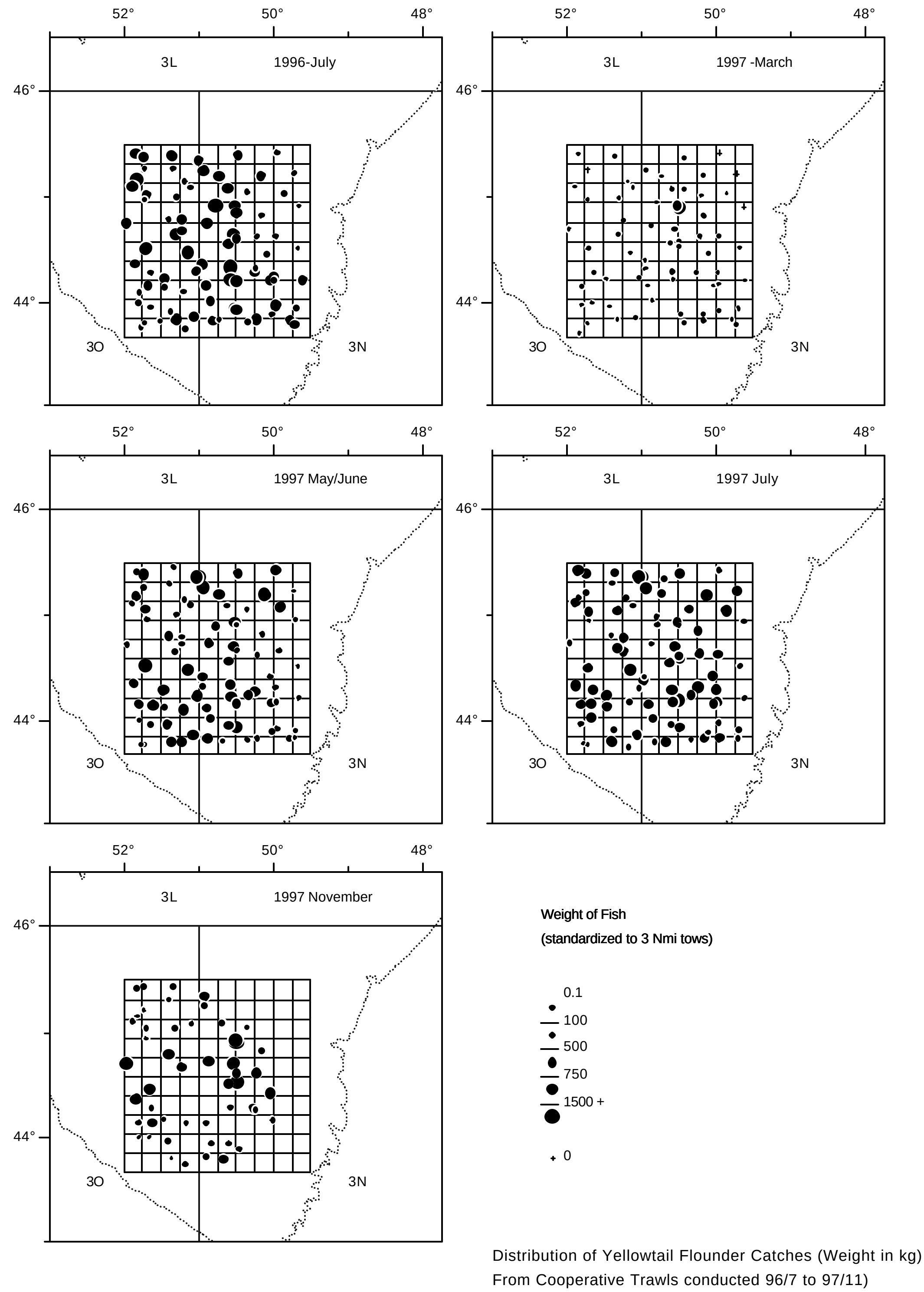
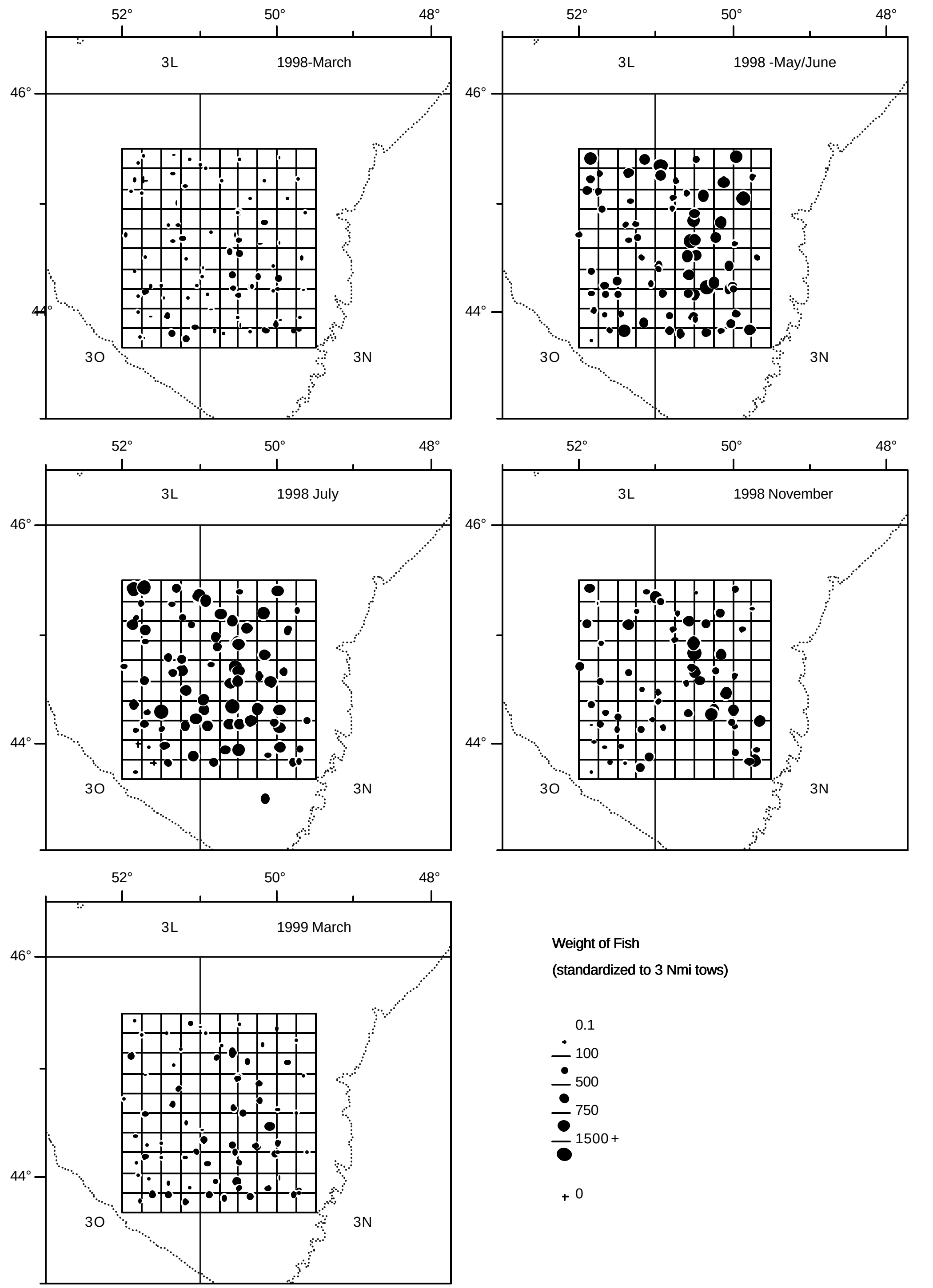


Figure 1: ACON plots of yellowtail flounder catches from FPI/DFO cooperative trawl surveys.



Distribution of Yellowtail Flounder Catches (Weight in kg)
From Cooperative Trawls conducted 98/3 to 99/3

Fig. 1. Cont'd

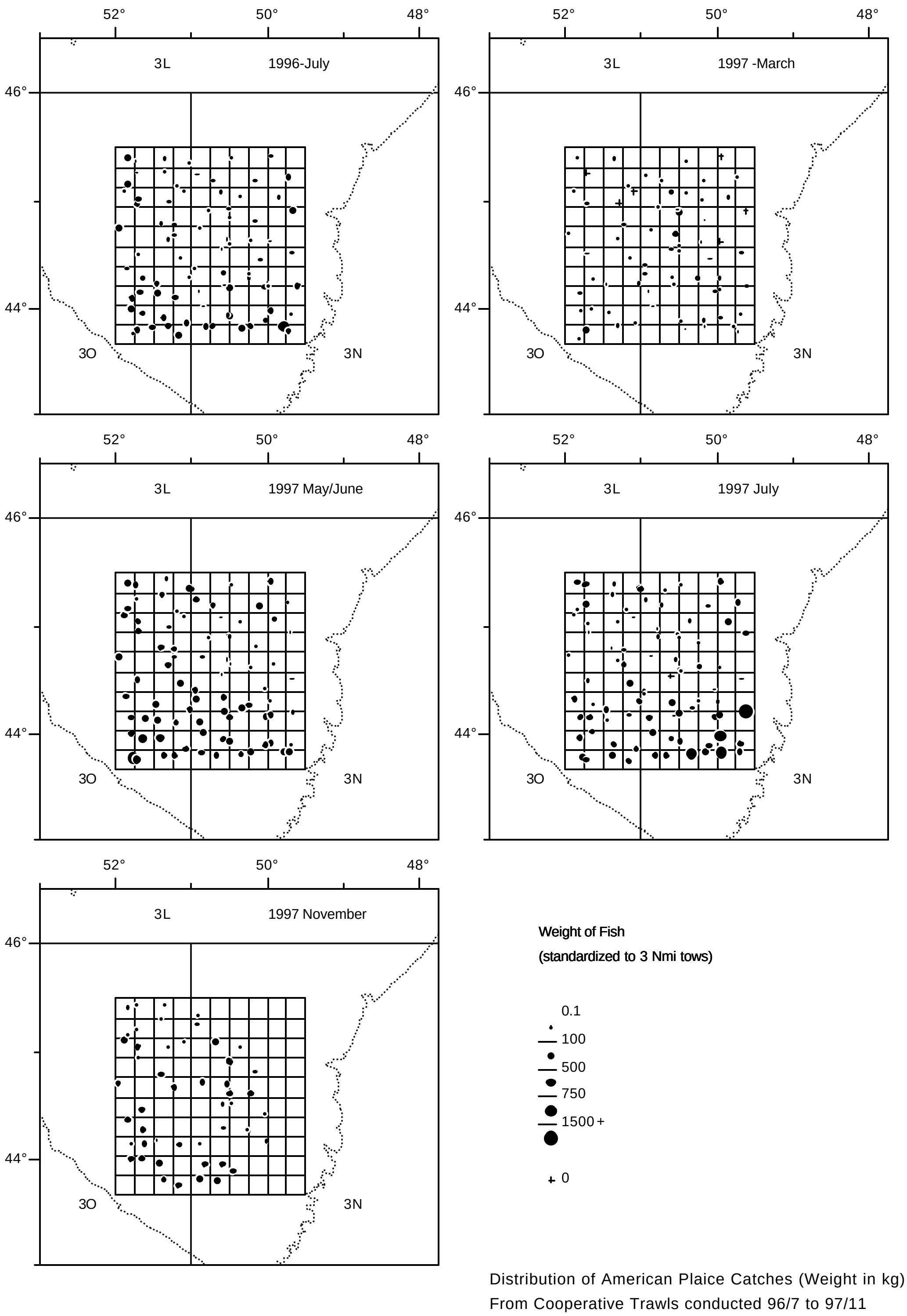


Figure 2. ACON plots of American Plaice catches from FPI/DFO cooperative trawl surveys.

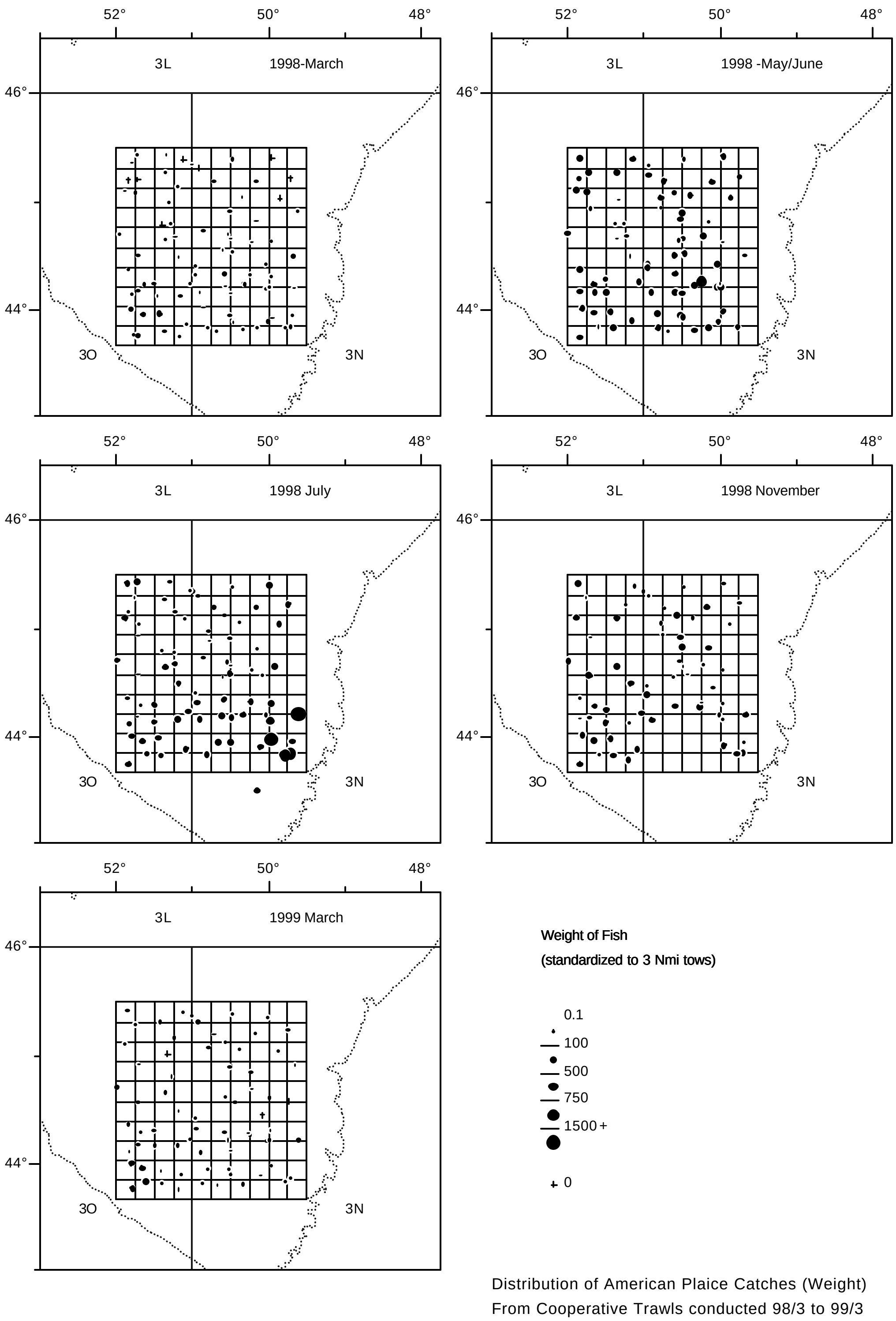

52°
50°
48°
46°
44°
3L
1998-March
3O
3N
1998 -May/June
1998 July
1998 November
1999 March
Weight of Fish
(standardized to 3 Nmi tows)
0.1
100
500
750
1500+
0
Distribution of American Plaice Catches (Weight)
From Cooperative Trawls conducted 98/3 to 99/3

Fig. 2. Cont'd

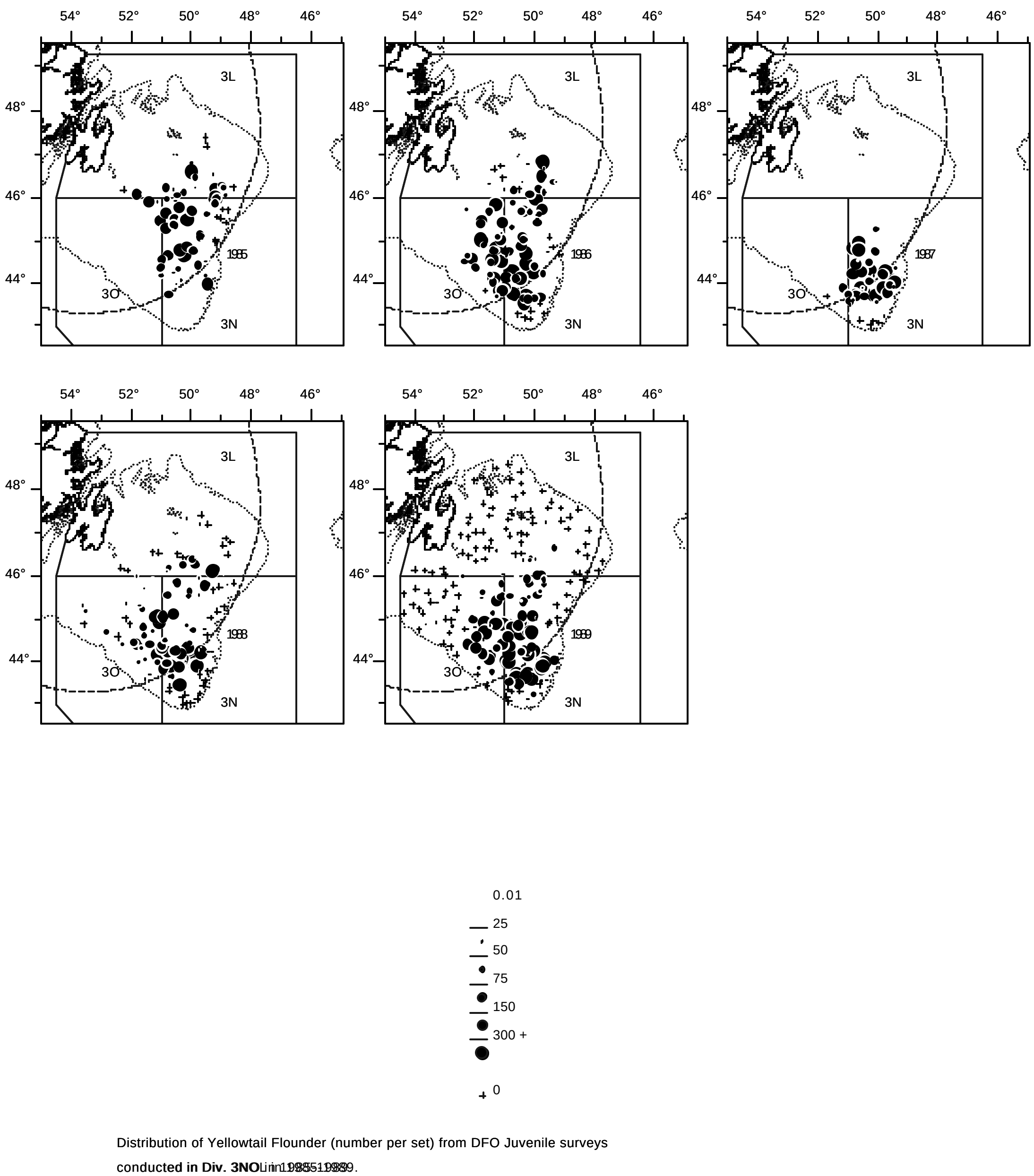
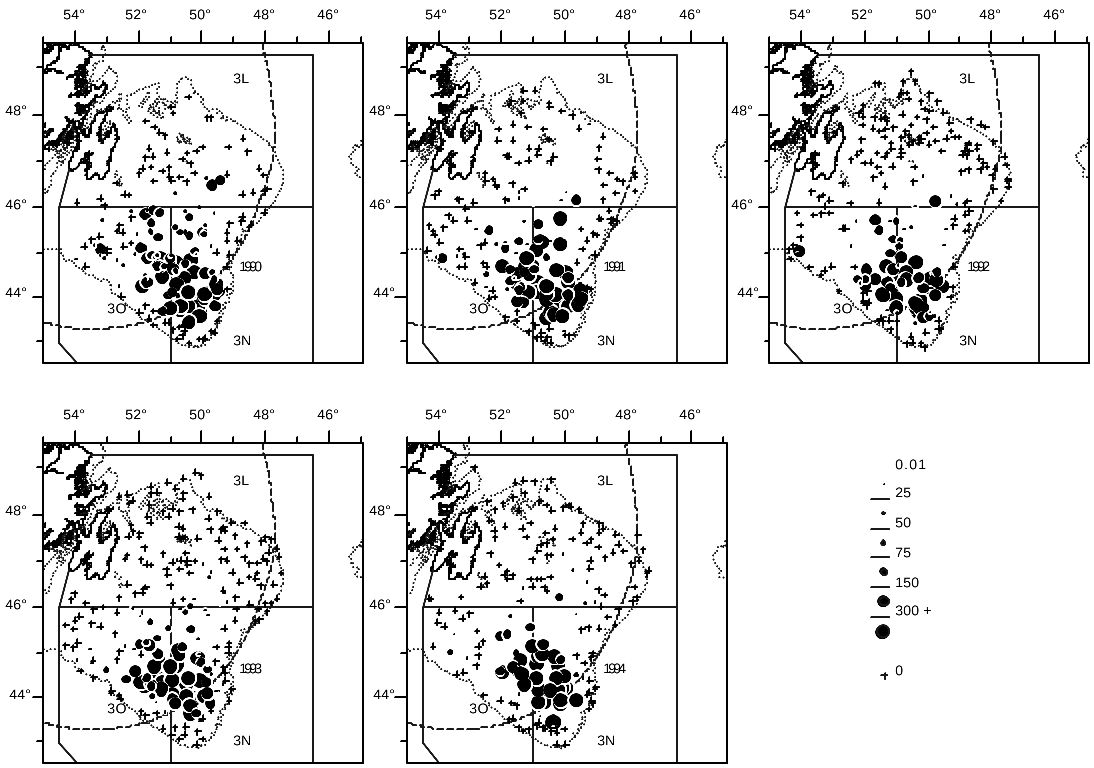
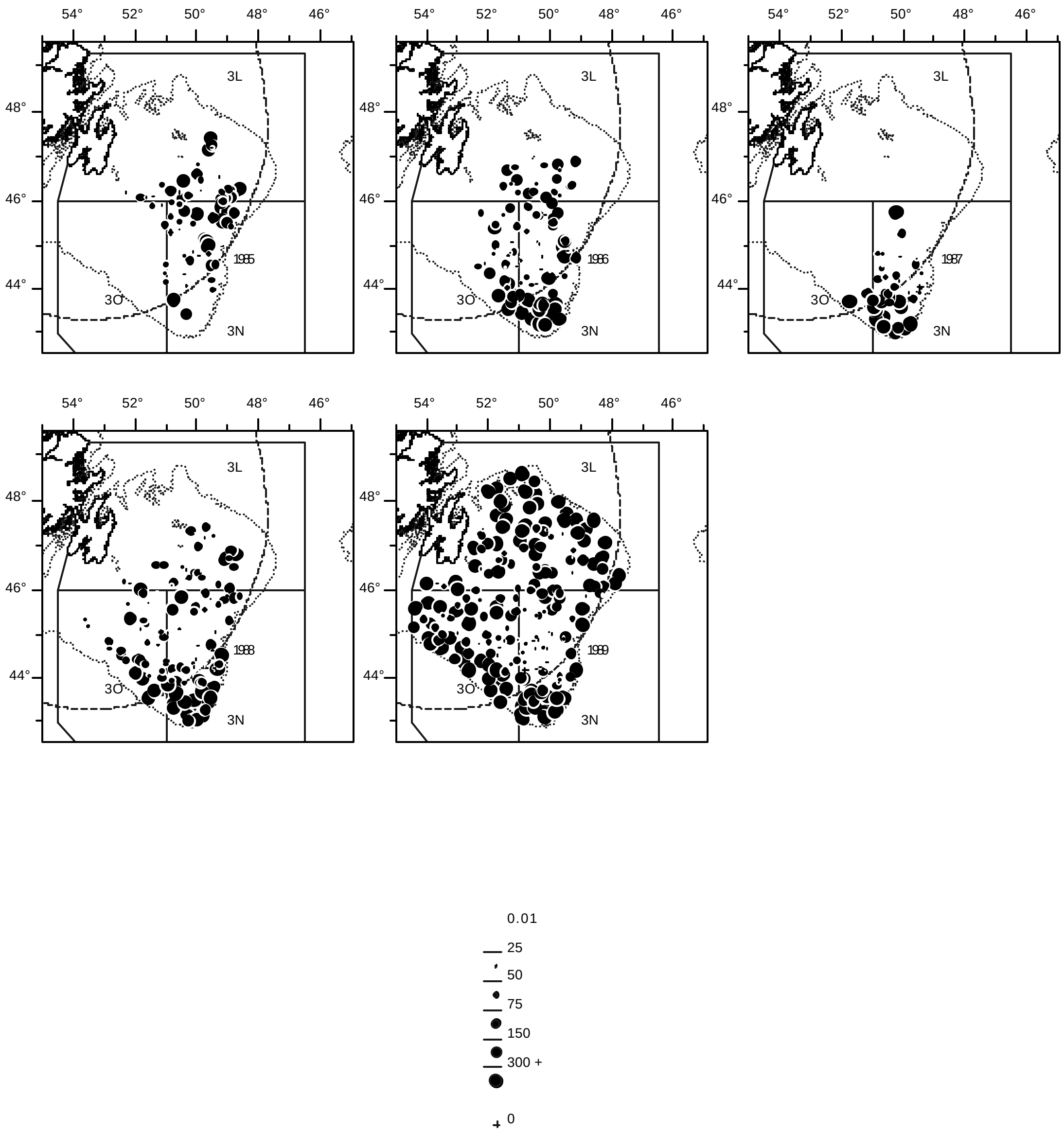


Figure 3. ACON plots of Yellowtail flounder catches from fall DFO Juvenile survey.



