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Is the Index from the NEFSC Spring Research Bottom Trawl Surveys Representative of the Abundance of the So-Called Northern Contingent of Atlantic Mackerel (*Scomber scombrus* L.)?

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ABSTRACT

An abundance index of Atlantic mackerel (*Scomber scombrus* L.) is calculated using data from a U.S. bottom trawl survey, which is conducted annually in the region between Cape Hatteras and Georges Bank. This index is supposed to represent the abundance of these two mackerel contingents in the northwest Atlantic. Point kriging was used on the catch data from this survey to measure the respective abundance of each contingent, assuming that the 70° west meridian represents their respective limit. The geographic distribution of catch data as well as the kriging results shows that the most numerous and most significant mackerel catches were generally associated with the area west of this limit and with the south contingent. These results also raise questions about the representativeness of fish from the north contingent in the American index, the validity of using this index in the abundance assessment of both contingents and the lack of information concerning the distribution and migration patterns of Atlantic mackerel in the northwest Atlantic.

RÉSUMÉ

Un indice d’abondance du maquereau bleu (*Scomber scombrus* L.) est calculé à partir des données d’un relevé américain au chalutage de fond qui est réalisé annuellement dans la région située entre Cape Hatteras et le Banc George. Cet indice est supposé représenter l’abondance des deux contingents de maquereau présents dans le nord-ouest de l’Atlantique. Le krigeage ponctuel a été utilisé sur les données de captures de ce relevé afin de mesurer l’abondance respective de chaque contingent en assumant que le méridien de 70° ouest représente leur limite respective. La distribution géographique des données de captures de même que les résultats du krigeage démontrent que les plus nombreuses et les plus importantes captures de maquereau étaient généralement associées à la zone située à l’ouest de cette limite et au contingent sud. Ces résultats soulèvent aussi des questions quant à la représentativité des poissons du contingent nord dans l’indice américain, sur la validité d’utiliser cet indice dans l’évaluation d’abondance des deux contingents et sur le manque d’information concernant les patrons de distribution et de migration du maquereau bleu dans le nord-ouest de l’Atlantique.

INTRODUCTION

"*It is very difficult to manage a stock that keeps on changing its distribution, particularly when nobody knows precisely where the entire stock is throughout the year or where it is likely to be in the next few years. I've always had sympathy with the managers on this one*!"

Molloy (2004) concerning the Atlantic mackerel in the Northeast Atlantic.

Stock Identification and Definition

The identification of ocean fish stocks is a fundamental pre-requisite to any abundance evaluation program and fisheries management (Cadrin et al. 2005, Molloy 2004). In fact, most models used in population dynamics assume that the group of fish under study has similar biological characteristics and a life cycle that enables young individuals to be produced by adults from the same group. A stock is defined as a population of organisms which, sharing a common gene pool with neighbouring stocks, is sufficiently discrete to warrant consideration as a self-perpetuating (Larkin 1972). Ihssen et al. (1981) defines a stock as an intraspecific group of randomly mating individuals with temporal or spatial integrity. Hilborn and Walters (1992) define a stock as a group of fish having the same biological characteristics and whose numbers are high enough to self-reproduce. Finally, Cushing (1968) defines an "ideal" fish stock as one that has a single spawning ground to which the adults return year after year.

There are two main approaches for identifying or defining ocean fish stocks (Hare 2005). A stock that is defined by a genotypic approach is characterized by individuals of a given species that breed among themselves and whose genetic integrity is ensured upon spawning by spatial or temporal isolation. At certain times of the year, these individuals can be mixed with those belonging to another stock. However, a stock that is defined by a phenotypic approach differs from another by the expression of certain meristic or morphological characteristics due to some environmental or genetic factors.

A stock can also be defined by a third approach, the contingent originally proposed by Clark (1968) and repeated more recently by Secord (1999). According to these authors, a contingent would be a group of individuals with spatial and temporal integrity due to a distinctive migration pattern. Hare (2005) mentions that the contingent concept is interesting because it reflects the same basic principles that served to define the hypotheses dealing with the structure of ocean fish populations (triangle migration, member-vagrant, basin model and migration loop hypotheses).

<u>Atlantic Mackerel in the Northwest Atlantic</u>

Sette (1950) is one of the first to examine the differentiation of mackerel (*Scomber scombrus* L.) in the northwest Atlantic. From a large number of commercial samples collected between 1926 and 1935, Sette (1950) observed differences between the lengths of Atlantic mackerel caught in U.S. and Canadian waters (Appendix 1). He also observed a slower growth in fish caught in U.S. waters. Based on these observations and on results from various tagging projects, and on the presence of two spawning sites and distinct migration patterns, Sette suggested the presence not of two stocks, but of two groups or contingents of mackerel in the northwest Atlantic. He did not establish any genetic distinction between these groups, but he did however mention the possibility.

Since Sette, various research has been conducted from meristic data (MacKay and Garside 1969), the daily otolith growth pattern during the first year of life (Simard et al. 1992) and their form (Castonguay et al. 1991) to describe and attempt to distinguish between the two contingents. However, genetic differences have been suggested by studies on the polymorphism of some proteins (MacKay 1967, Maguire et al. 1987). More recently, phylogenetic and molecular variance analysis (AMOVA) did not reveal genetic differences between the northern and southern contingents (Lambrey de Souza et al. 2006). This lack of apparent difference could be explained by the occurrence of mixing between the two contingents, by the very high variability of the studied mtDNA fragment or by the small sample size (Lambrey de Souza et al. 2006).

Distribution and Migration

<u>Sette's Perspective (Sette 1950)</u>

According to commercial fishery data available to Sette, Atlantic mackerel of the northwest Atlantic are found from North Carolina to Newfoundland. Some catches are made along the southern and western coasts of Newfoundland, but not enough to support a regular fishery. During the fishing season, mackerel distribution extends from Chesapeake Cape north to the Magdalen Islands and the Gaspé Peninsula.

Also according to commercial fishery data available to Sette, the first mackerel appear in early April in the area between Chesapeake and Delaware Capes. In April and May, individuals move closer to the coast and then travel to New England. These movements are associated with warmer surface temperatures. At about the same period, mackerel appear along the coast of Nova Scotia. During the following 2- weeks, schools of mackerel travel to and frequent the Gulf of Maine and the southern Gulf of St. Lawrence where they remain until September. The schools leave the northernmost regions and travel south in October and November before leaving the coasts in December. Juveniles have a different migration pattern, preferring coastal waters where they stay until late in the season (December). Winter habitats are found in deep waters and on the edge of the continental shelf between Cape Hatteras and the southern edge of Georges Bank and possibly up to Sable Island. Individuals from the southern contingent can be found in the southern portion of this area and individuals from the northern contingent in the northern portion.

In the spring, individuals from the northern contingent likely travel from the Hudson Channel, and as they near the coast, they mix with the southern contingent over a short period of time. According to length frequency data, individuals from the northern contingent are larger. Successive waves from offshore join the main front moving eastward and along the coast of Nova Scotia. In the fall, individuals from both contingents likely migrate in the opposite direction. The two contingents likely mix for a second time north of Nantucket Shoals and of the spring mixing area.

Recent commercial fishery data is generally consistent with the above description. However, mackerel now occur in larger numbers and over a longer period of time on the three coasts of