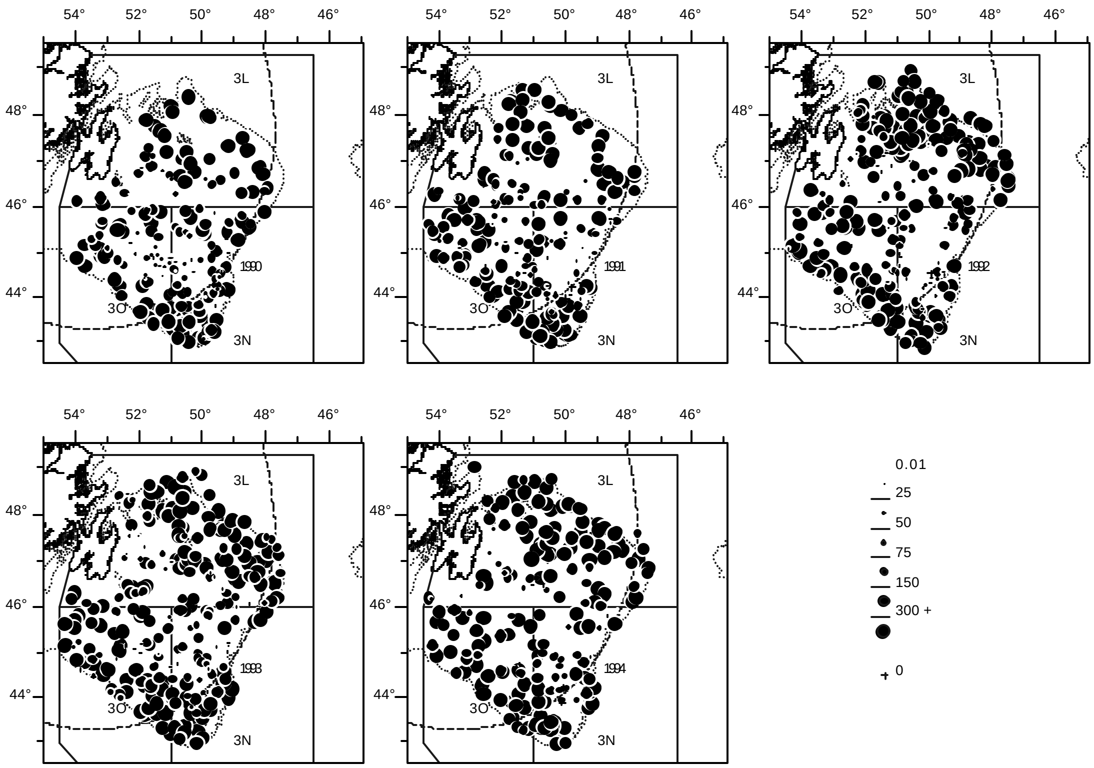
Distribution of Yellowtail Flounder (number per set) from DFO Juvenile surveys conducted in Div. 3NOL in 1990-1994.

Fig. 3. Cont'd



Distribution of American plaice (number per set) from DFO Juvenile surveys conducted in Div. 3NOL in 1985-1989.

Figure 4. ACON plots of American Plaice catches from fall DFO Juvenile survey.



Distribution of American plaice(number per set) from DFO Juvenile surveys
conducted in Div. 3NOL in 1990-1994.

Fig. 4. Cont'd

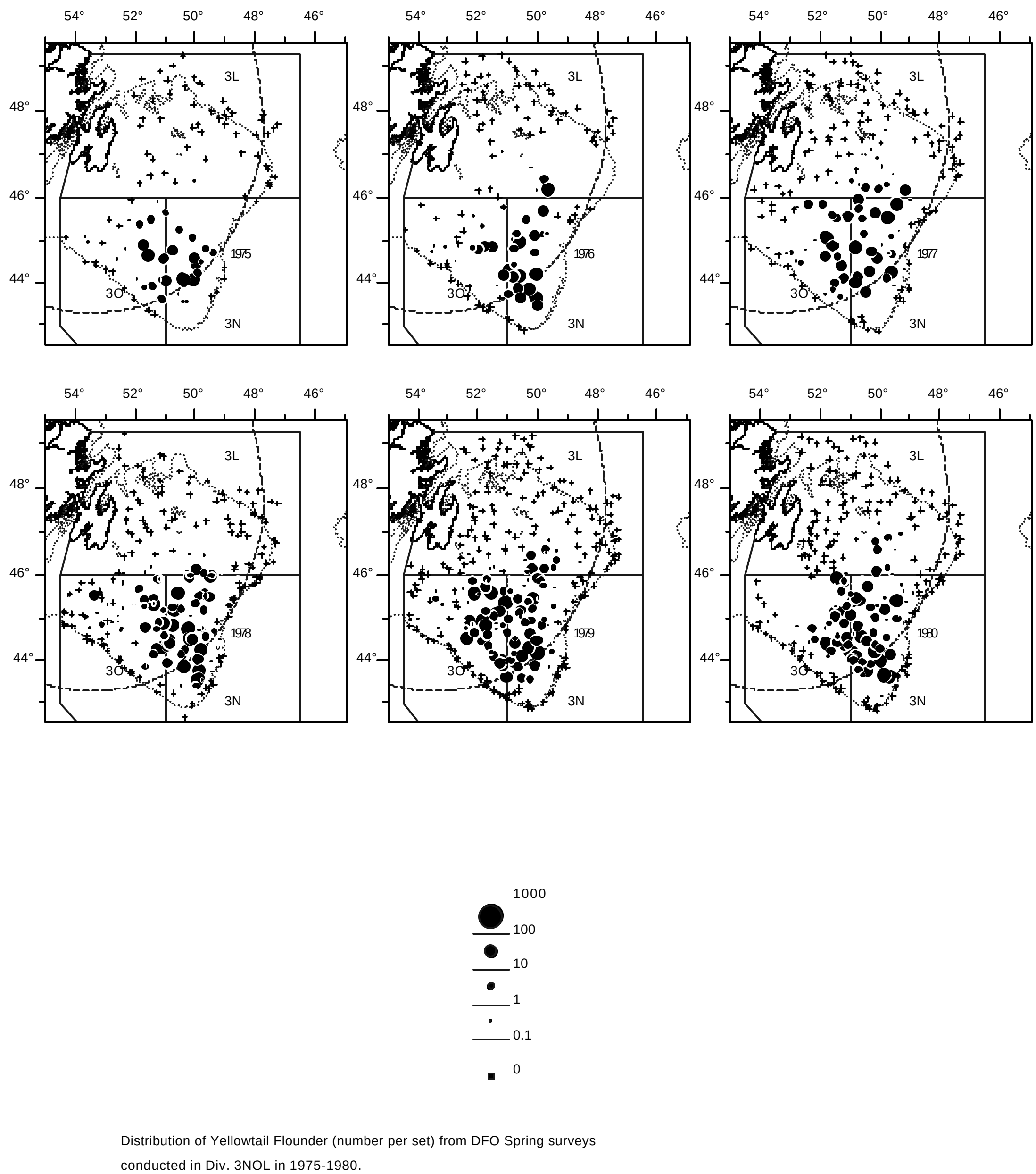
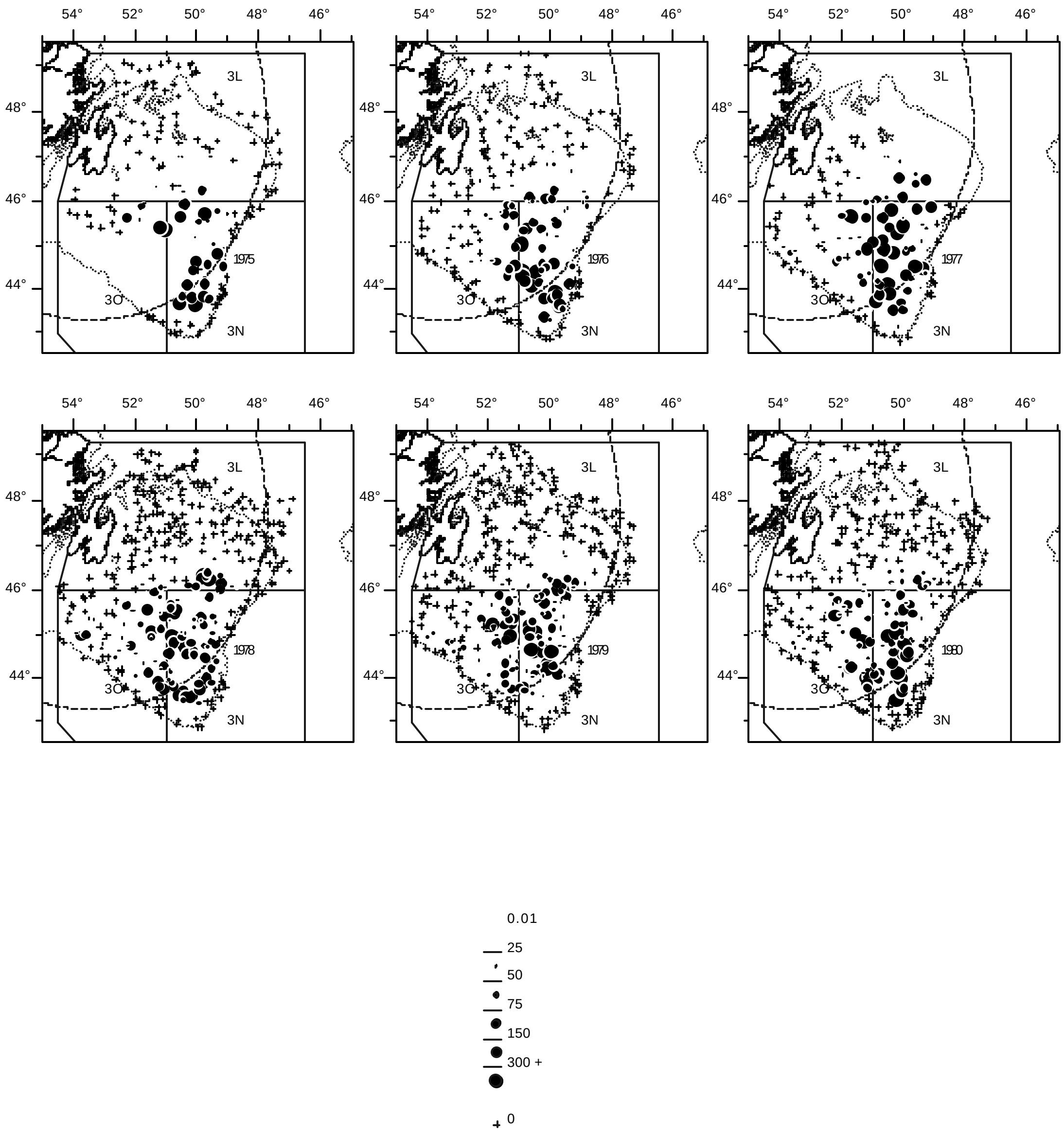
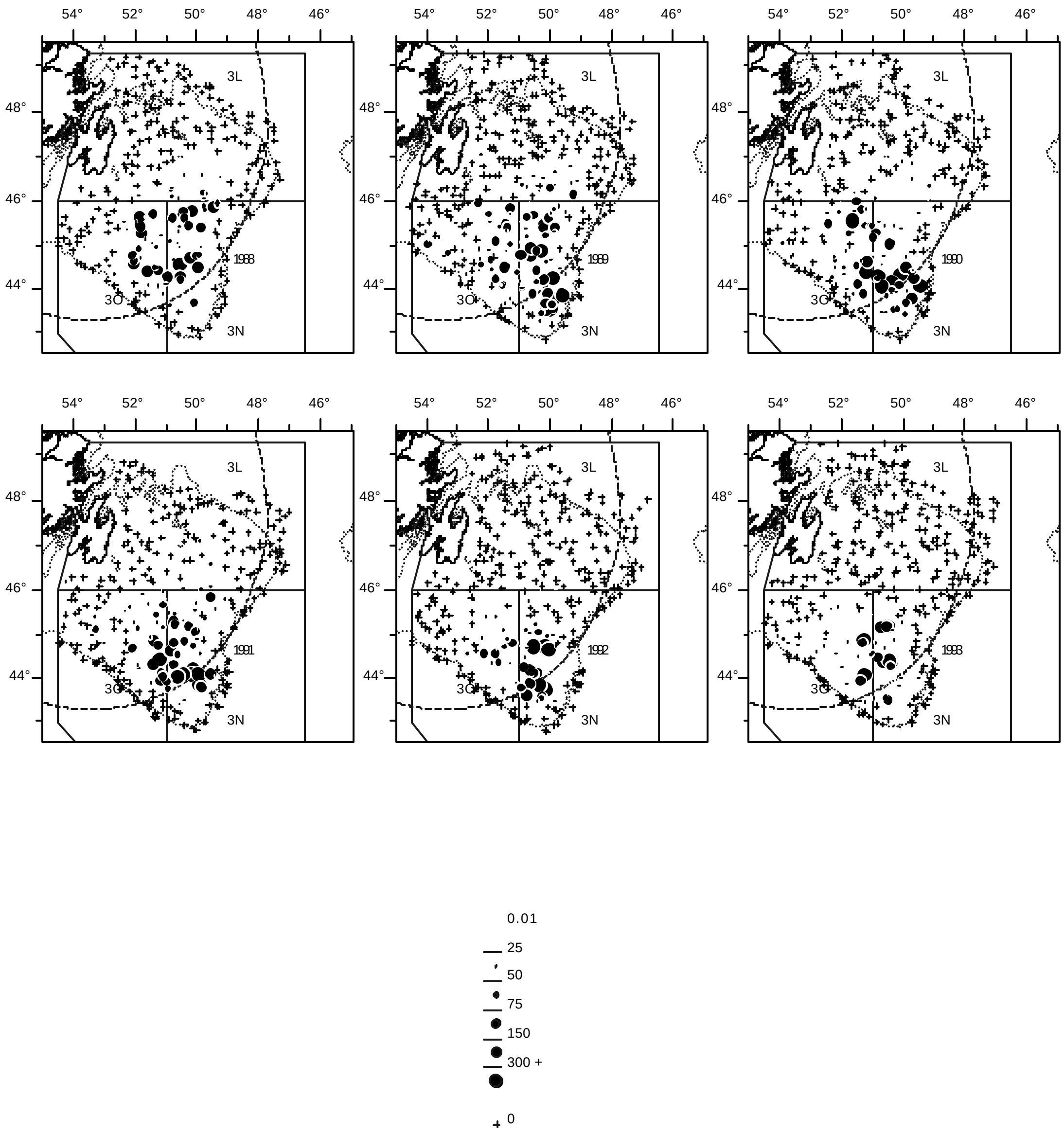


Figure 5. ACON plots of Yellowtail flounder catches from spring DFO research vessel surveys.



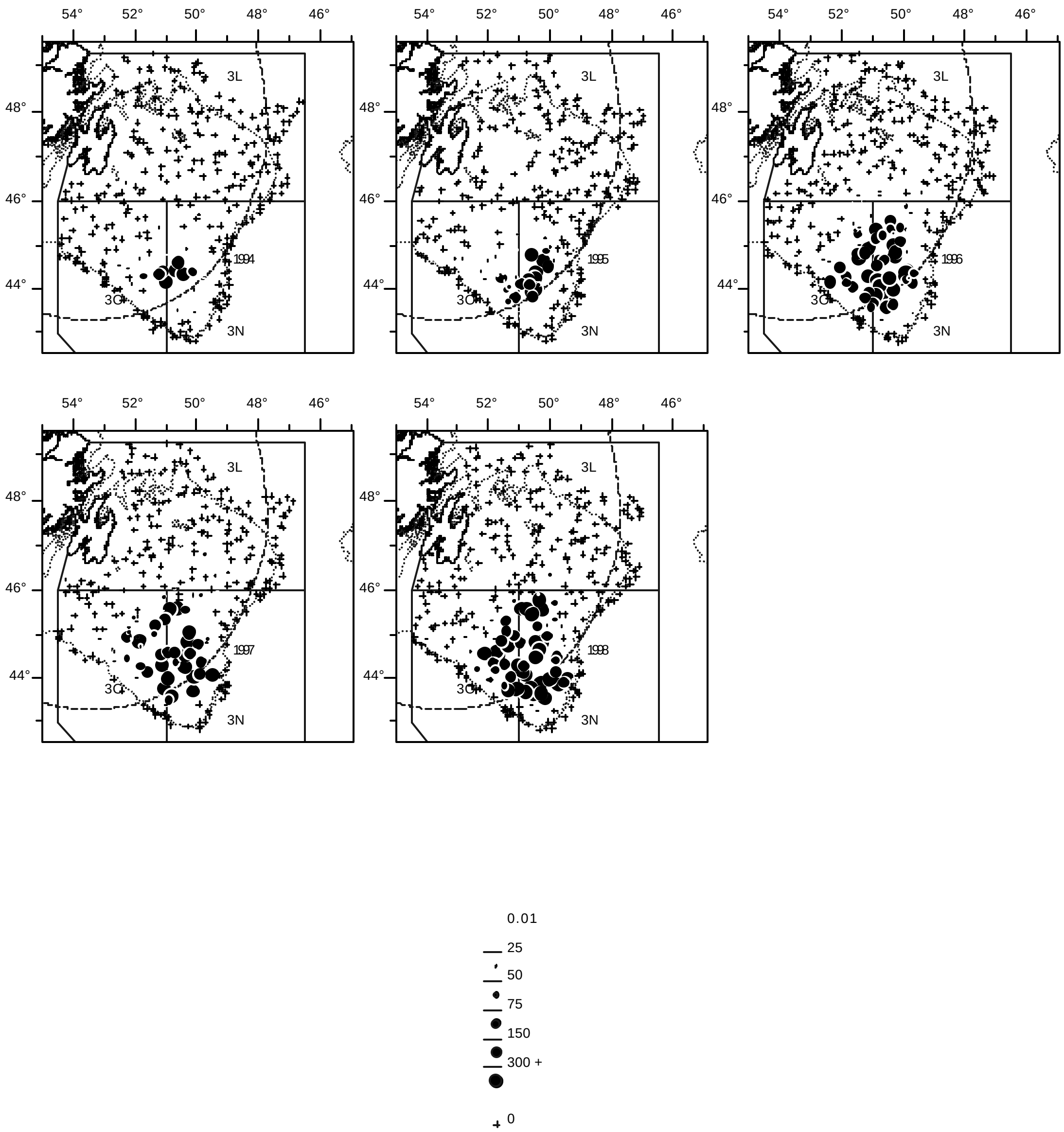
Distribution of Yellowtail Flounder (number per set) from DFO Spring surveys
conducted in Div. 3NOL in 1981-1987.

Fig. 5. Cont'd



Distribution of Yellowtail flounder (number per set) from DFO Spring surveys conducted in Div. 3NOL in 1988-1993.

Fig. 5. Cont'd



Distribution of Yellowtail flounder (number per set) from DFO Spring surveys conducted in Div. 3NOL in 1994-1998.

Fig. 5. Cont'd

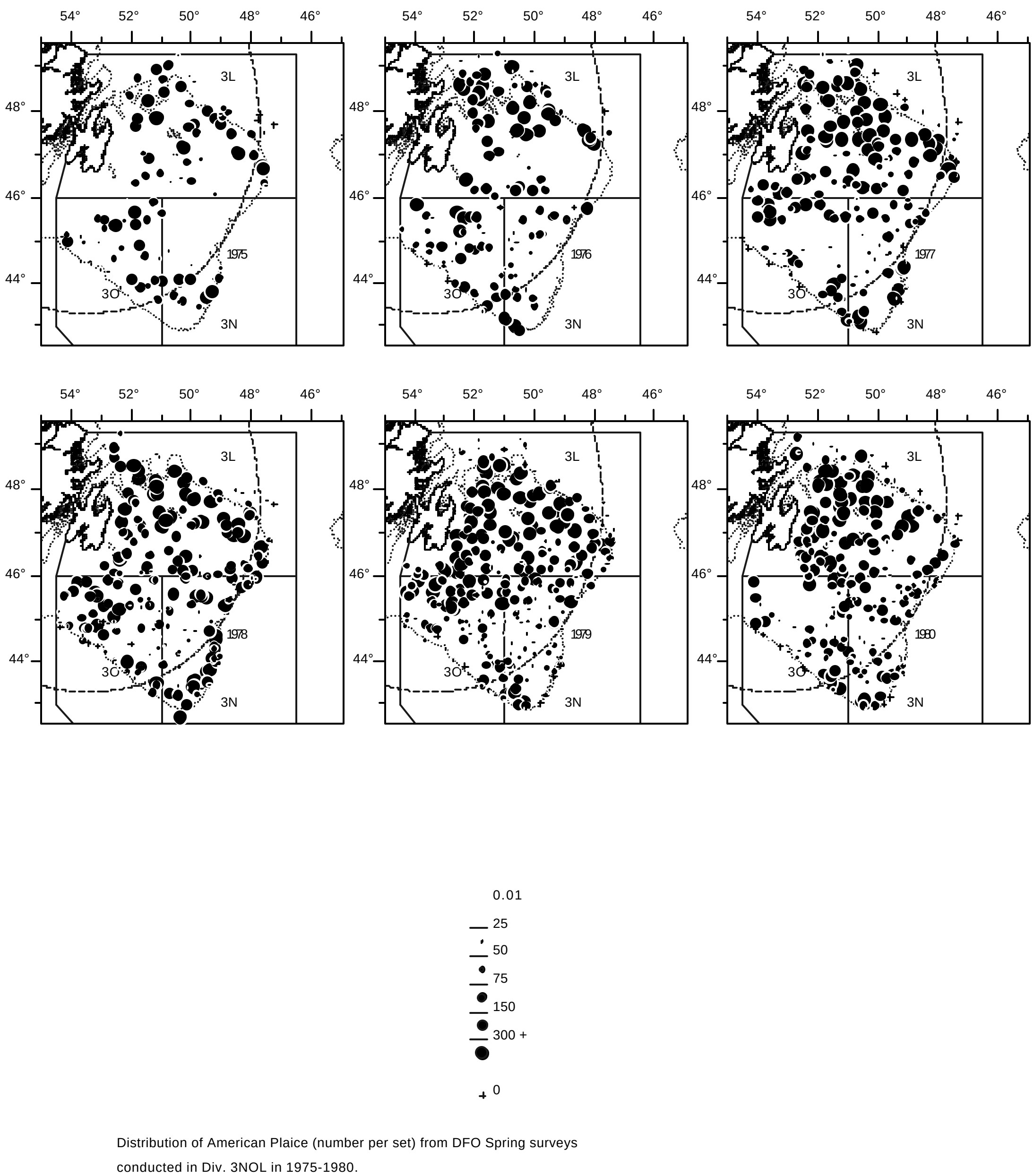
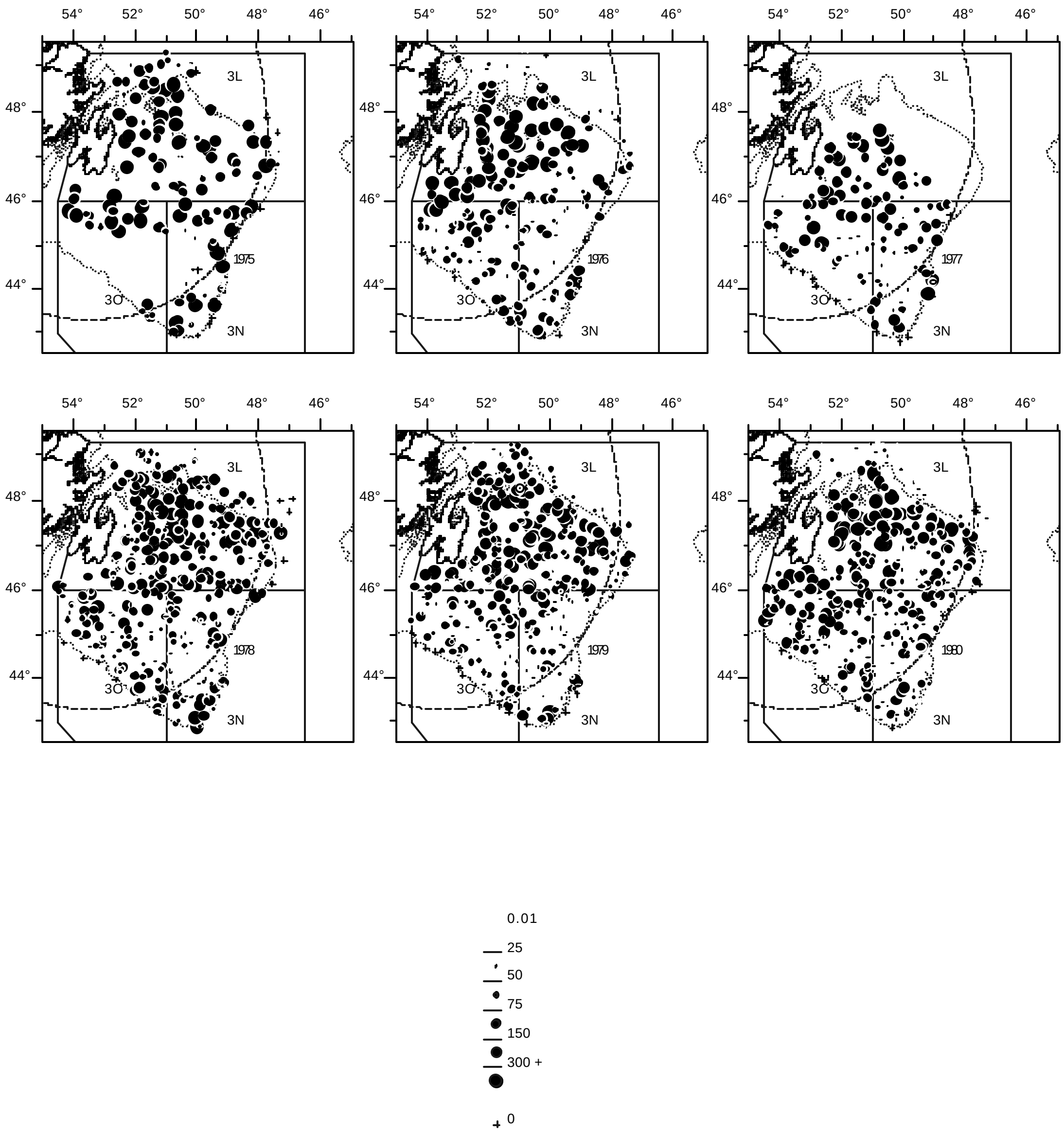
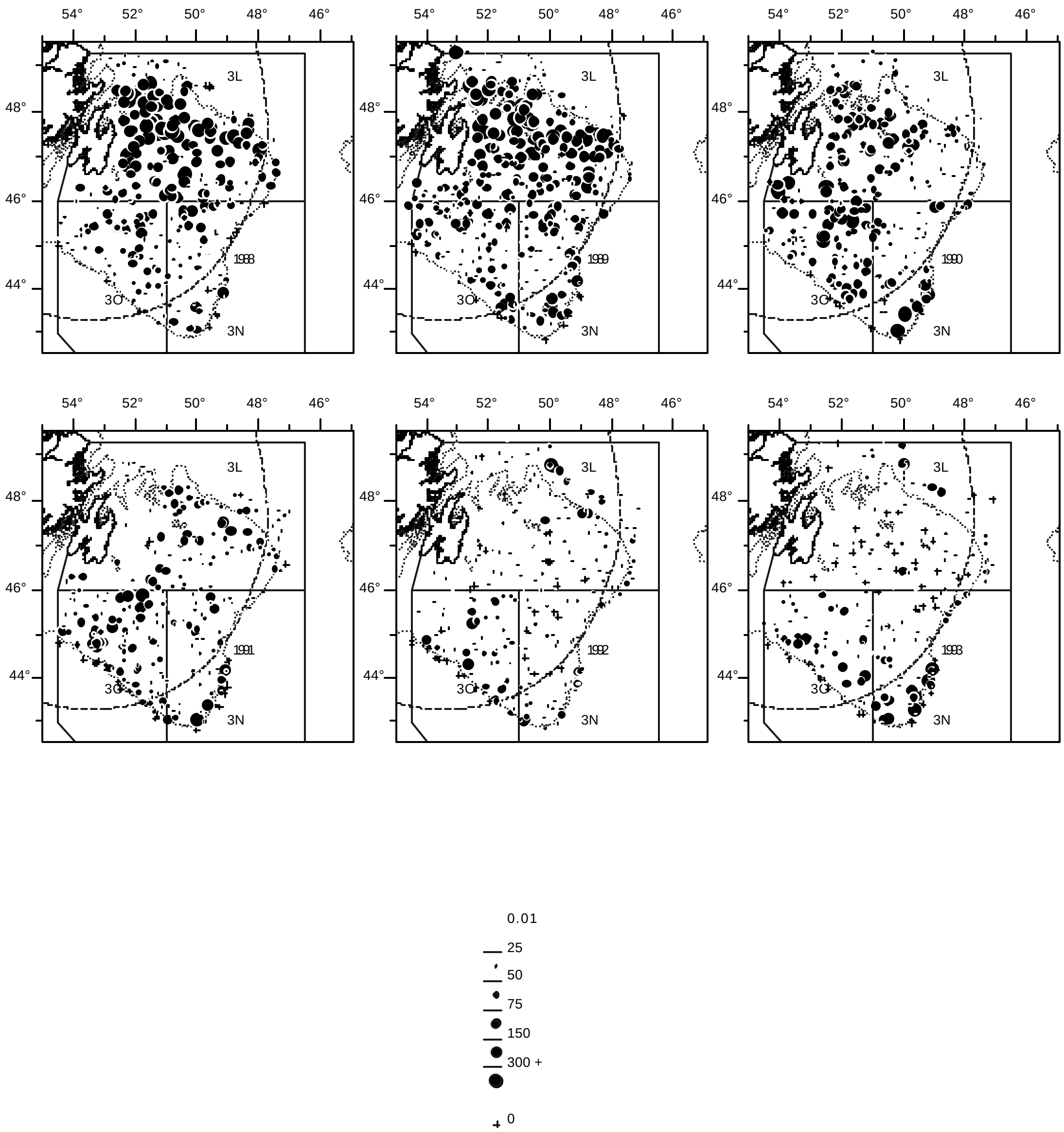


Figure 6. ACON plots of American Plaice catches from spring DFO research vessel surveys.



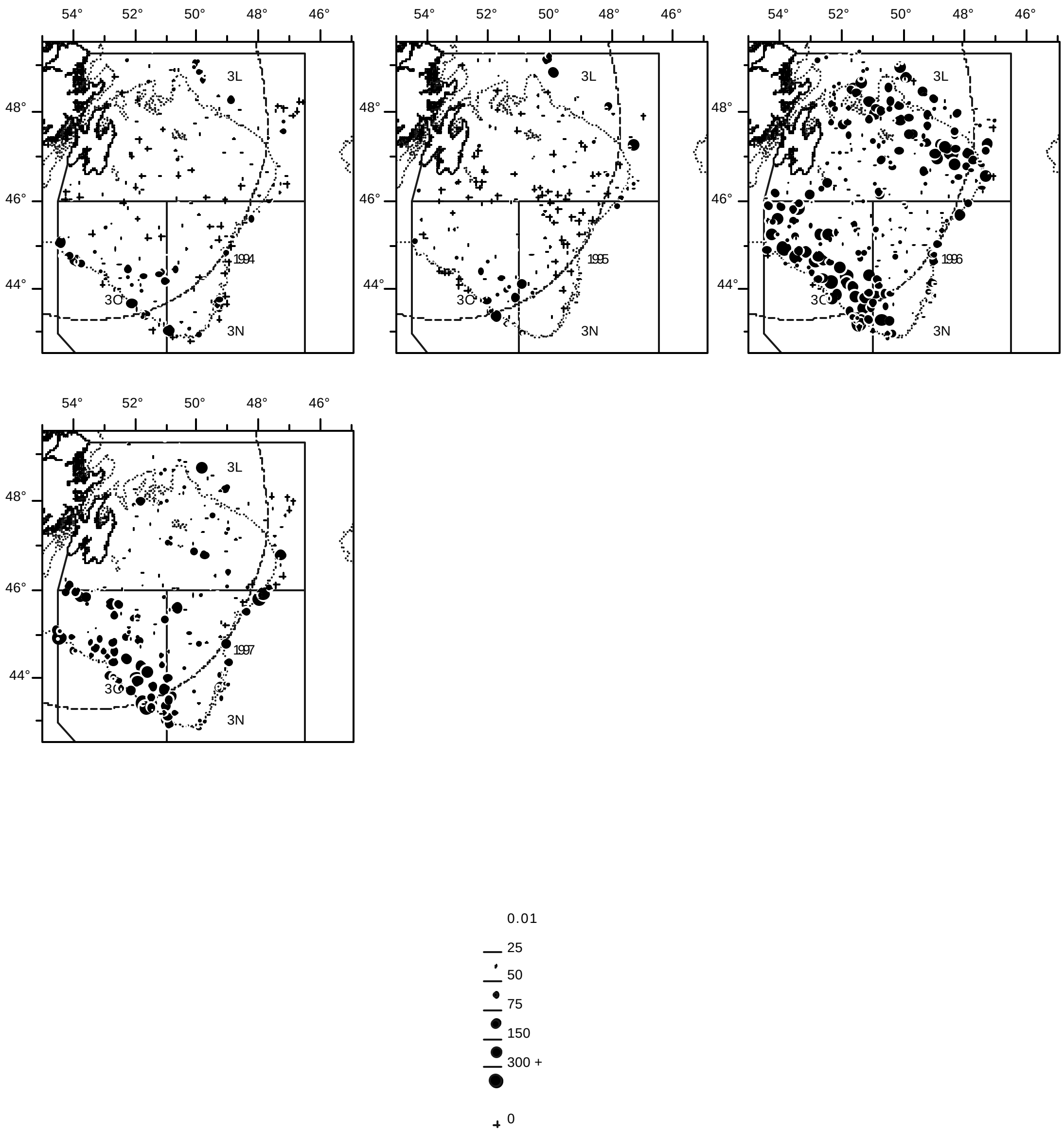
Distribution of American plaice (number per set) from DFO Spring surveys
conducted in Div. 3NOL in 1981-1987.

Fig. 6. Cont'd



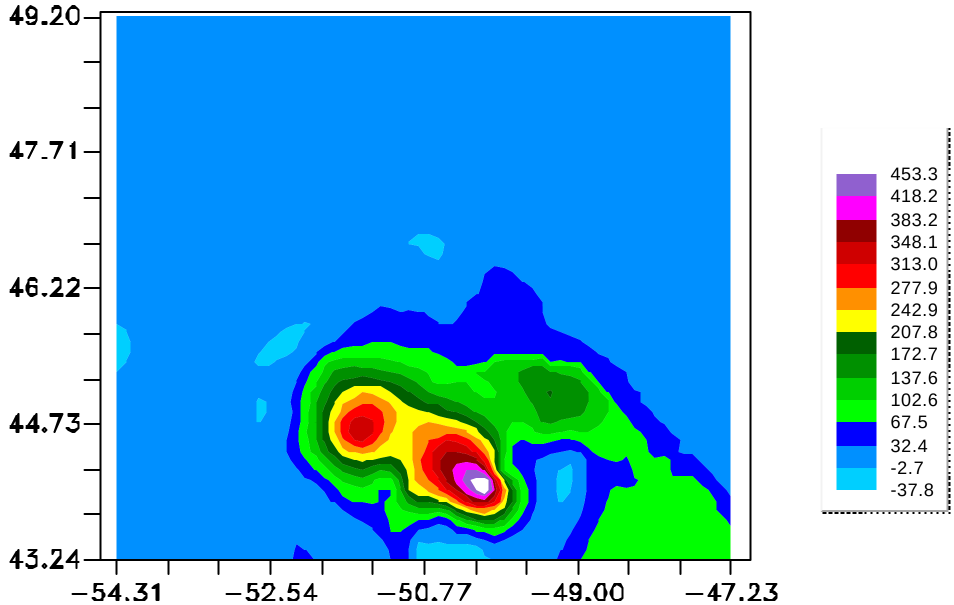
Distribution of American plaice (number per set) from DFO Spring surveys conducted in Div. 3NOL in 1988-1993.

Fig. 6. Cont'd

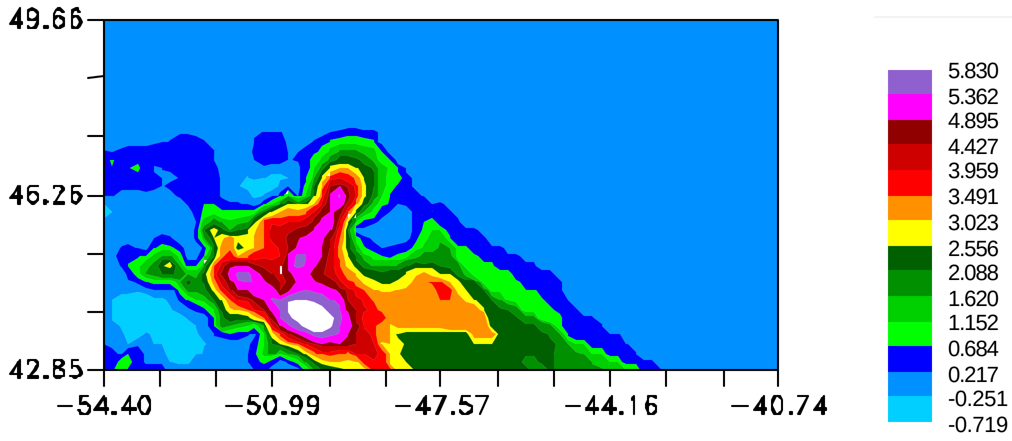


Distribution of American Plaice (number per set) from DFO Spring surveys conducted in Div. 3NOL in 1994-1997.

Fig. 6. Cont'd

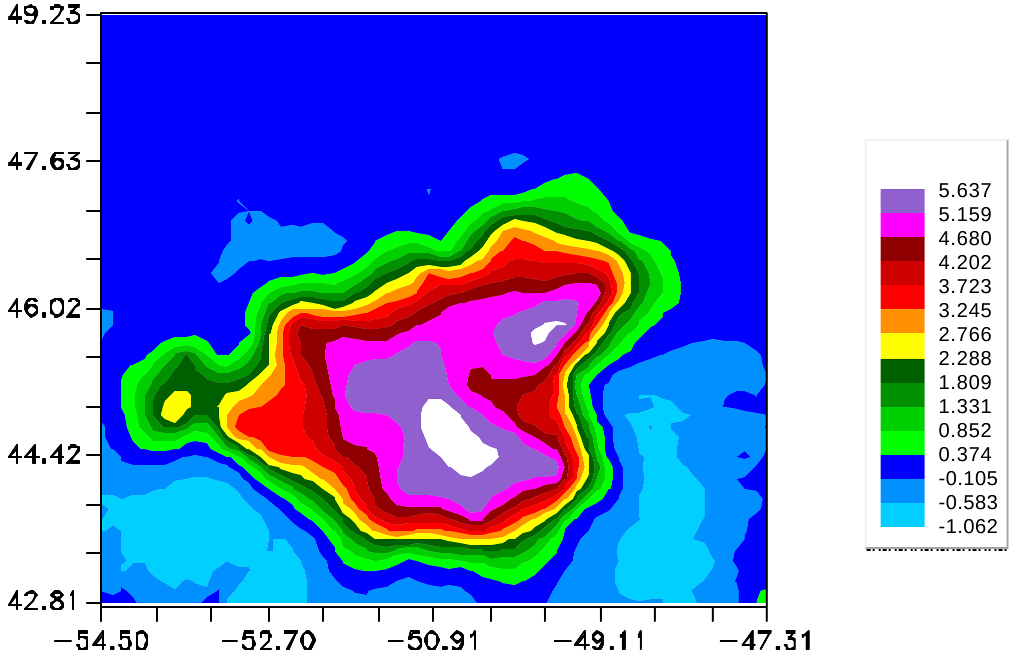


1975

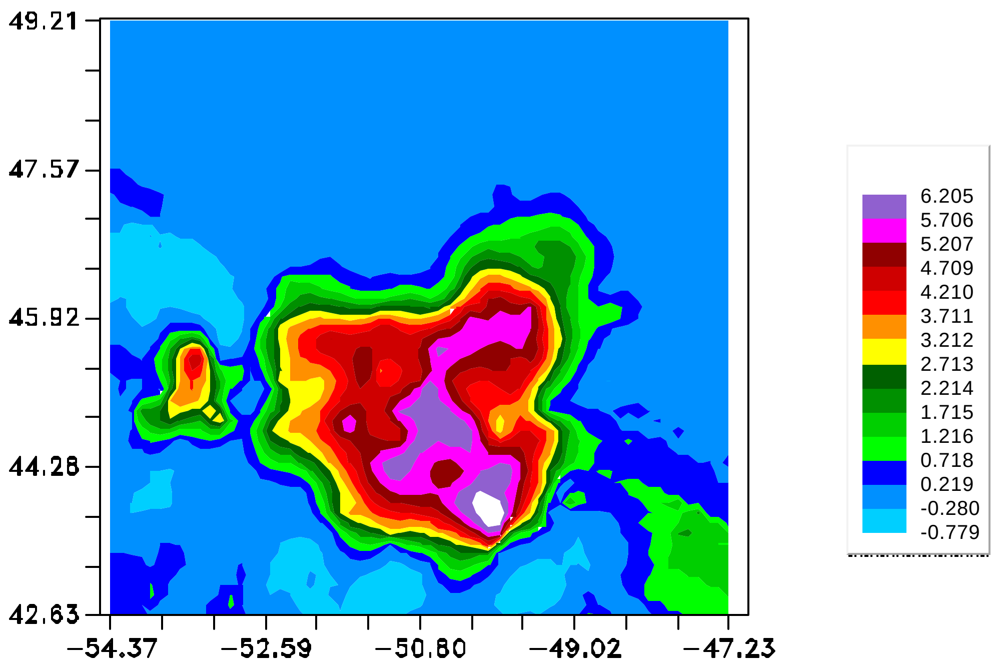


1976

Figure 7. Spatial distribution of kriged estimates (Z) for Yellowtail flounder derived from DFO spring research vessel surveys.

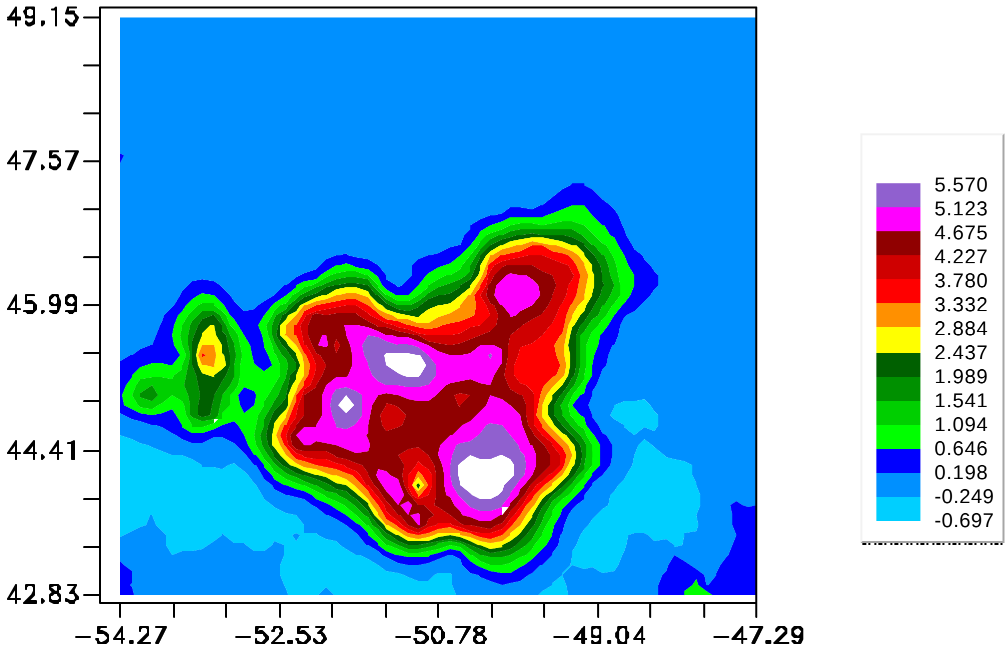


1977



1978

Fig. 7. Cont'd



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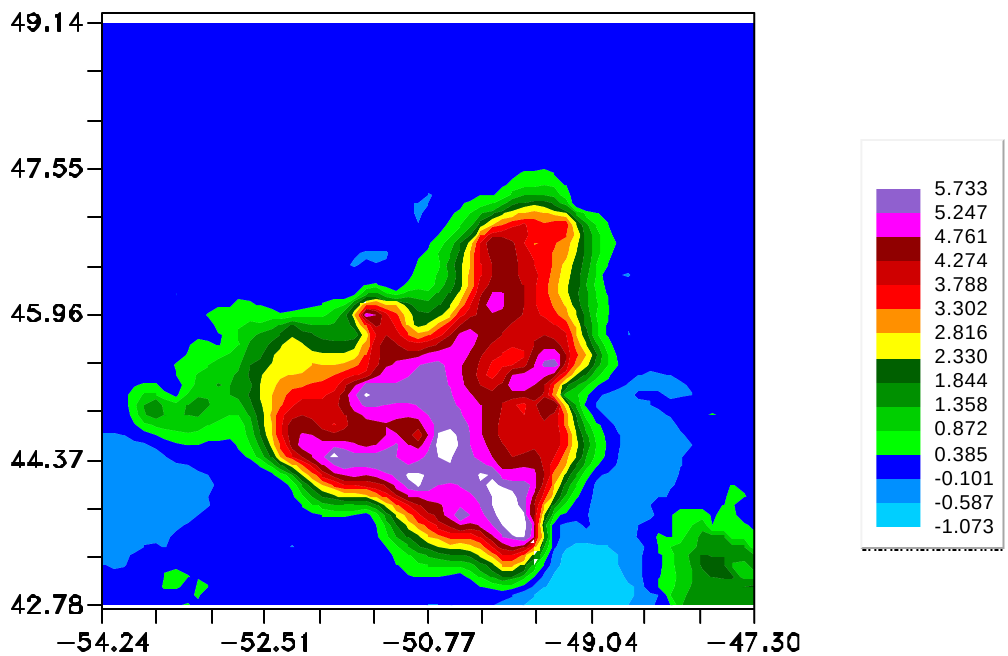
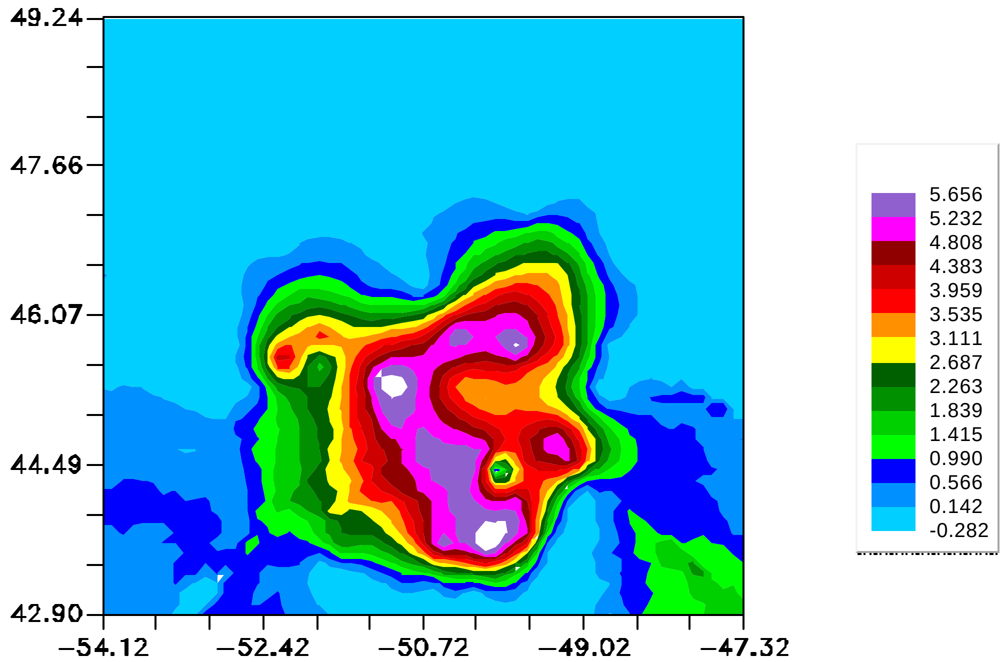
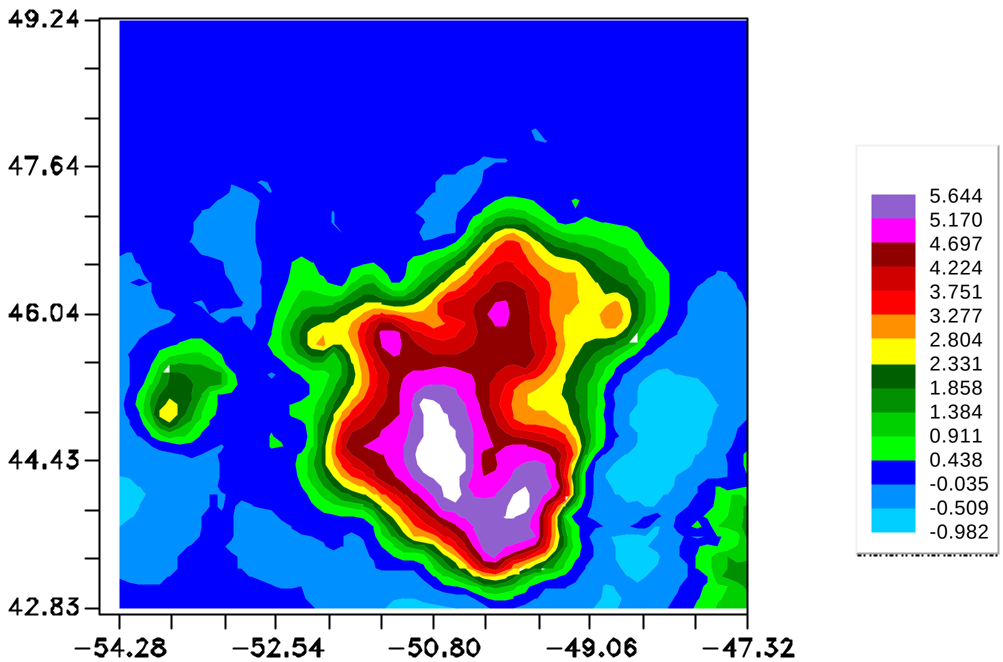


1980

Fig. 7. Cont'd



1981



1982

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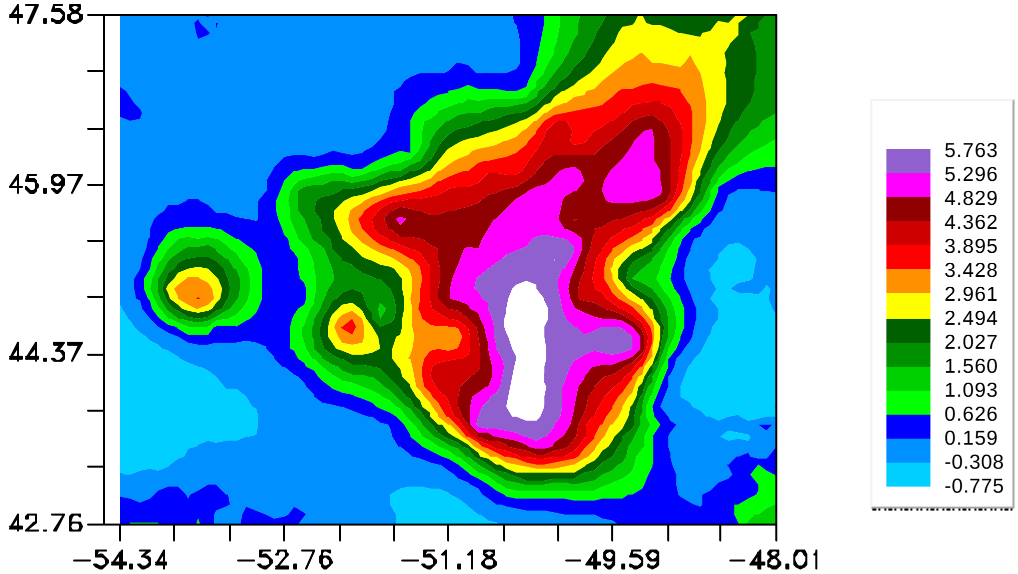

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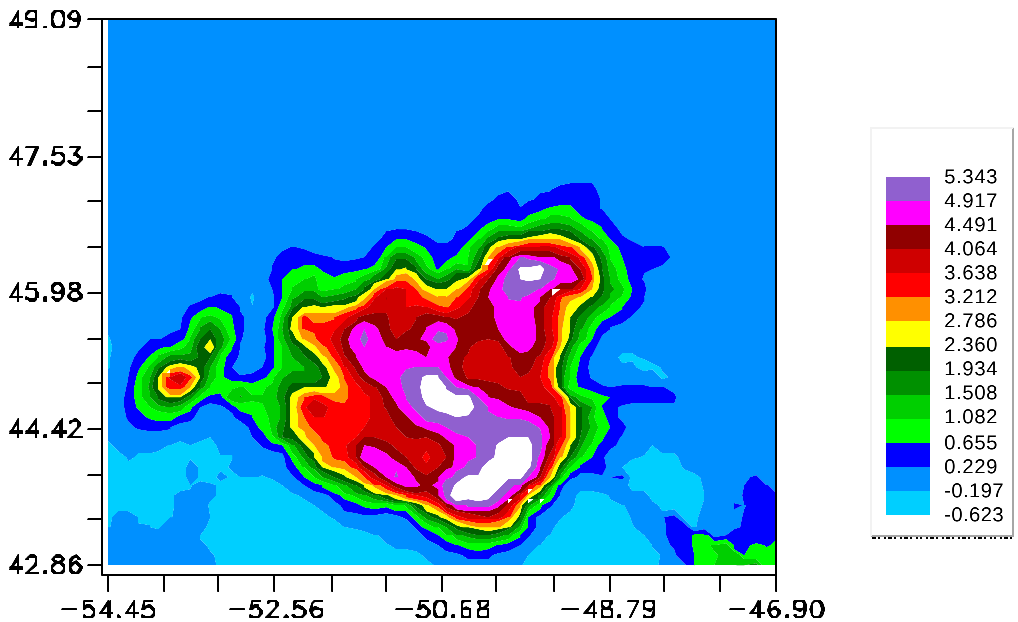

1985

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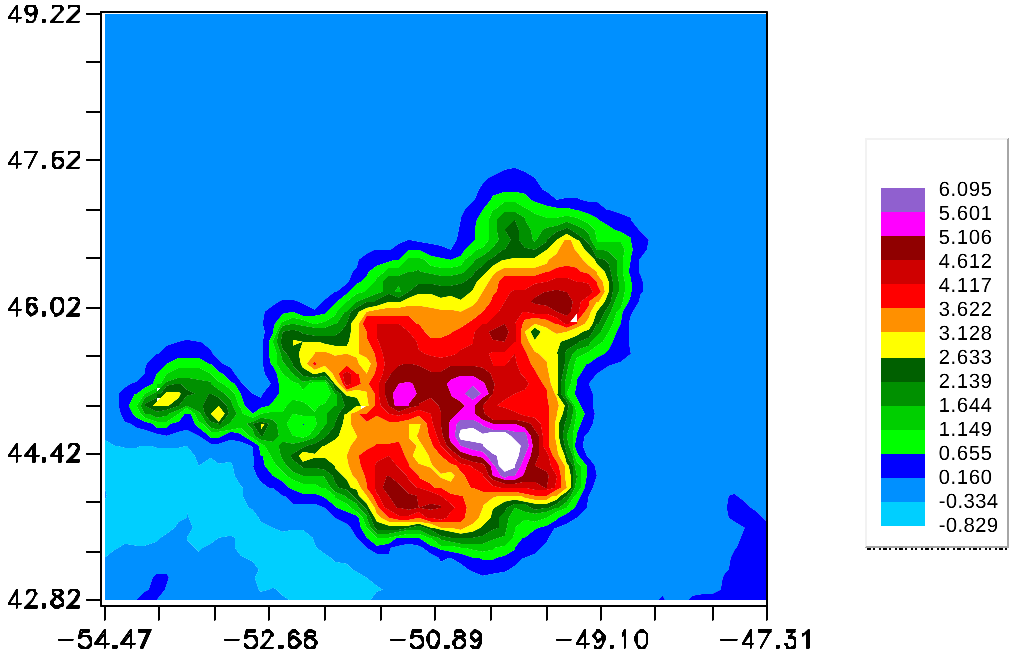
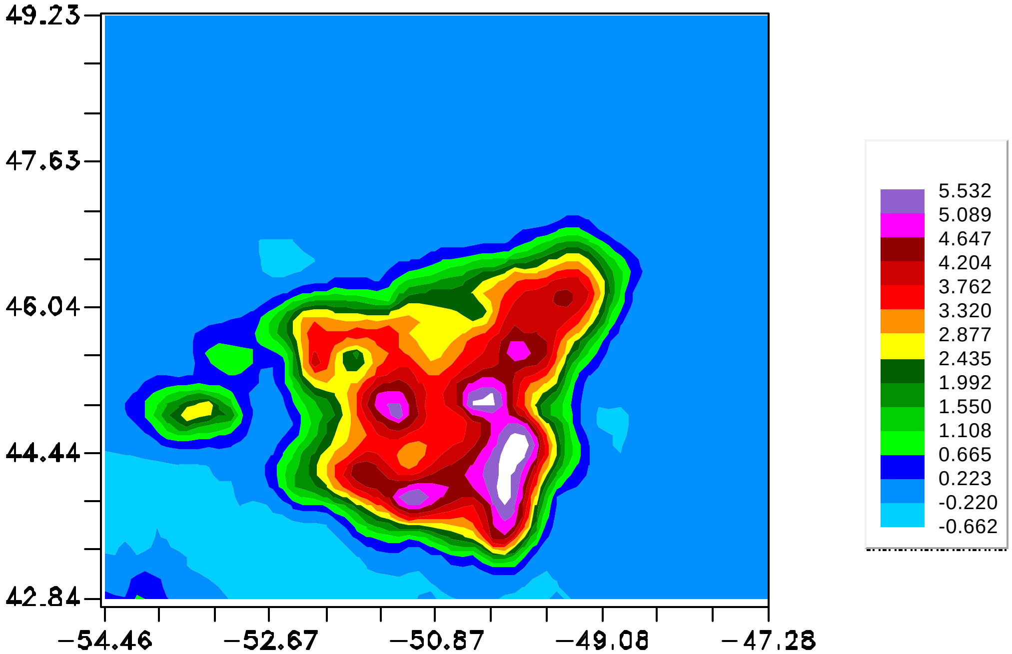


1986



1987

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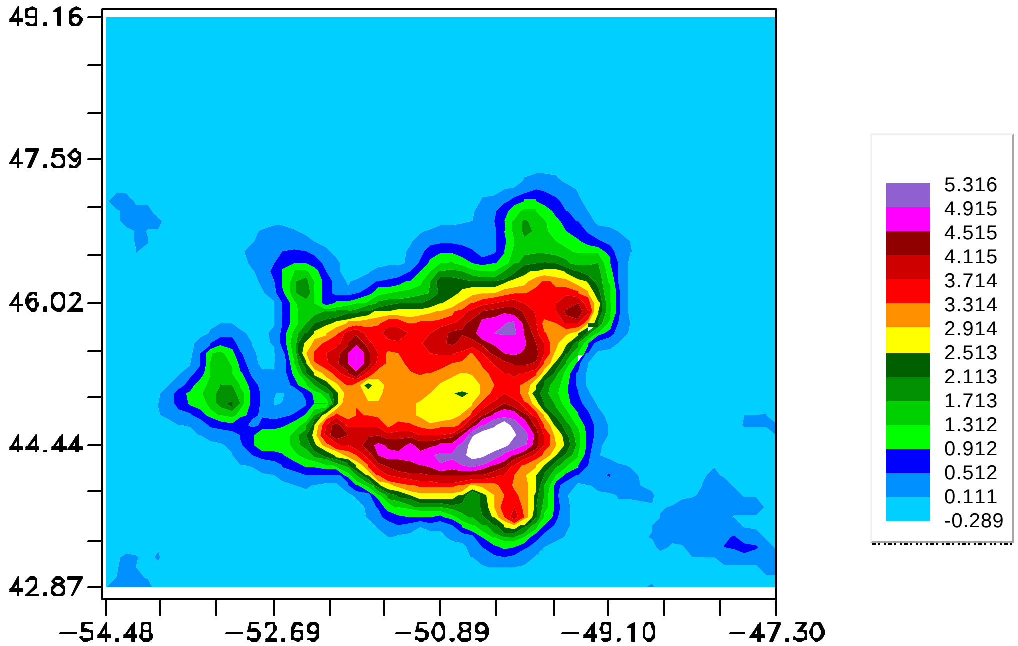
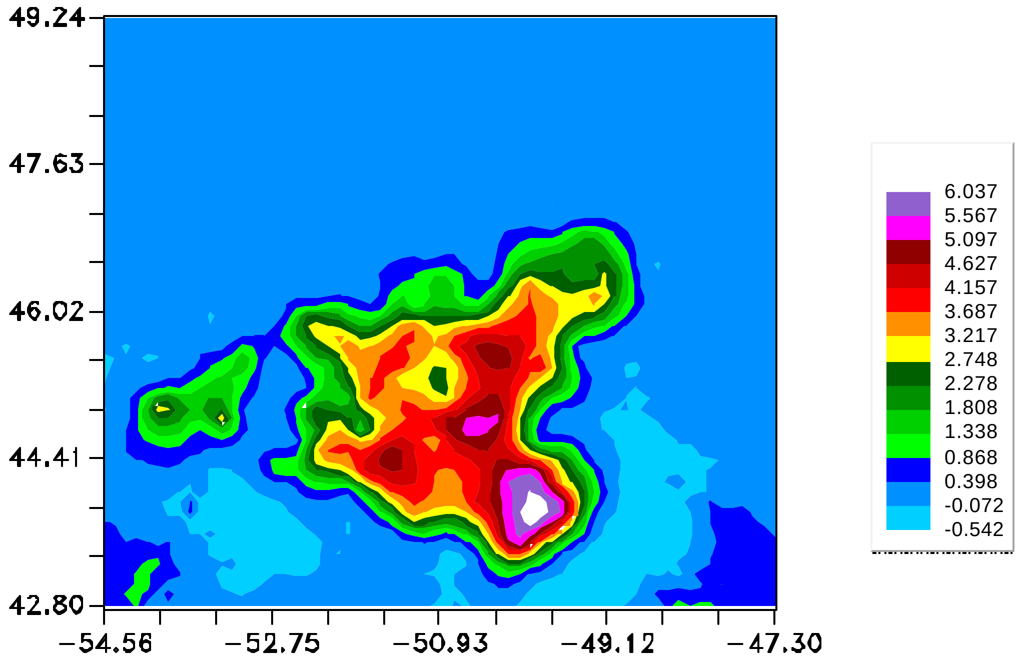
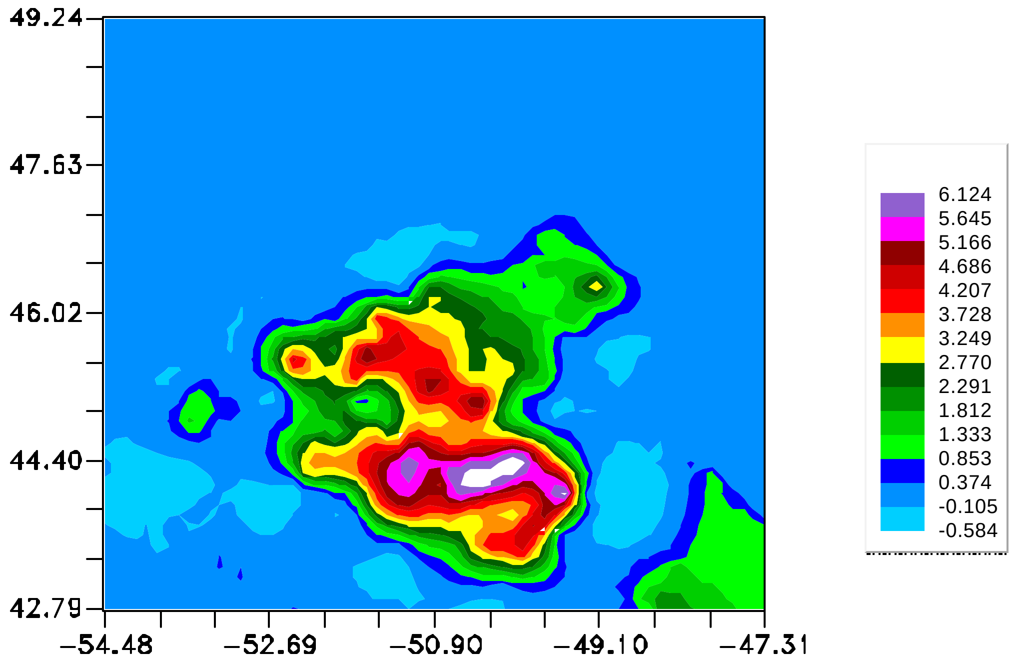


1988

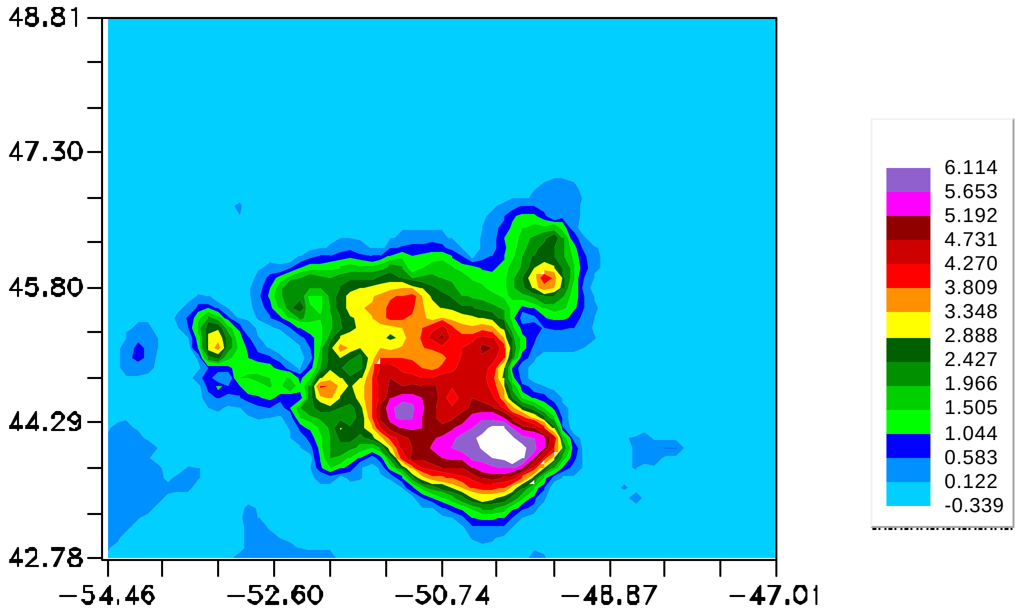


1989

Fig. 7. Cont'd



1990



1991

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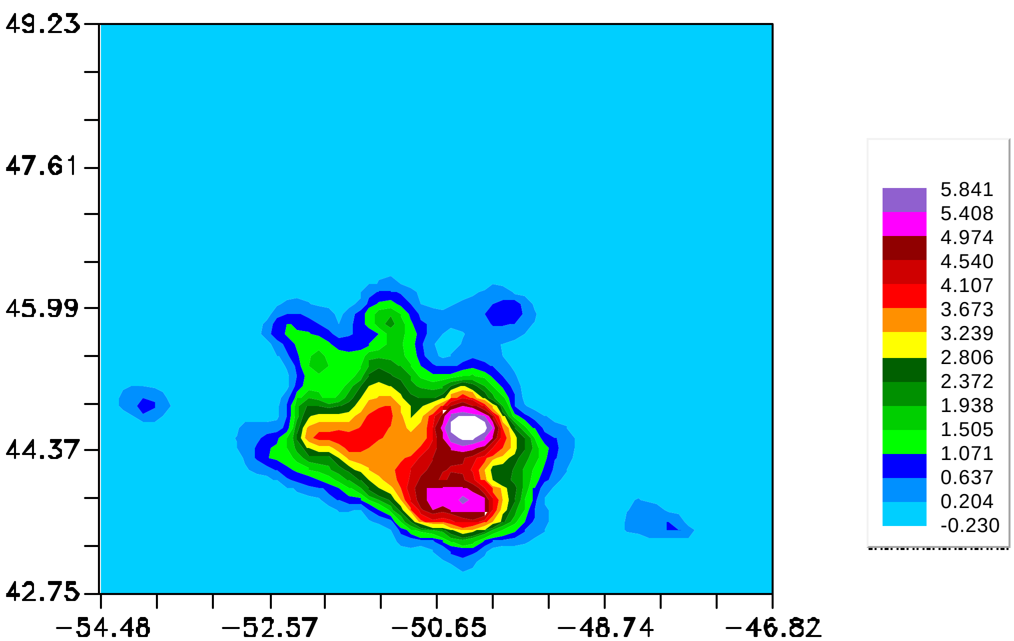
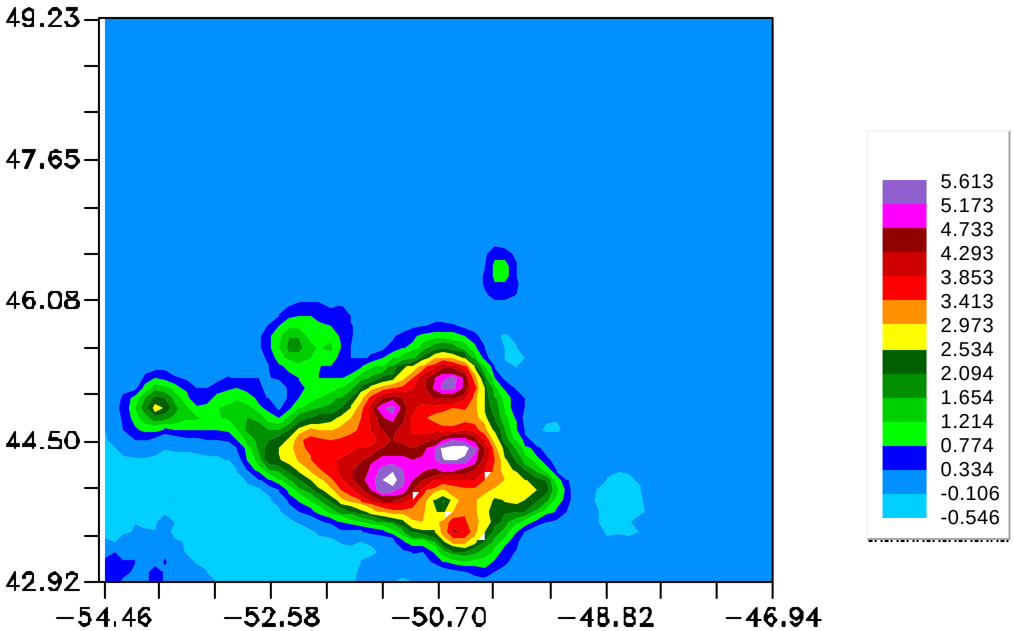


1992



1993

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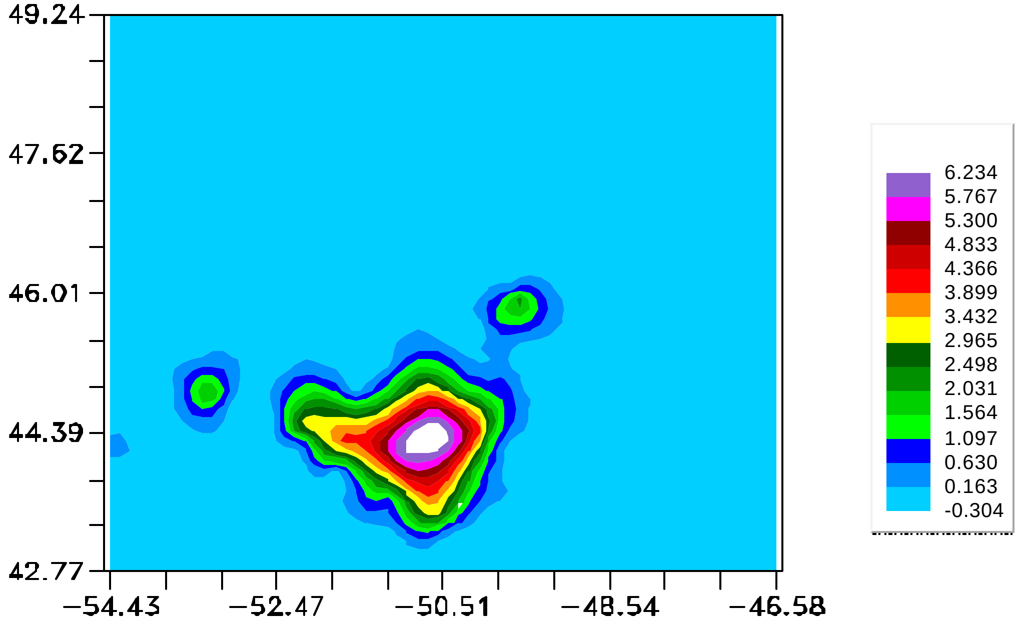
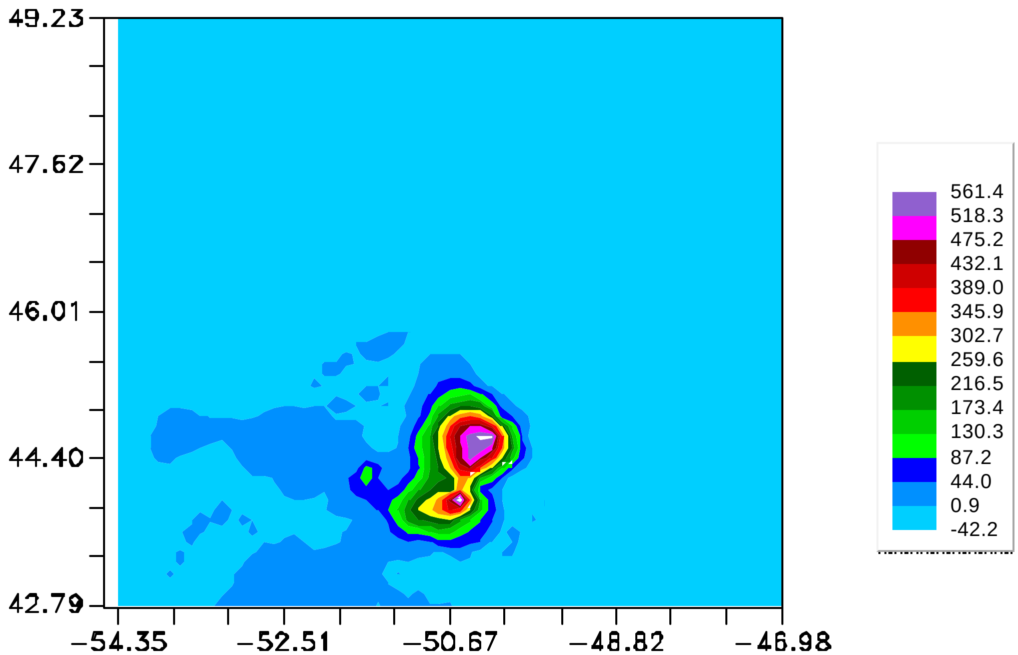


1994



1995

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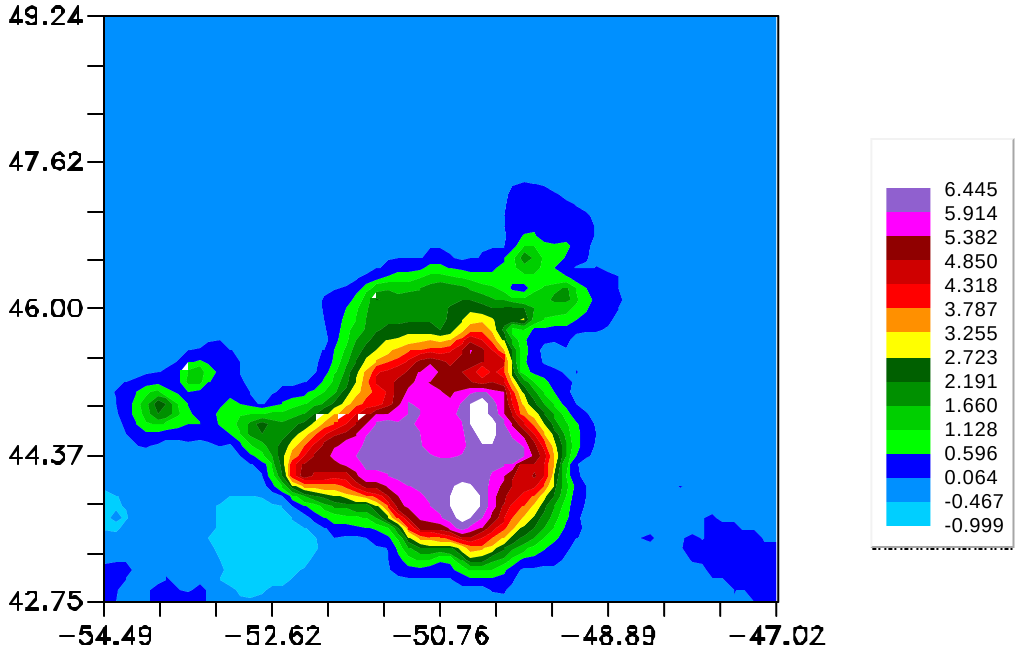

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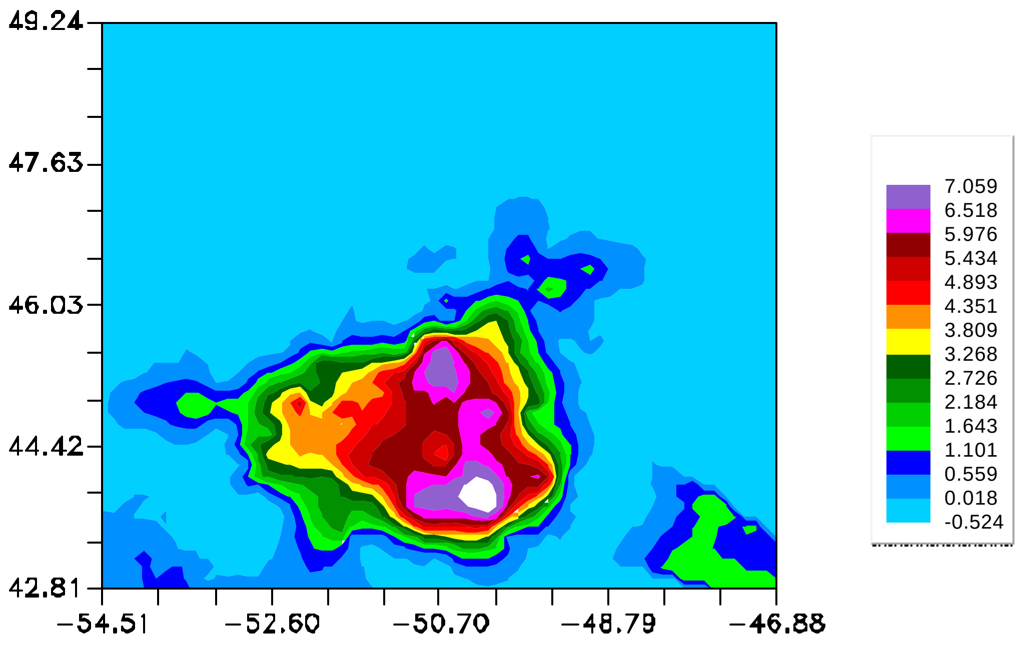

1997

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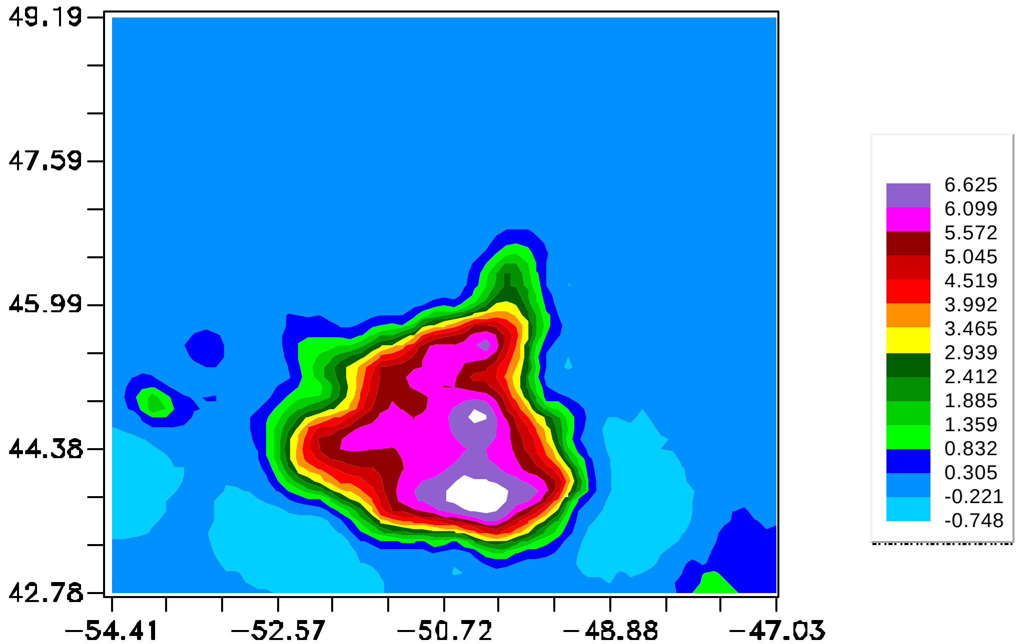
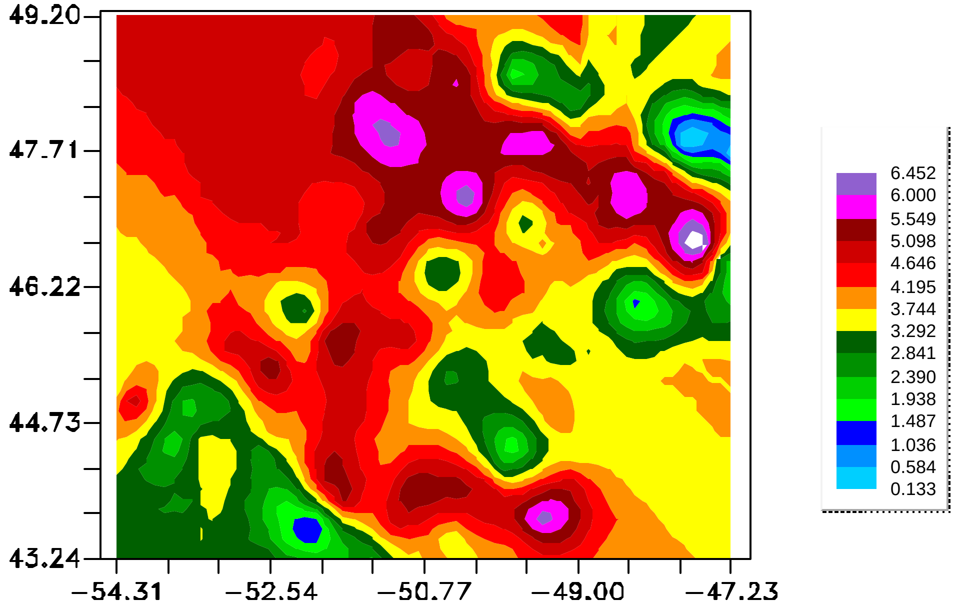


1998

Fig. 7. Cont'd

1975



1976

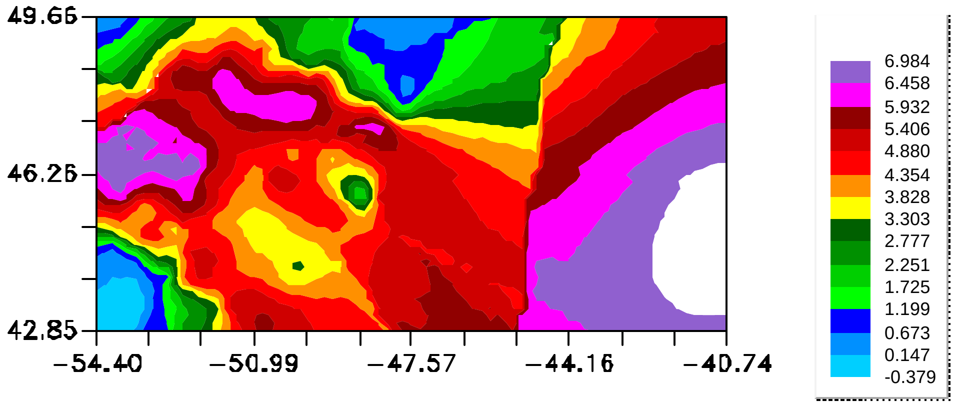
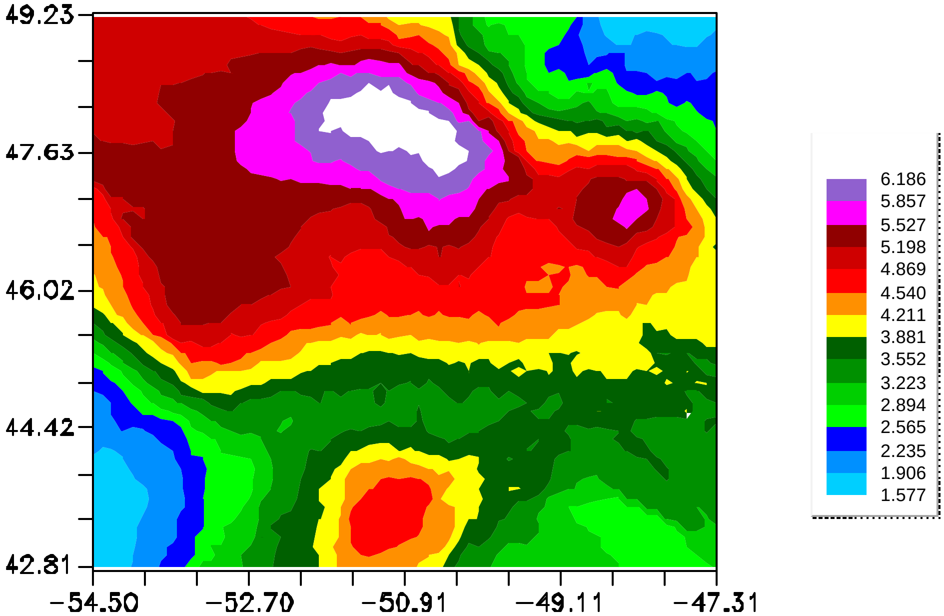
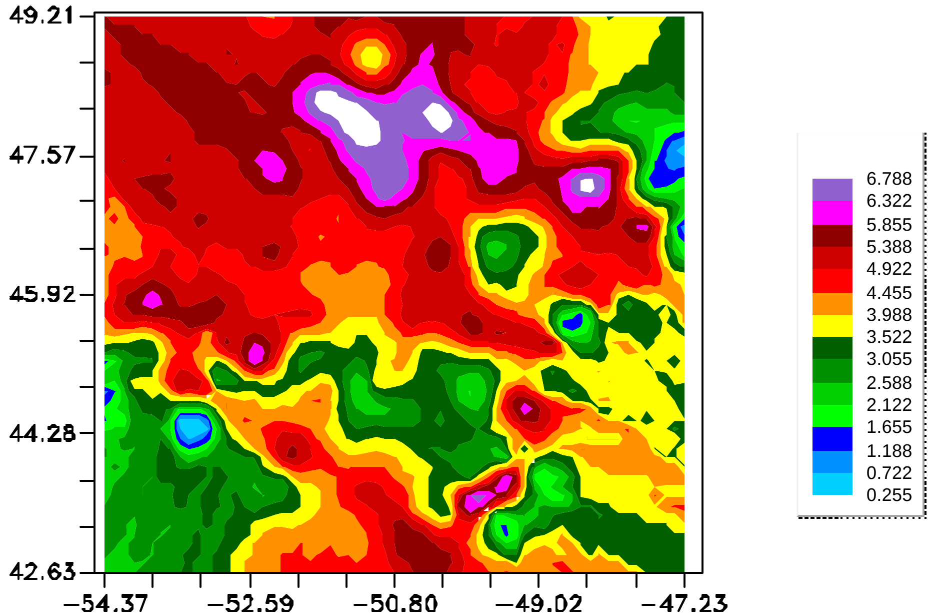


Figure 8. Spatial distribution of kriged estimates (Z) for American Plaice derived from DFO spring research vessel surveys.

1977



1978



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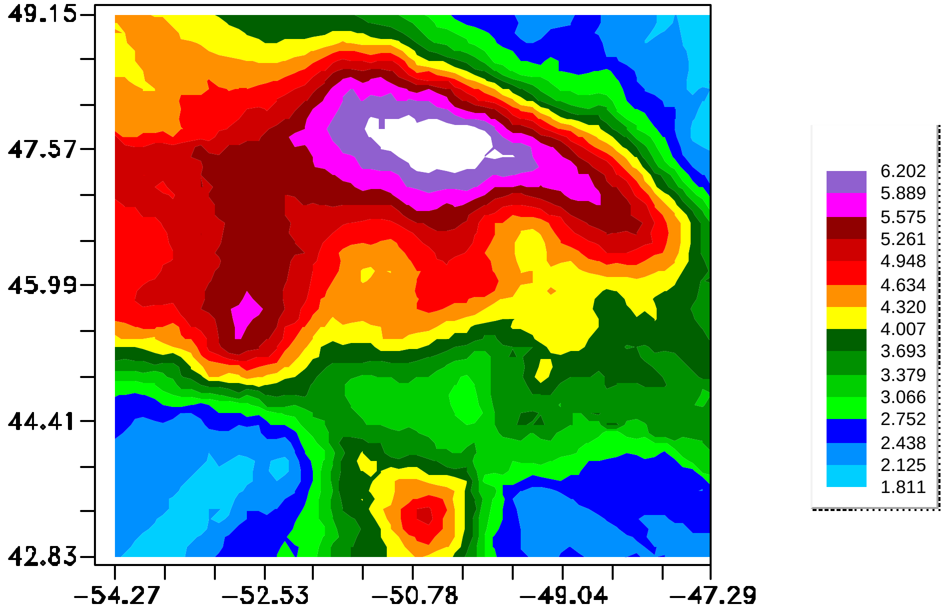
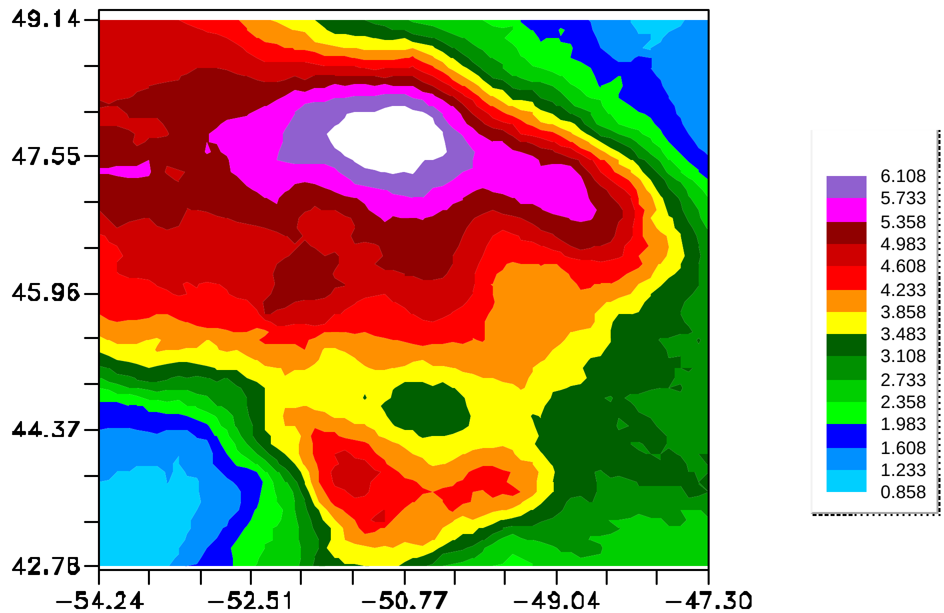
1979



1980



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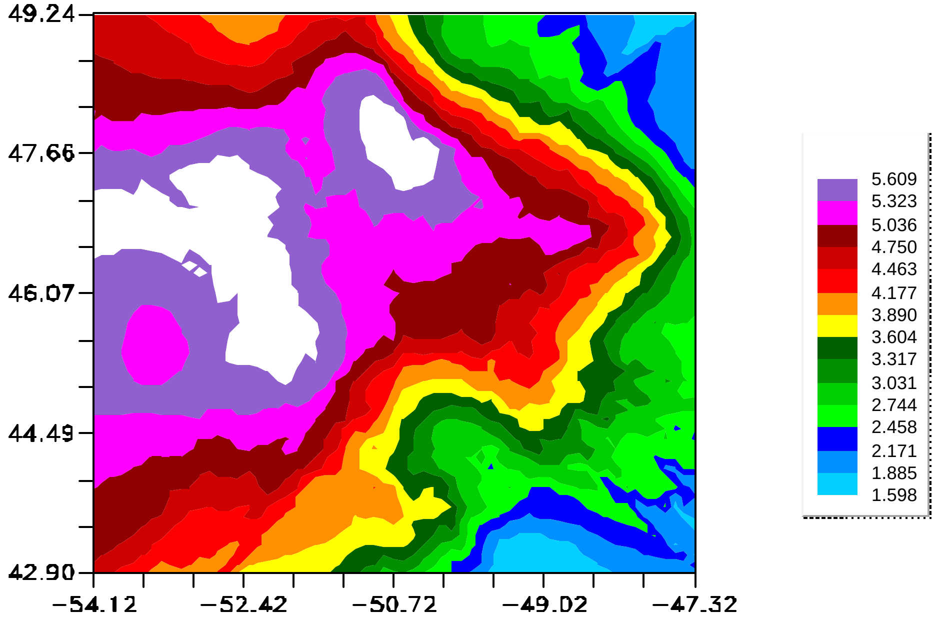
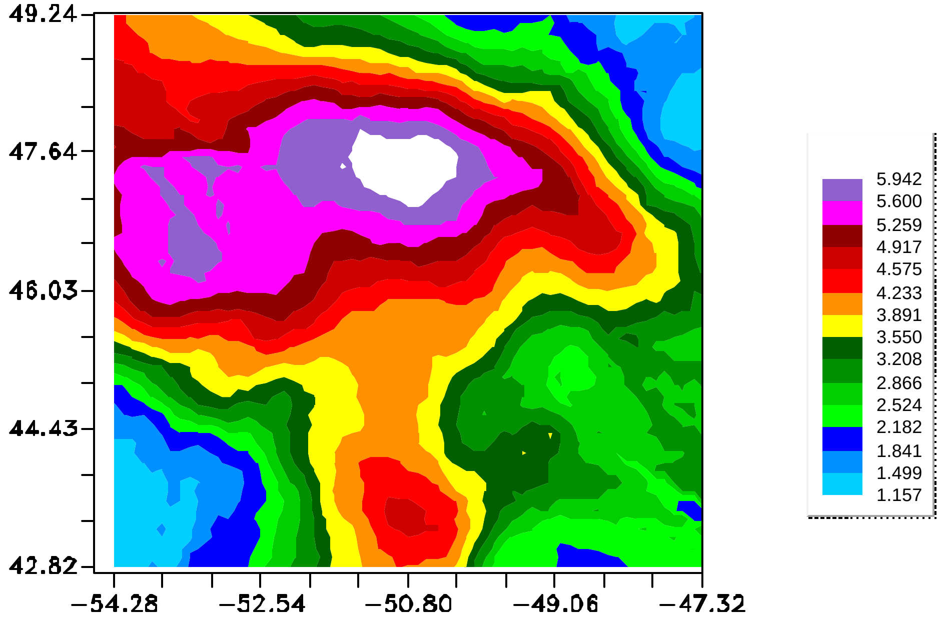
1981



1982



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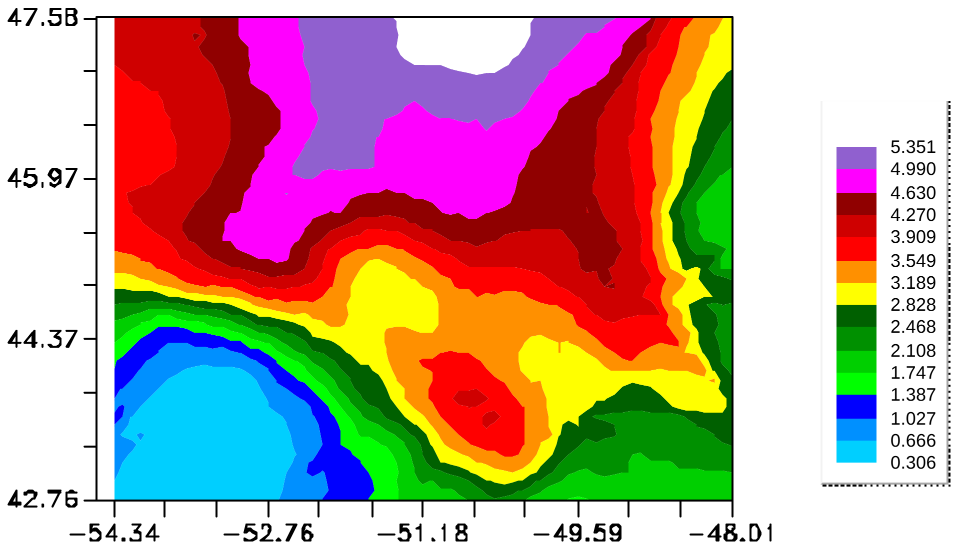

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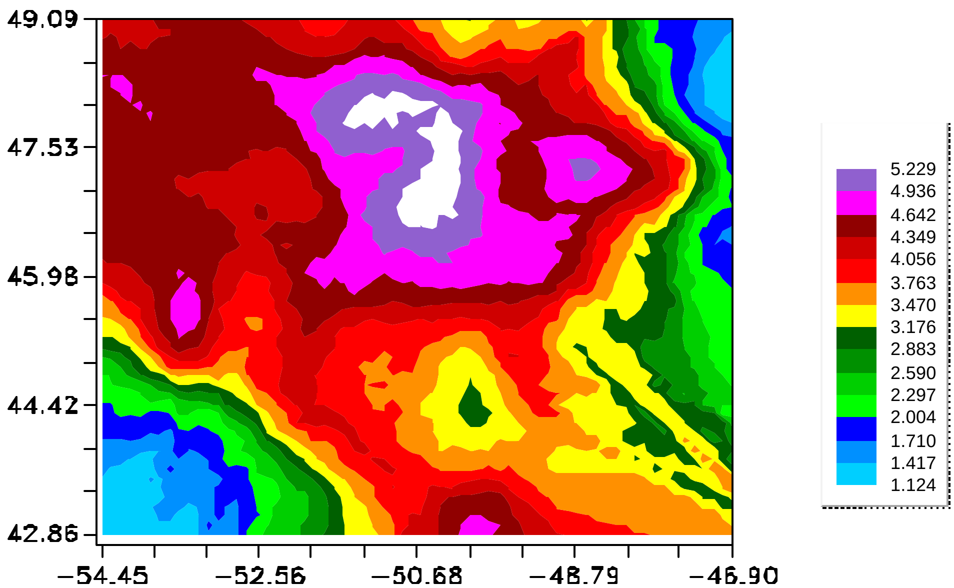

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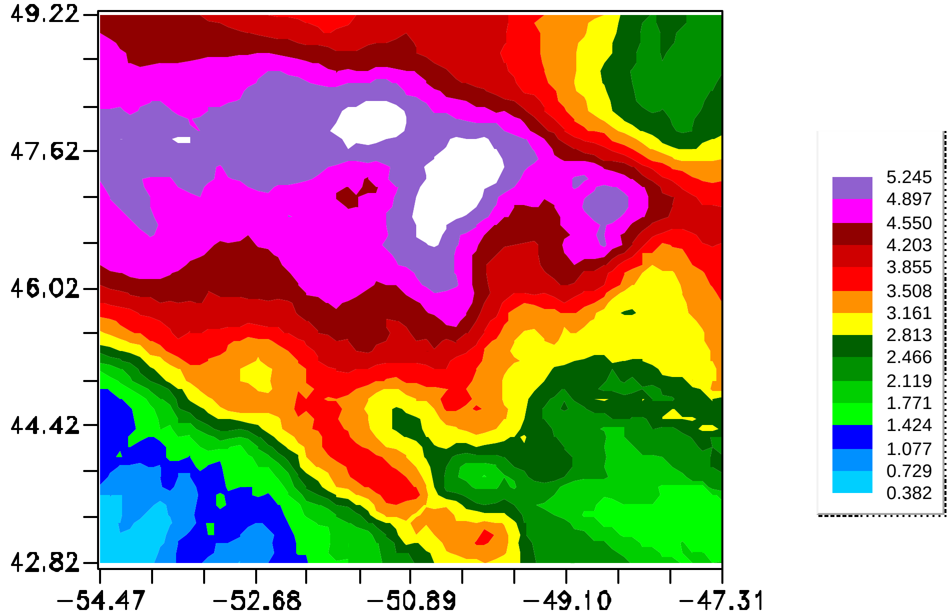


1987

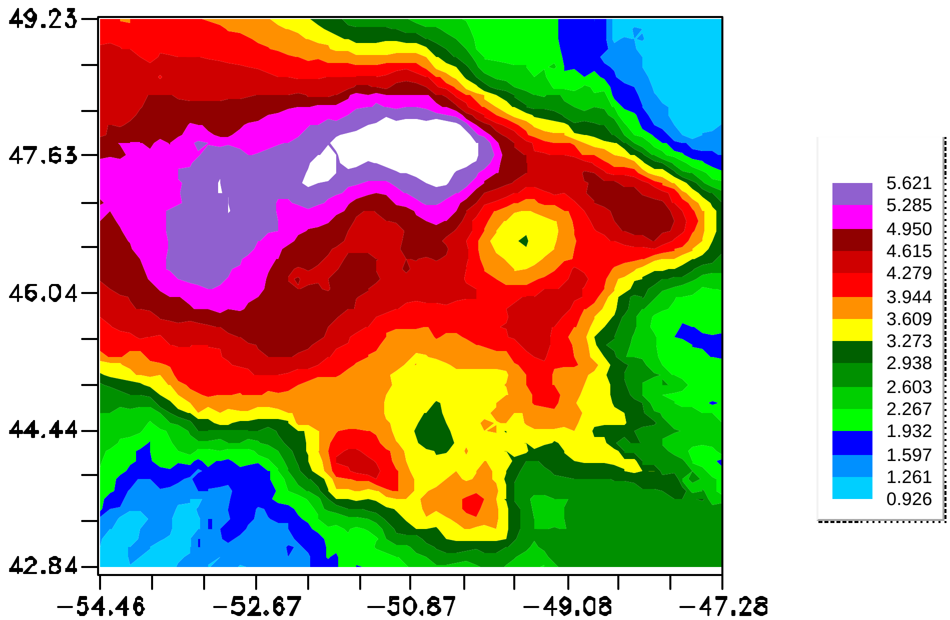
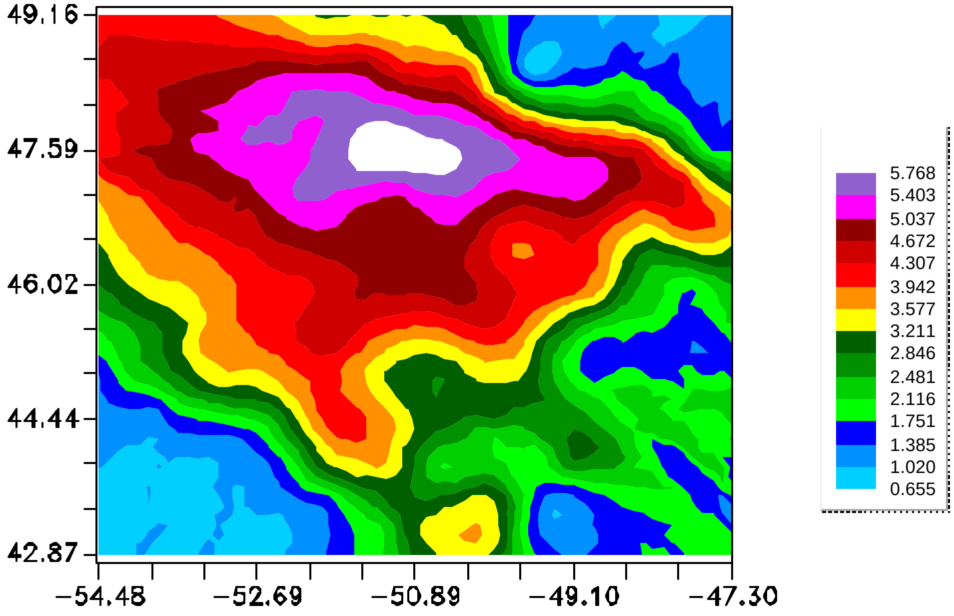
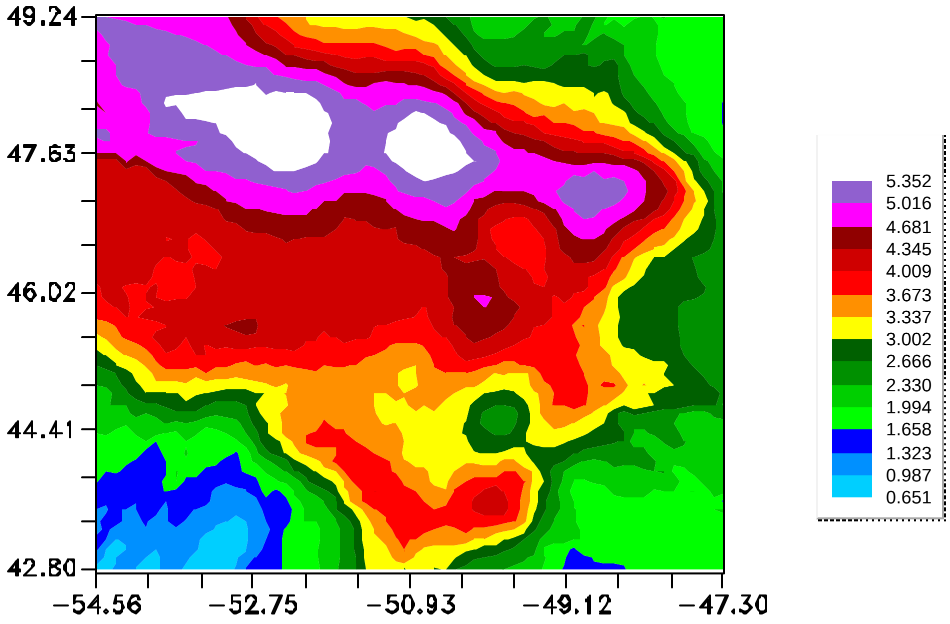


Fig. 8. Cont'd

1988



1989



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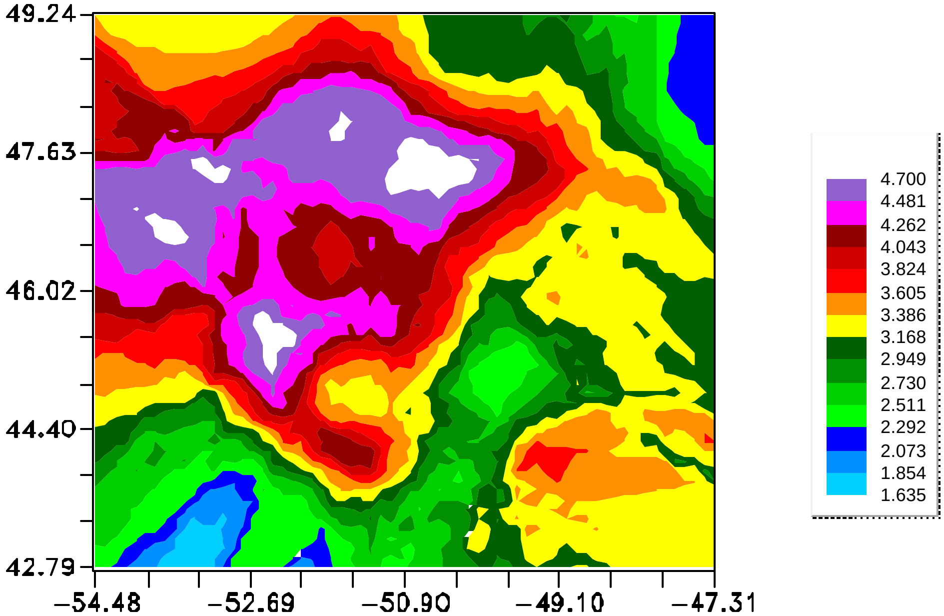
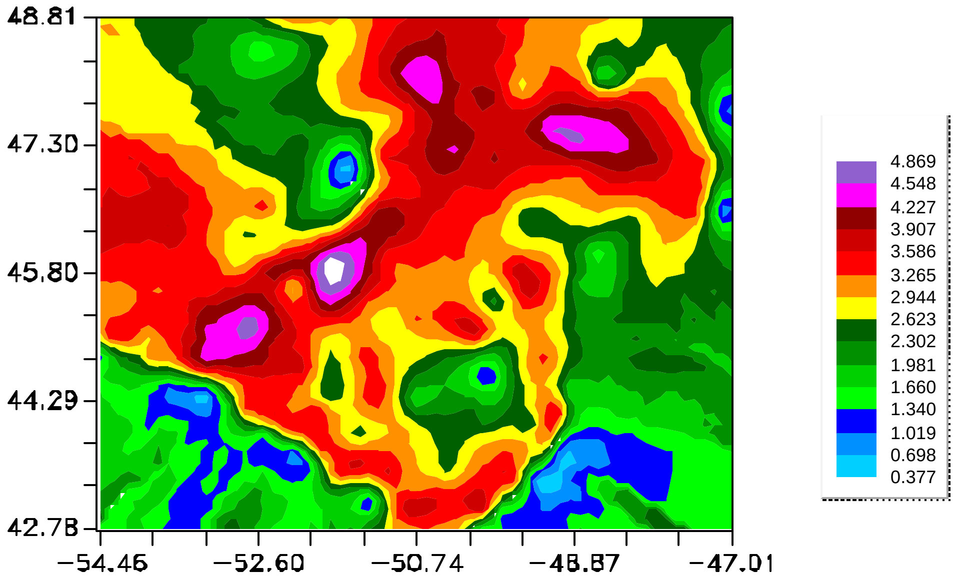
1990



1991



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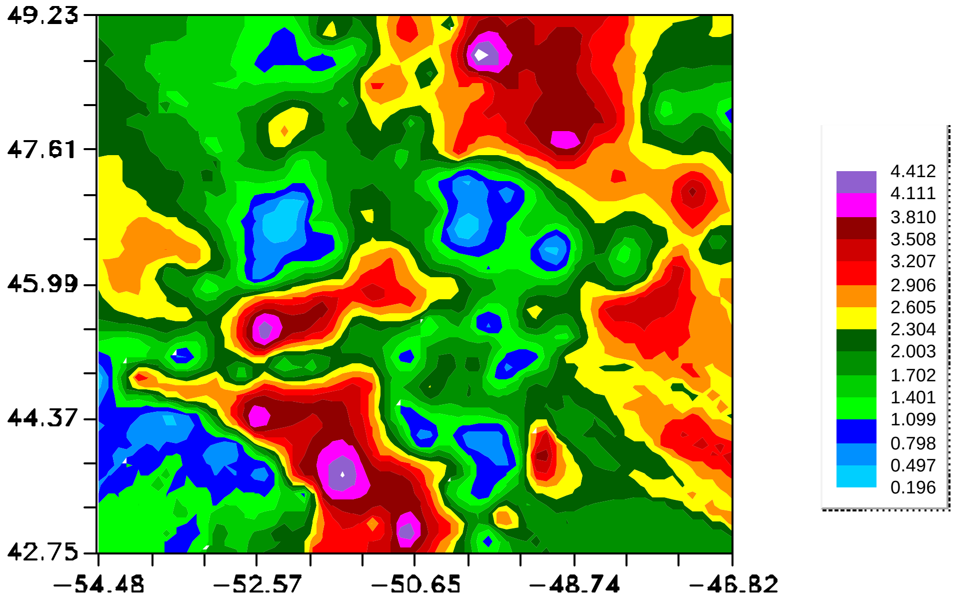
1992



1993

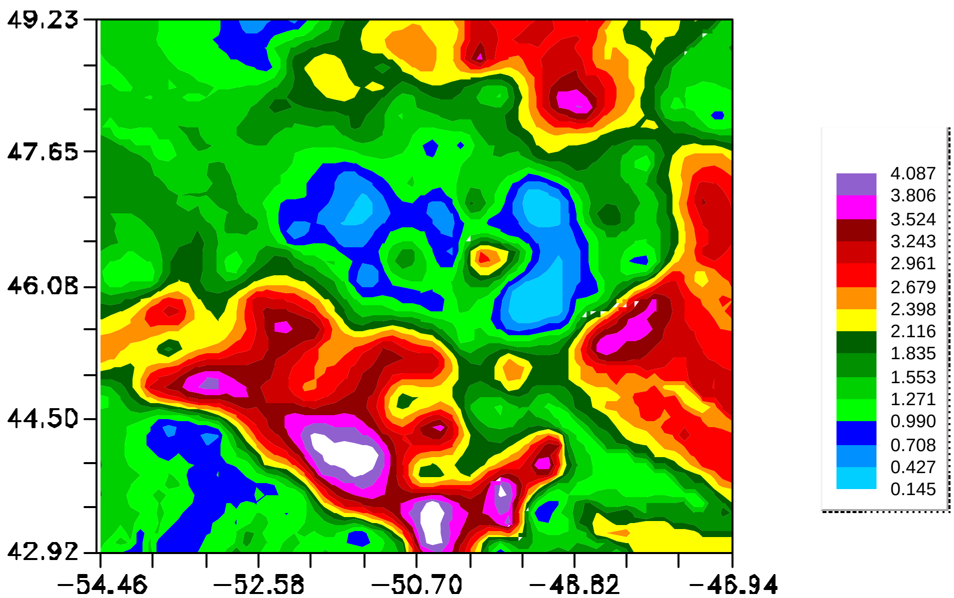
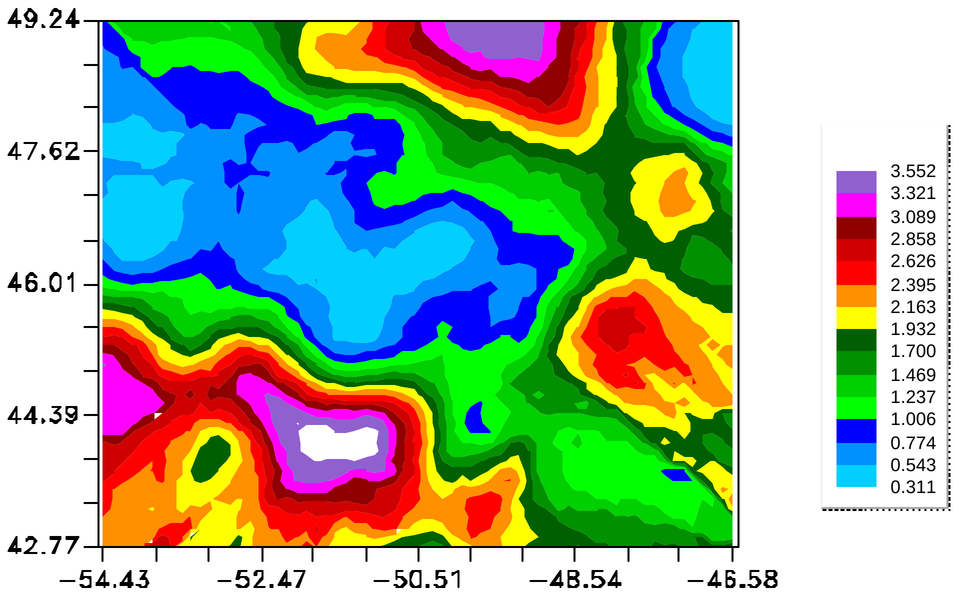


Fig. 8. Cont'd

1994



1995

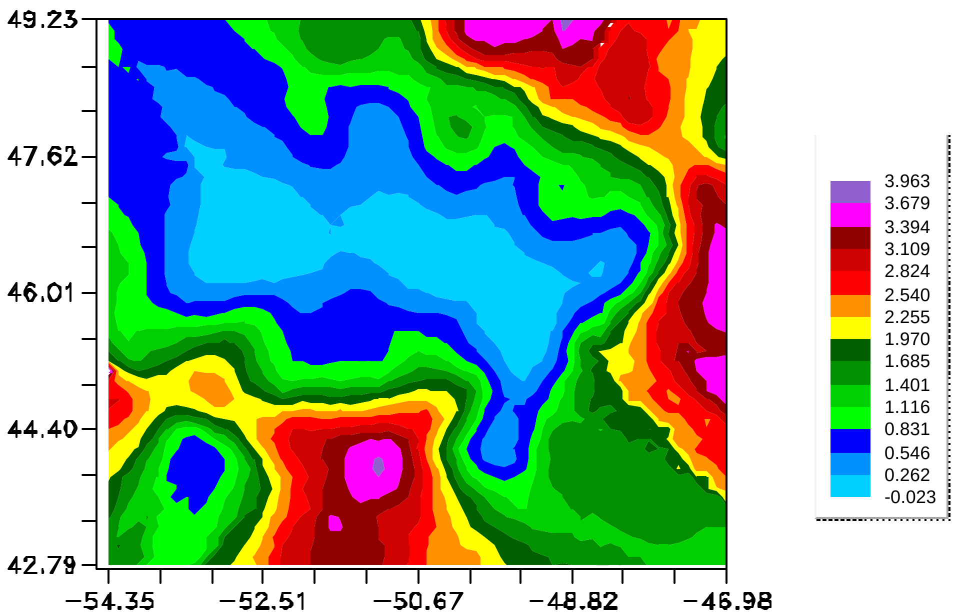
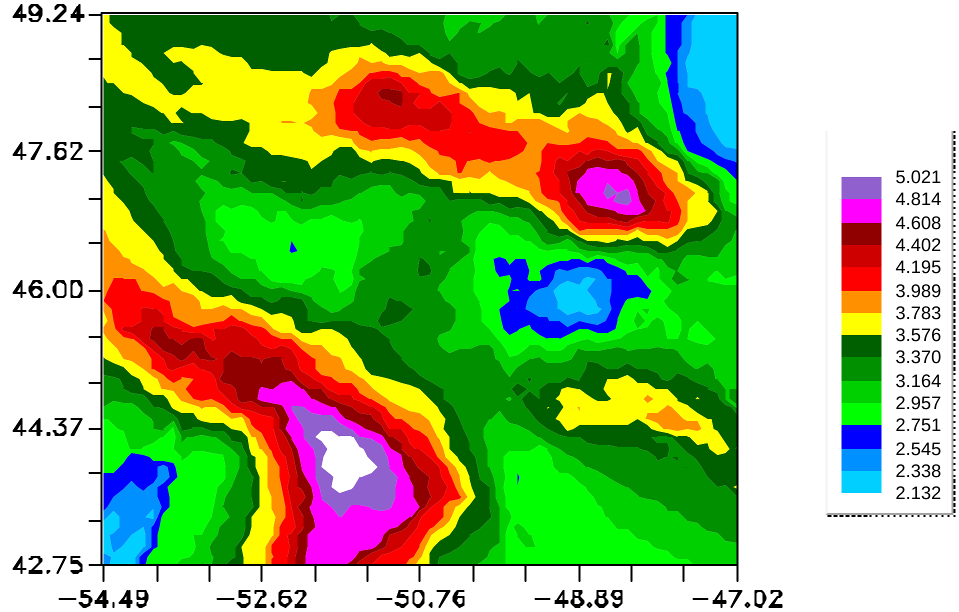
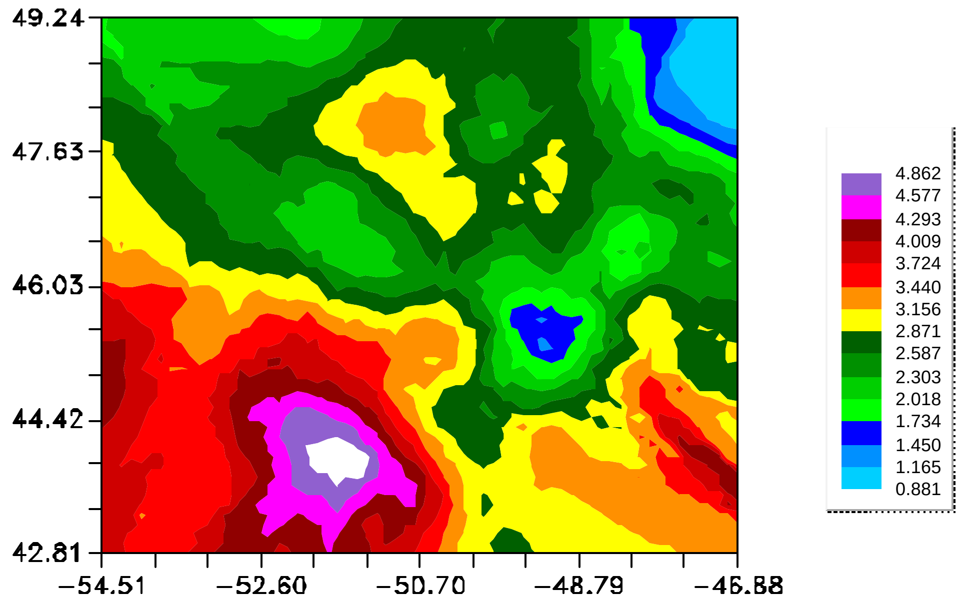


Fig. 8. Cont'd

1996



1997



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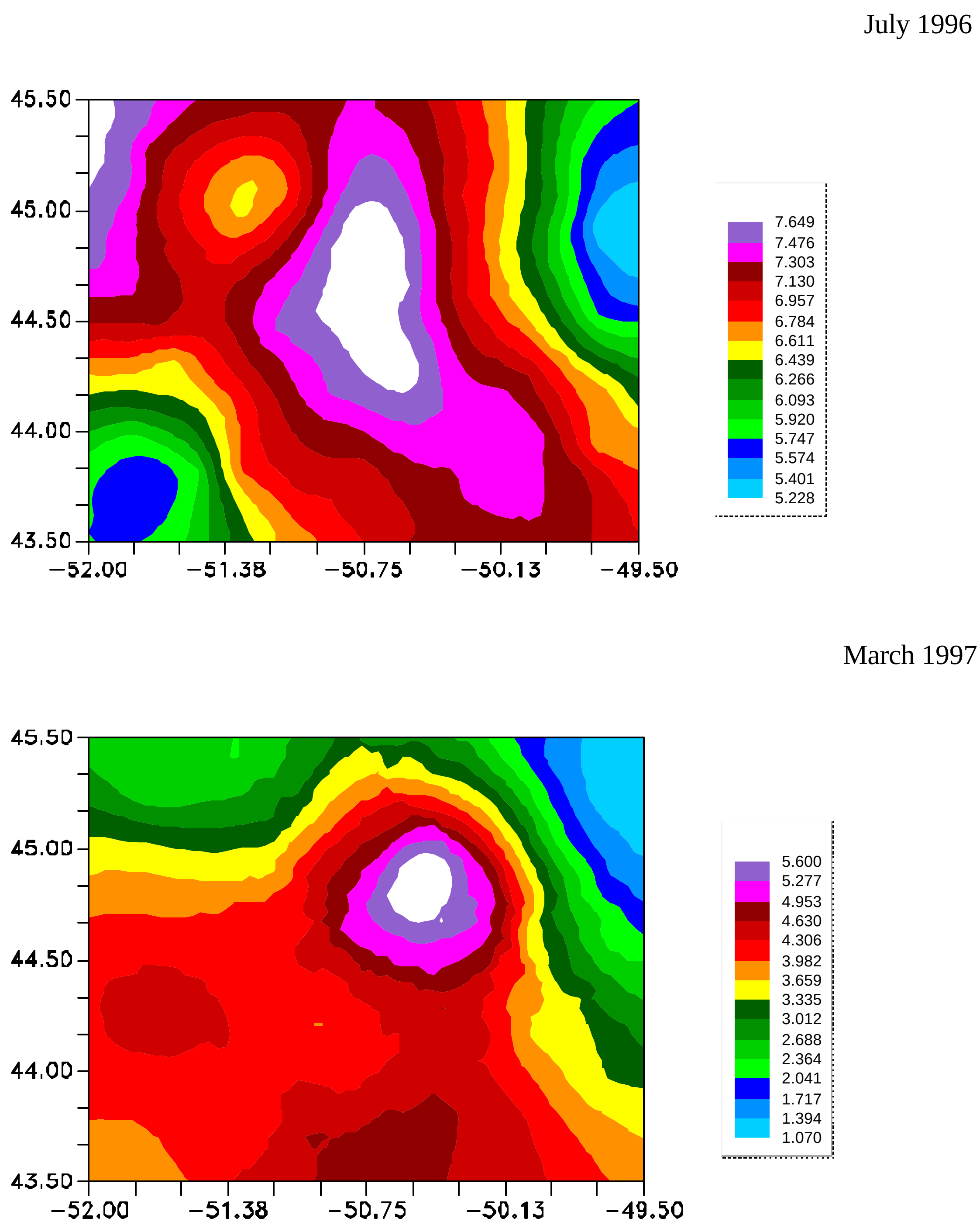
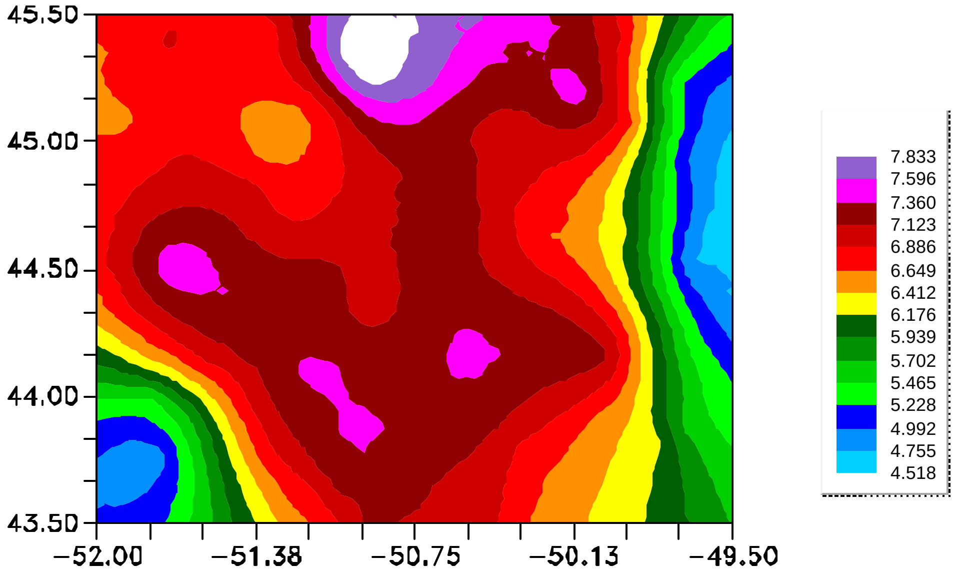


Figure 9. Spatial distribution of kriged estimates (Z) for Yellowtail flounder derived from FPI/DFO cooperative surveys.

May/June 1997



July 1997

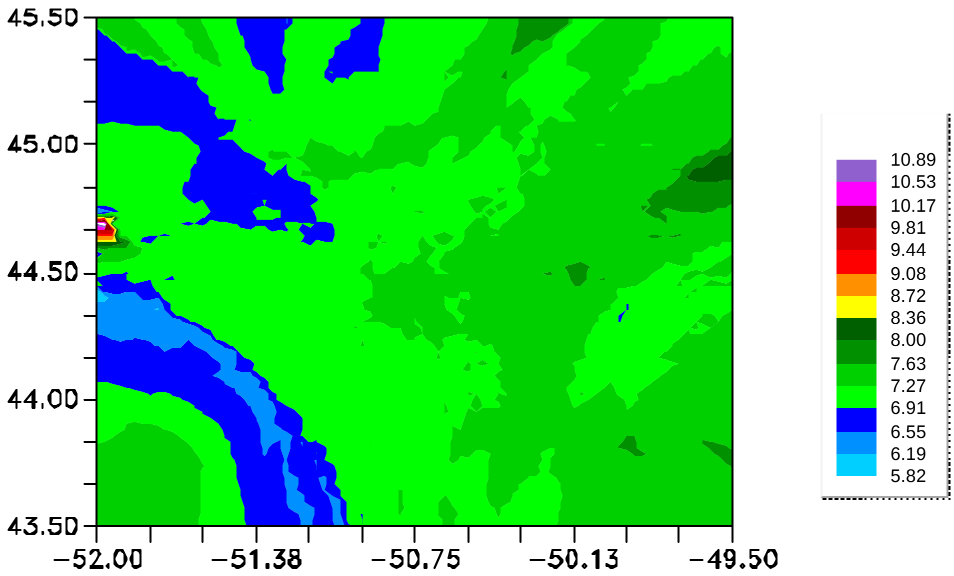
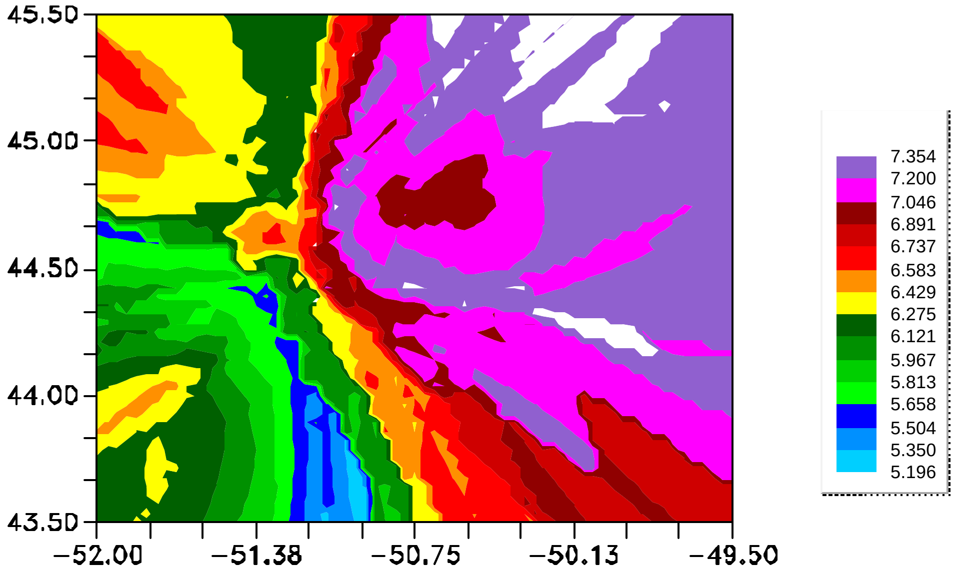


Fig. 9. Cont'd

November 1997



March 1998

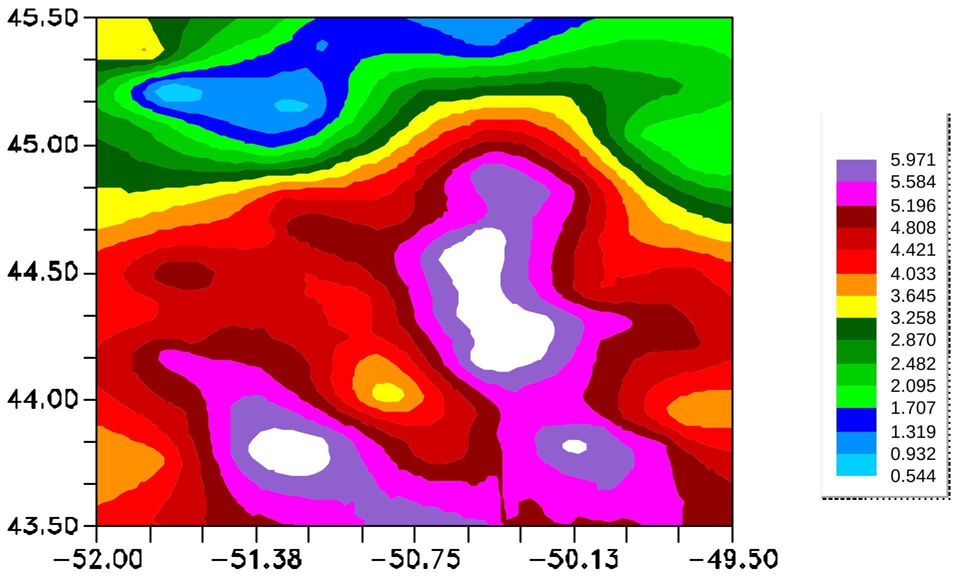
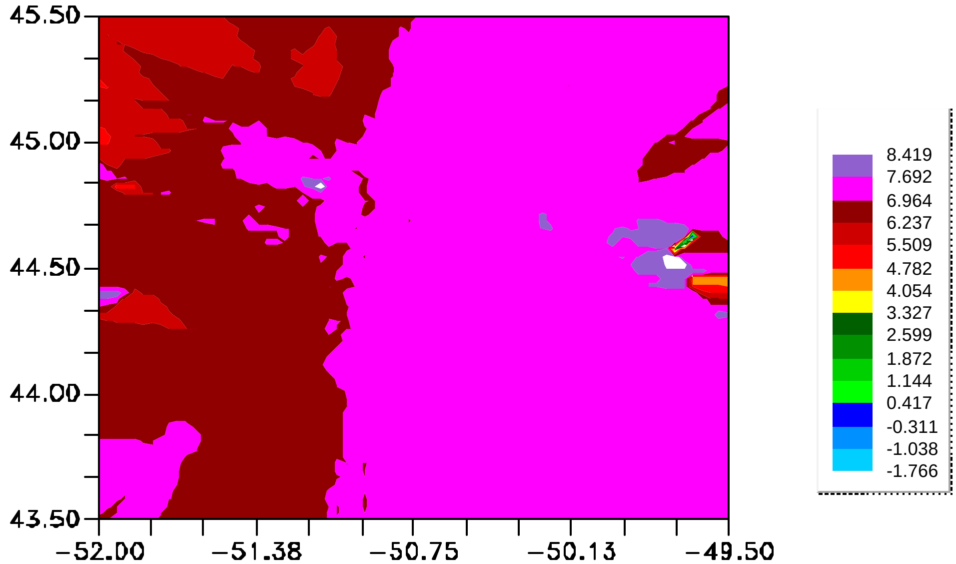


Fig. 9. Cont'd

May/June 1998



July1998

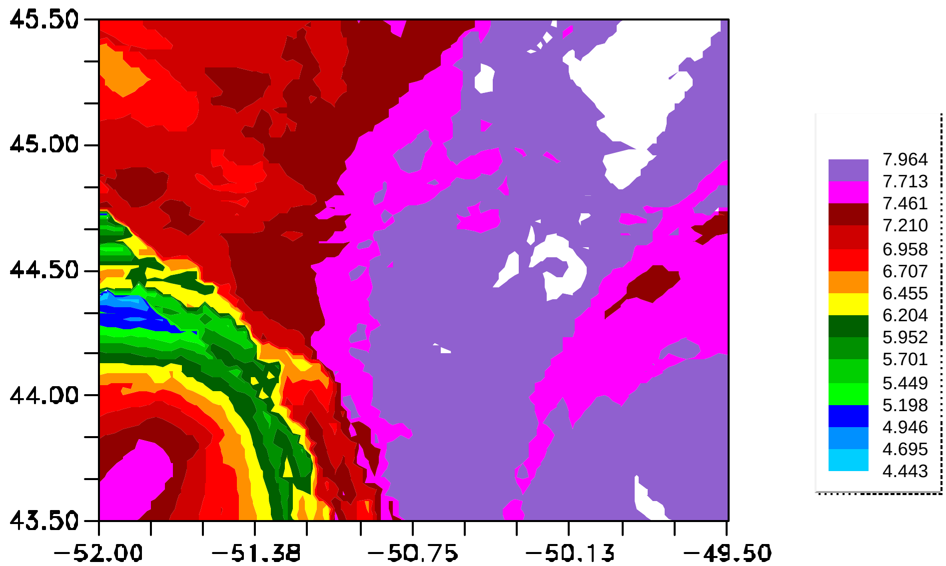
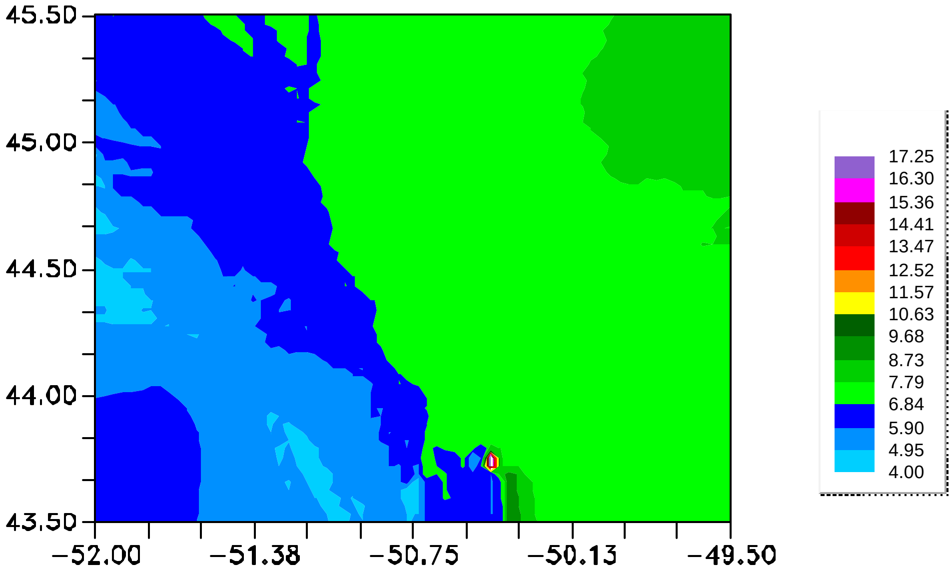
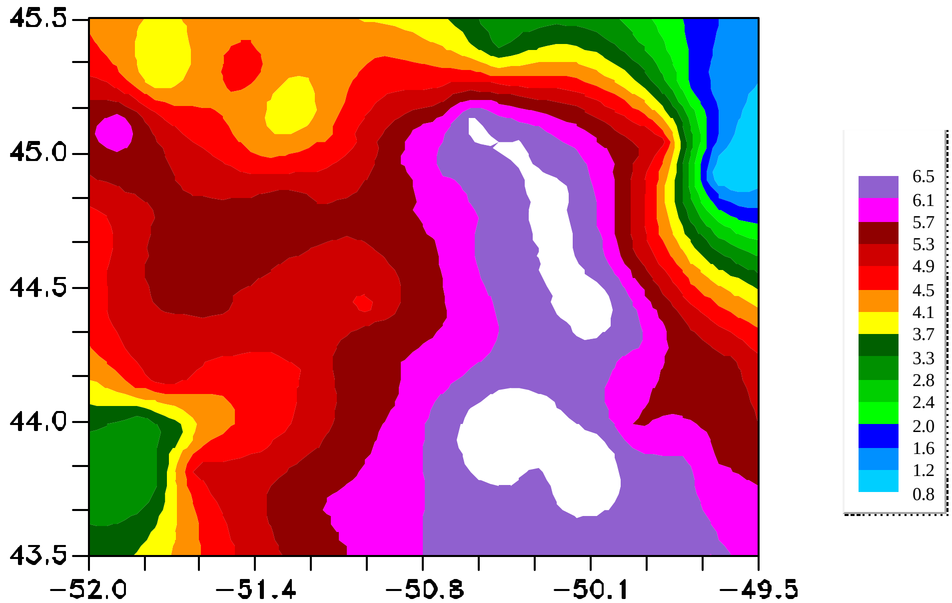


Fig. 9. Cont'd

November 1998



March 1999



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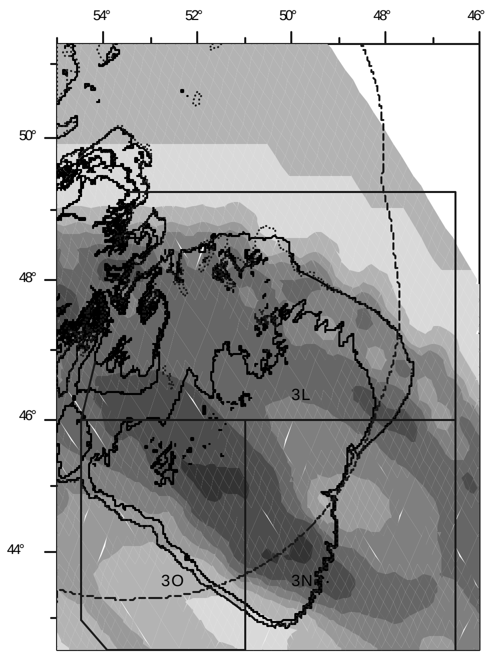
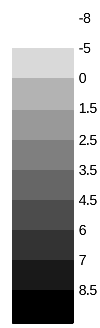
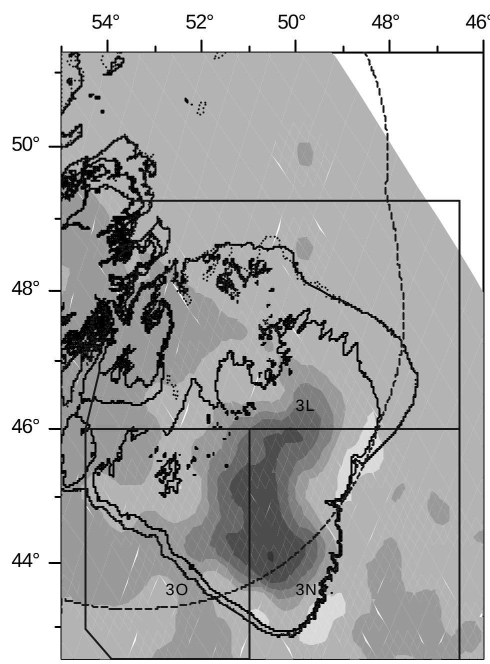
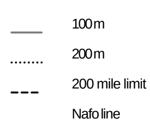




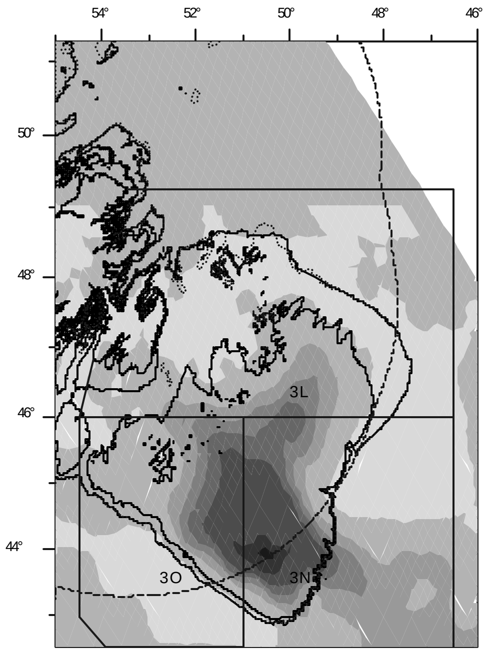
Distribution of Interpolated values for yellowtail flounder,
from DFO fall survey data, 1987.



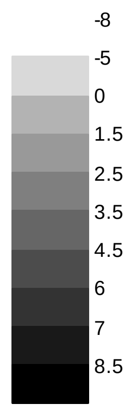


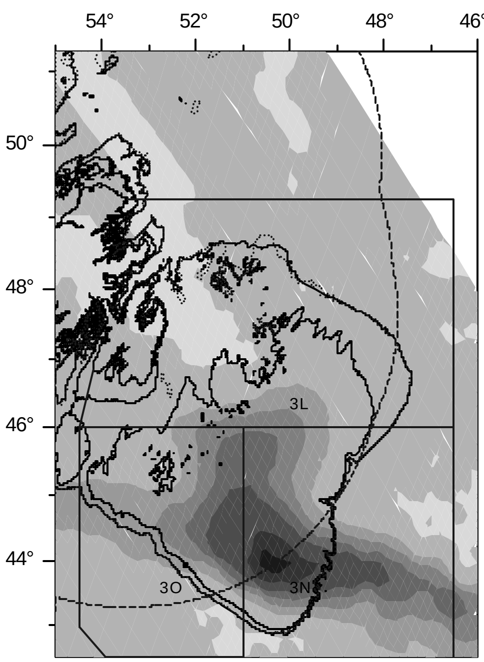
Distribution of Interpolated values for yellowtail flounder,
from DFO fall survey data, 1988.

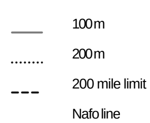
Figure 10. Distribution of yellowtail flounder from fall DFO surveys.



Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1989.

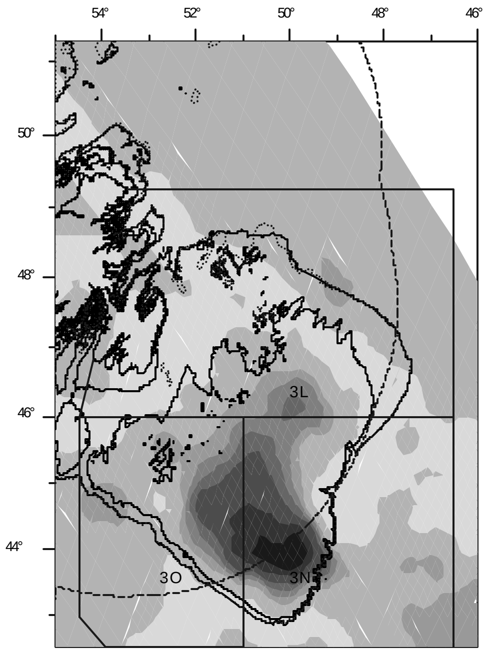




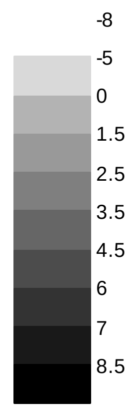


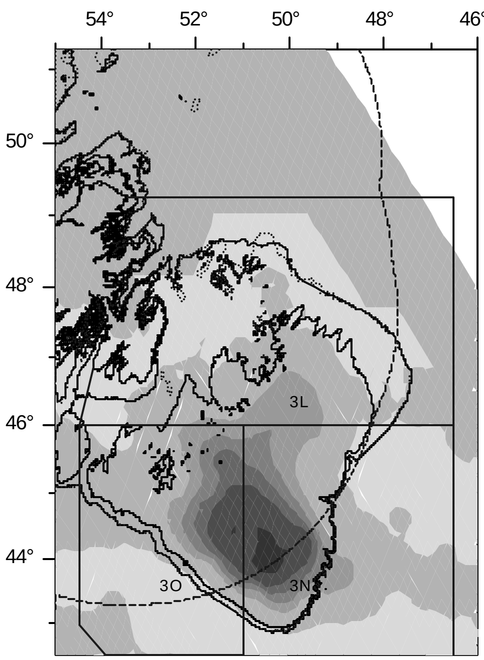
Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1990.

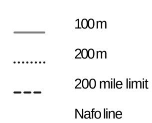
Fig. 10. Cont'd



Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1991.

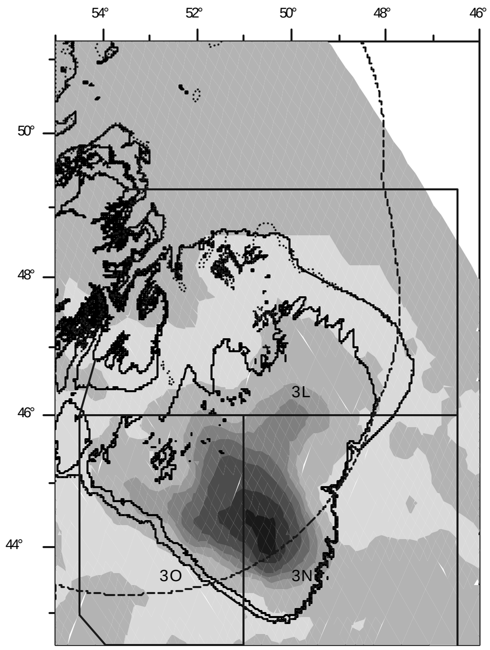




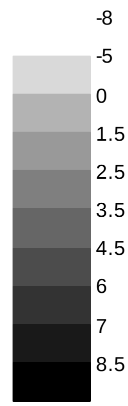


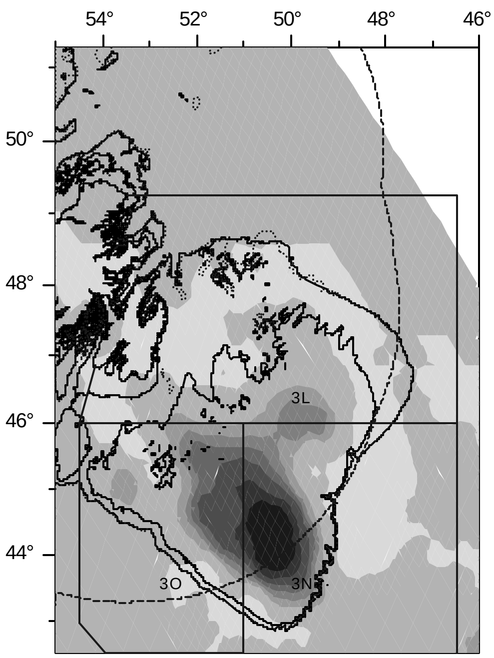
Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1992.

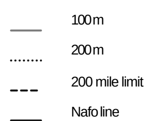
Fig. 10. Cont'd



Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1993.

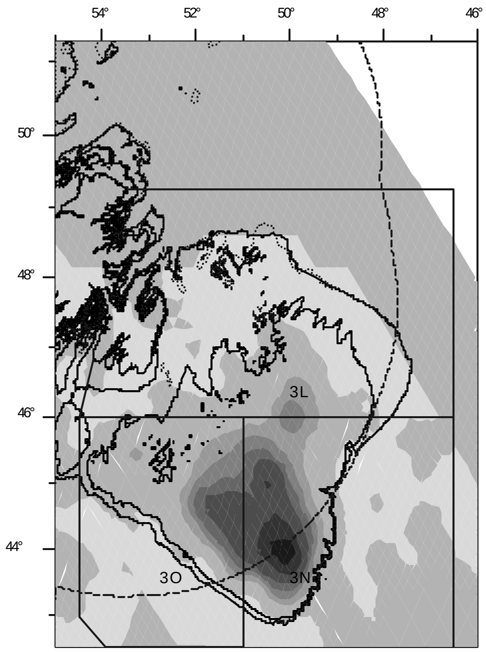


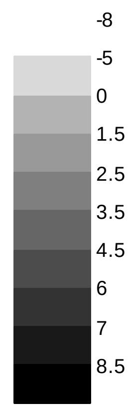




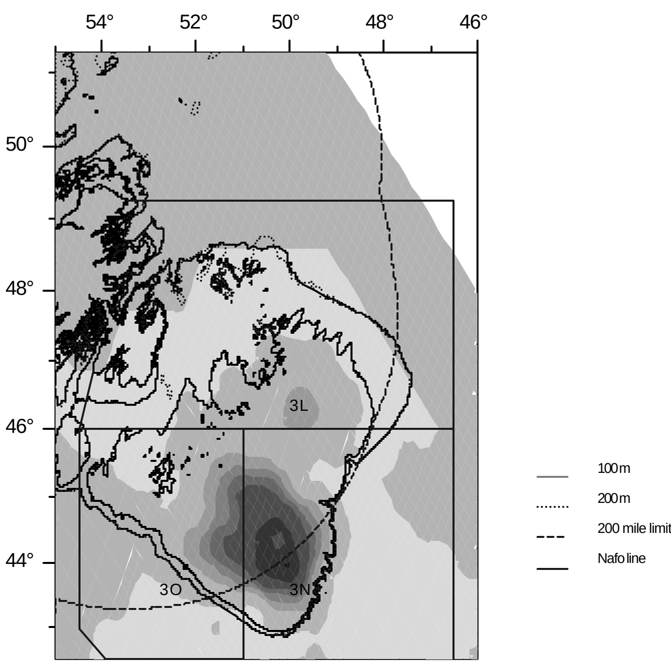
Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1994.

Fig. 10. Cont'd



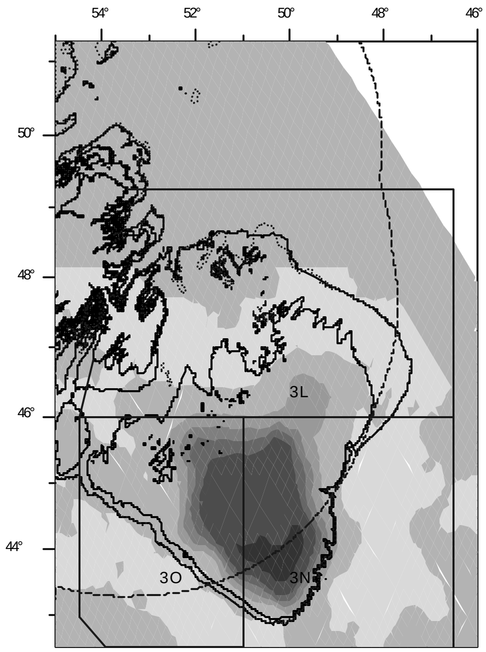


Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1995.

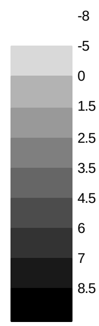


Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1996.

Fig. 10. Cont'd



Distribution of Interpolated values for yellowtail flounder, from DFO fall survey data, 1997.



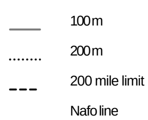


Fig. 10. Cont'd

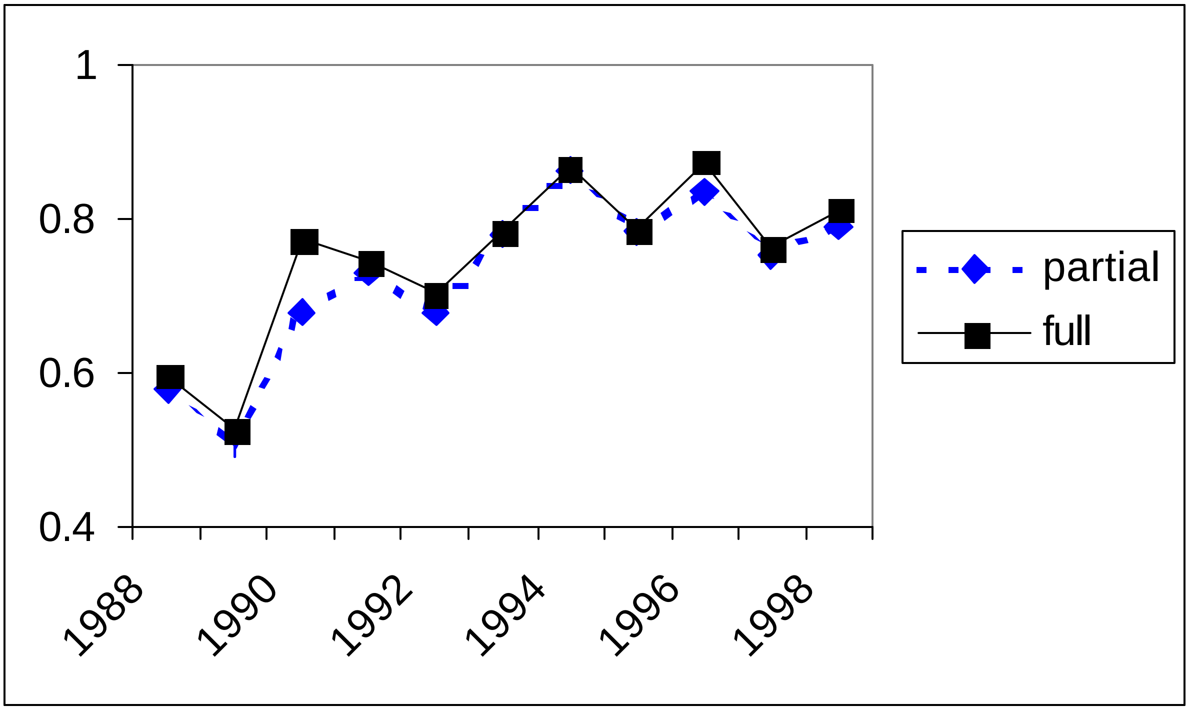


Figure 11. Variation in the pseudo-R^2 for partial (catch~depth +temperature) and full (Catch~depth+temperature+latitude+longitude) GAM models through time.

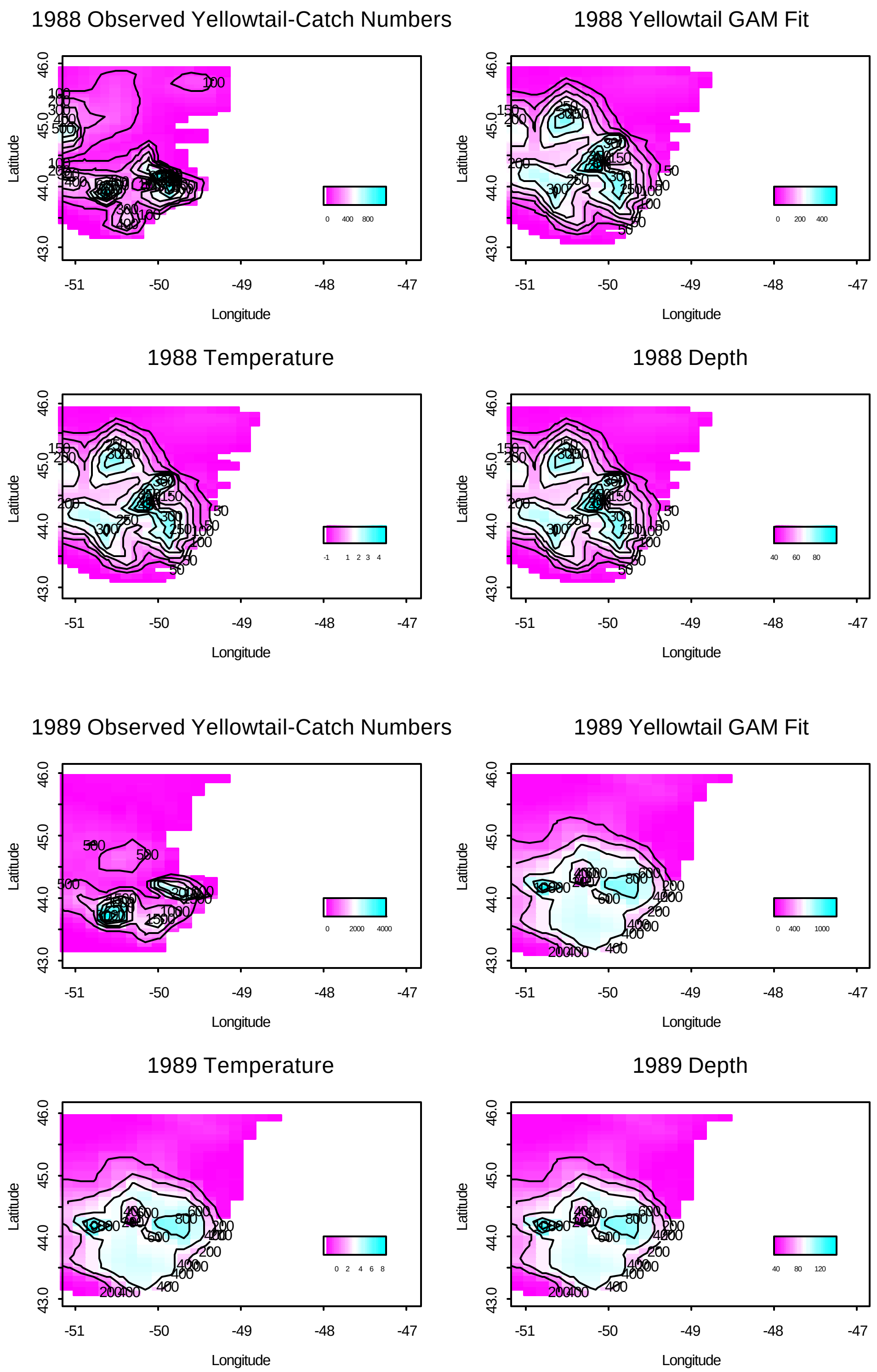


Figure 12. Observed yellowtail catches and fitted spatial GAM.

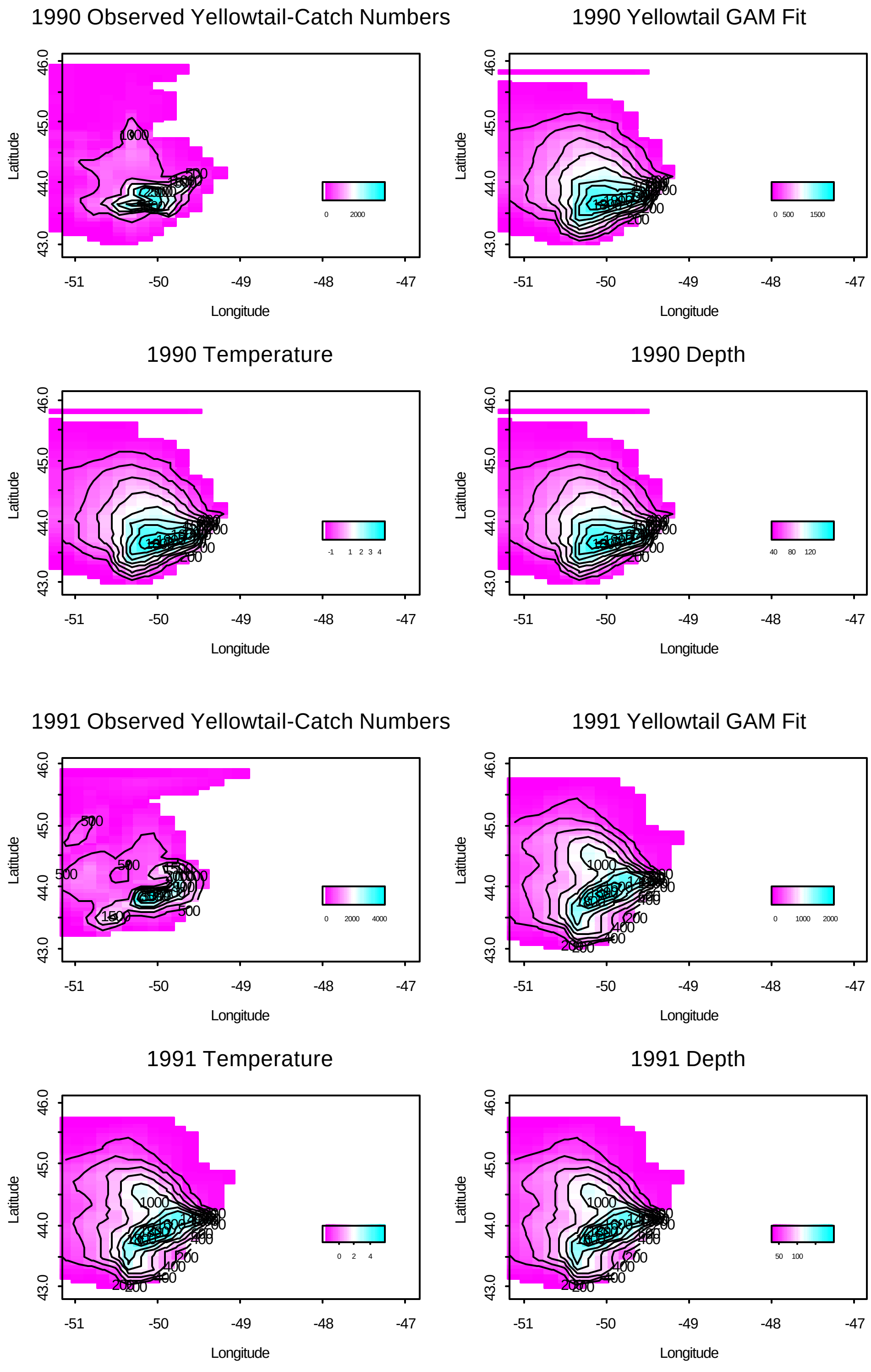

1990 Observed Yellowtail-Catch Numbers
1990 Yellowtail GAM Fit
1990 Temperature
1990 Depth
1991 Observed Yellowtail-Catch Numbers
1991 Yellowtail GAM Fit
1991 Temperature
1991 Depth
Latitude
Longitude
43.0
44.0
45.0
46.0
-51
-50
-49
-48
-47

Fig. 12. Cont'd

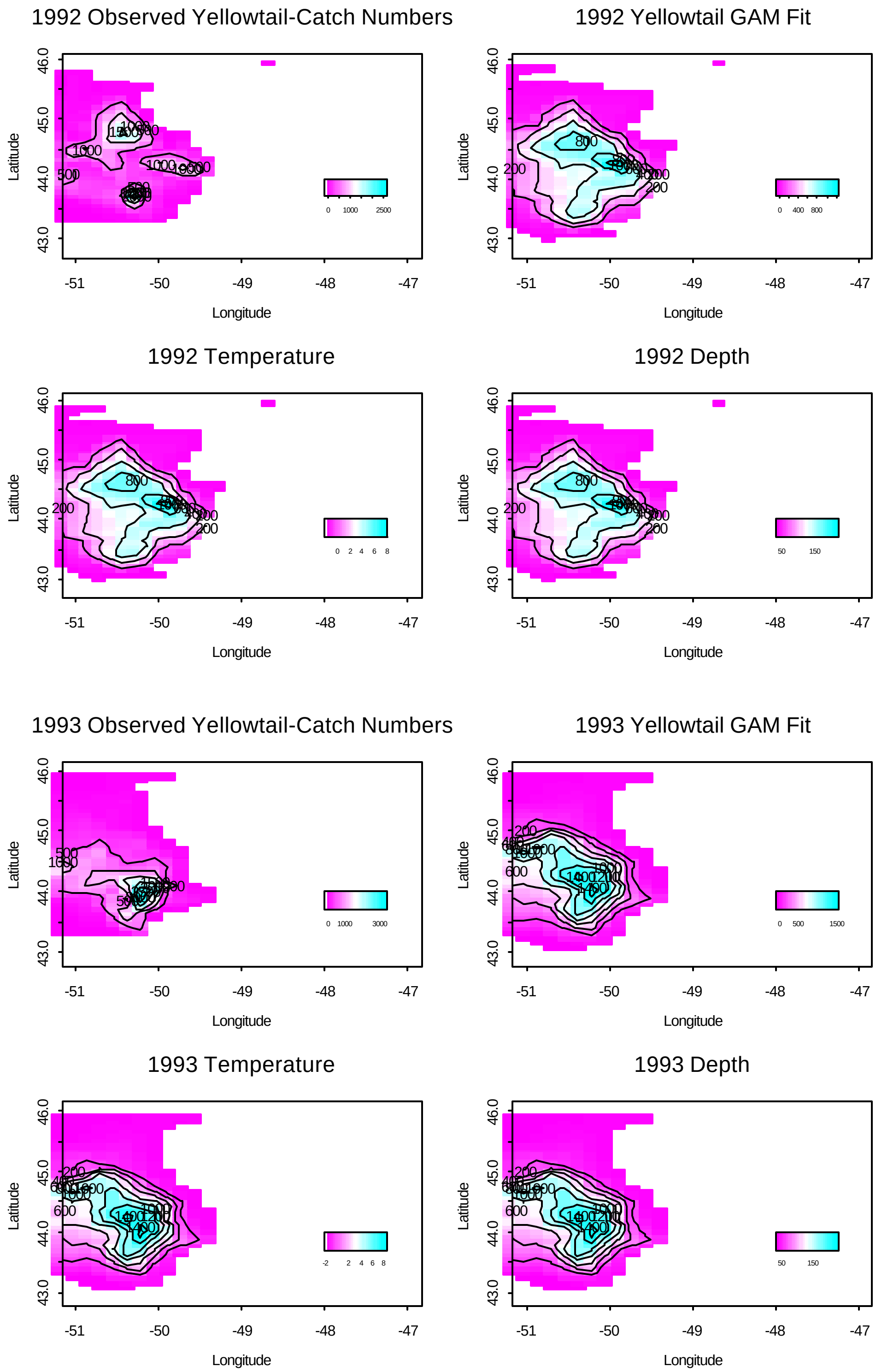

1992 Observed Yellowtail-Catch Numbers
1992 Yellowtail GAM Fit
1992 Temperature
1992 Depth
1993 Observed Yellowtail-Catch Numbers
1993 Yellowtail GAM Fit
1993 Temperature
1993 Depth
Latitude
Longitude
46.0
45.0
44.0
43.0
-51
-50
-49
-48
-47

Fig. 12. Cont'd

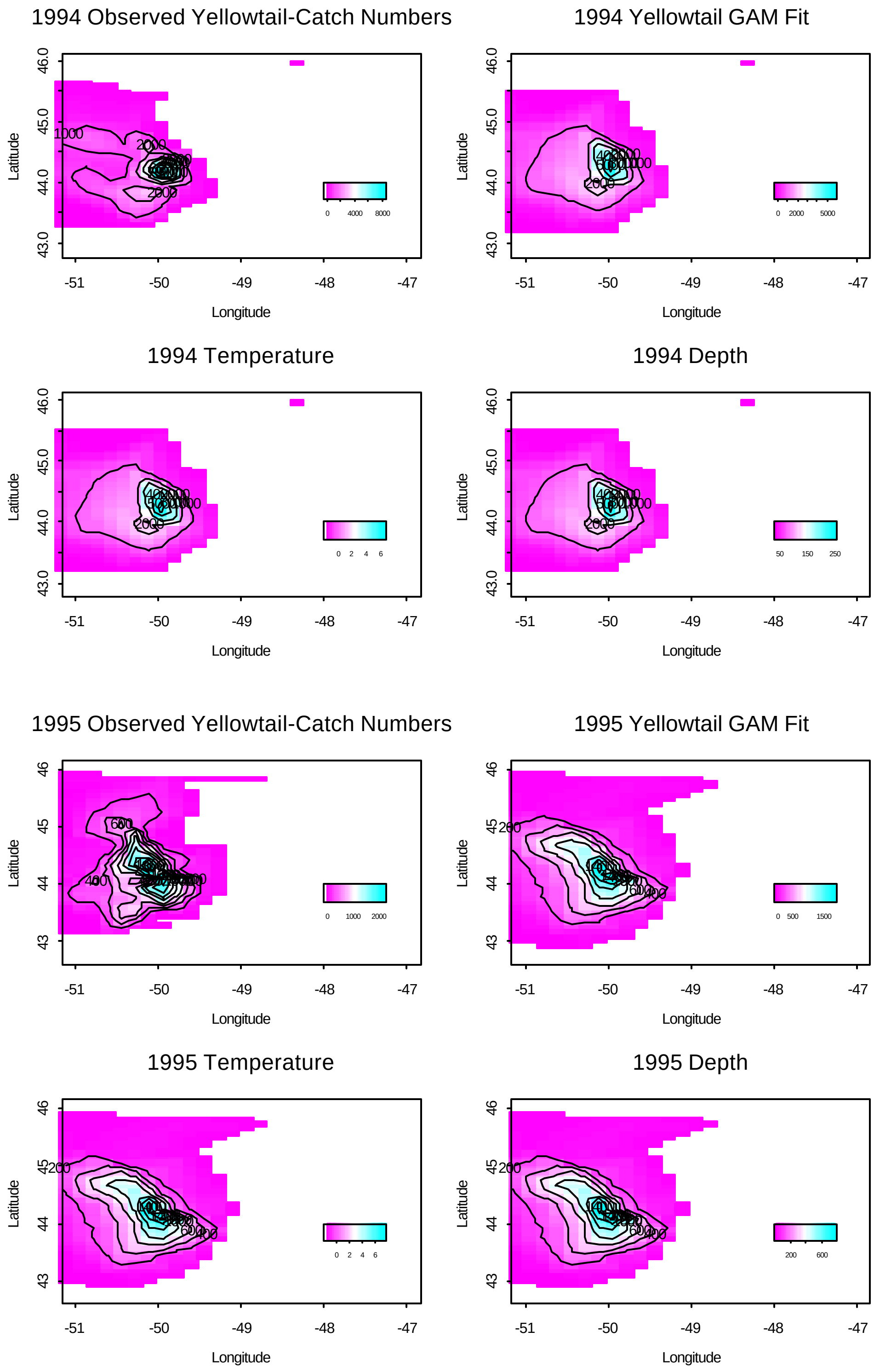

1994 Observed Yellowtail-Catch Numbers
1994 Yellowtail GAM Fit
1994 Temperature
1994 Depth
1995 Observed Yellowtail-Catch Numbers
1995 Yellowtail GAM Fit
1995 Temperature
1995 Depth
Latitude
Longitude
43.0
44.0
45.0
46.0
43
44
45
46
-51
-50
-49
-48
-47
0 4000 8000
0 2000 5000
0 2 4 6
50 150 250
0 1000 2000
0 500 1500
200 600

Fig. 12. Cont'd

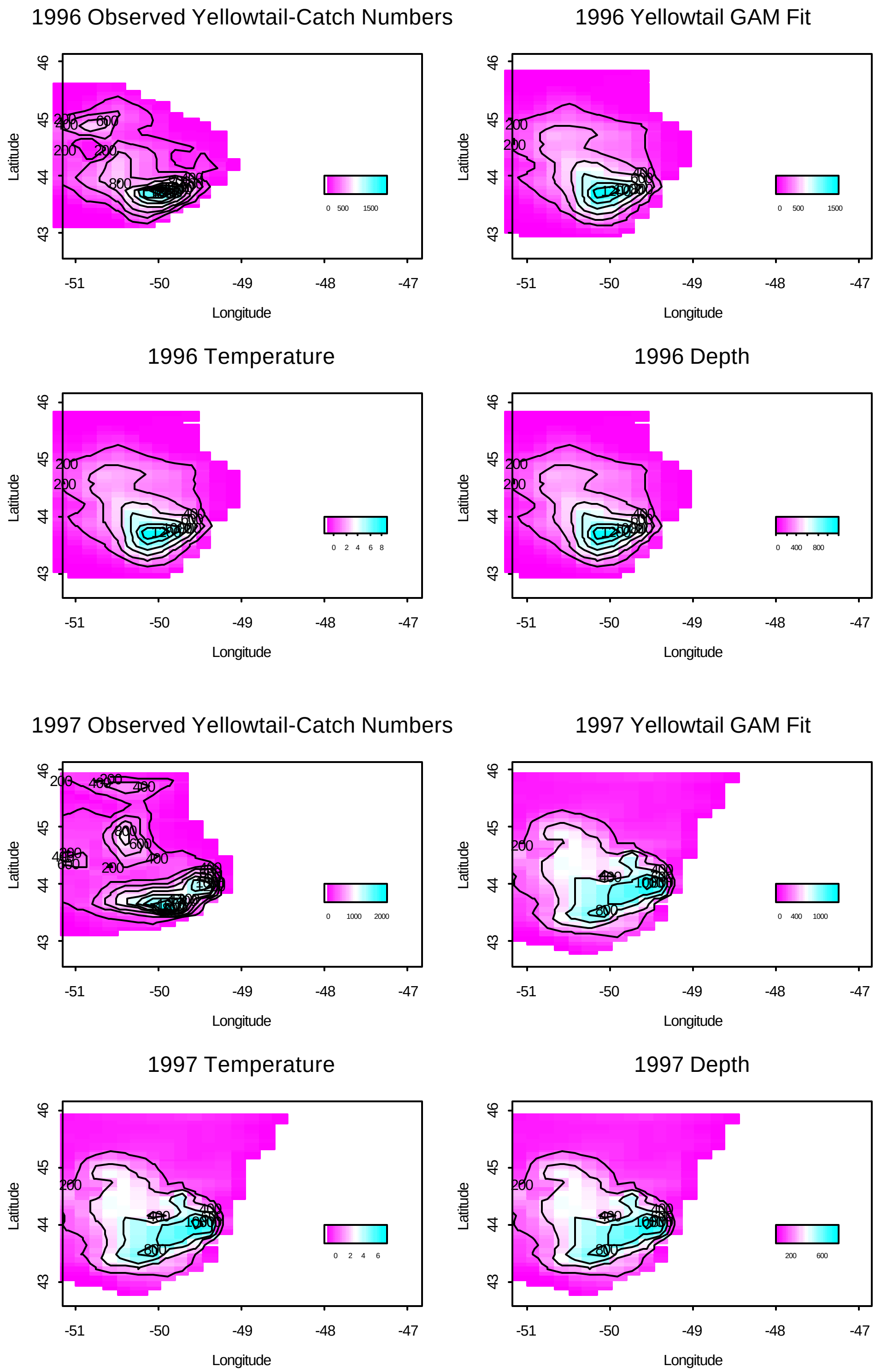

1996 Observed Yellowtail-Catch Numbers
1996 Yellowtail GAM Fit
1996 Temperature
1996 Depth
1997 Observed Yellowtail-Catch Numbers
1997 Yellowtail GAM Fit
1997 Temperature
1997 Depth
Latitude
Longitude
43
44
45
46
-51
-50
-49
-48
-47

Fig. 12. Cont'd

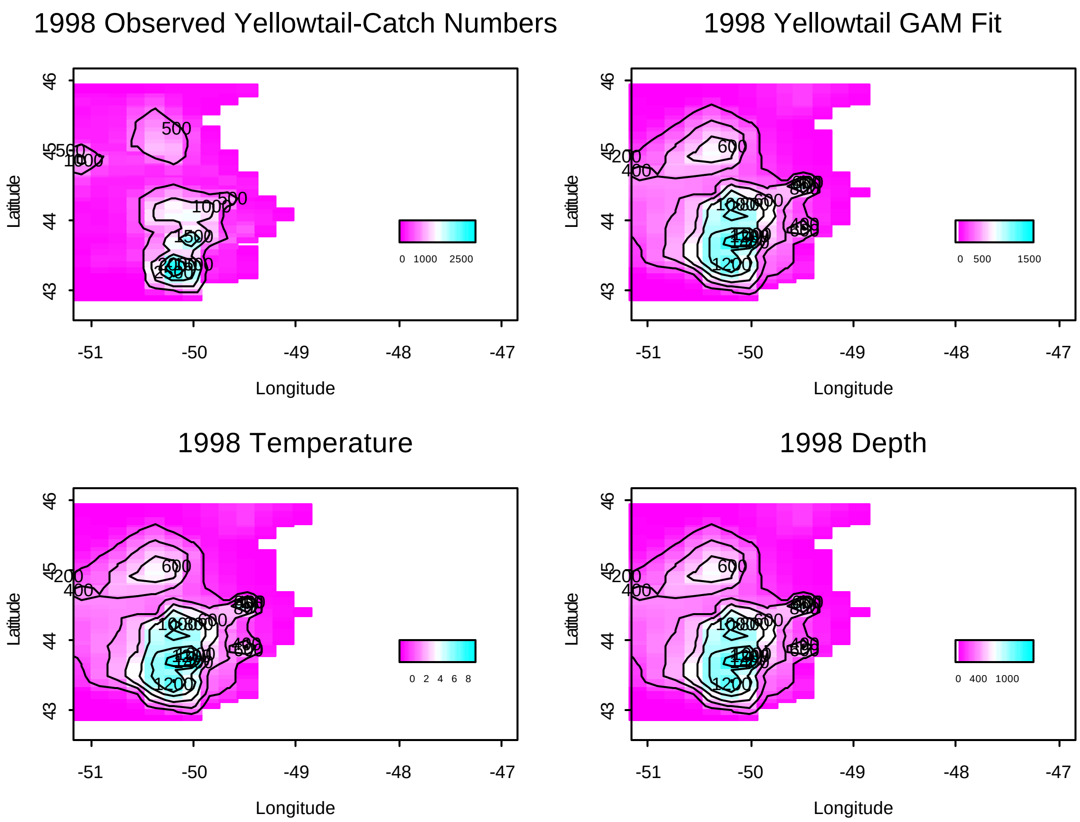

1998 Observed Yellowtail-Catch Numbers
1998 Yellowtail GAM Fit
1998 Temperature
1998 Depth
Latitude
Longitude
0 1000 2500
0 500 1500
0 2 4 6 8
0 400 1000

Fig. 12. Cont'd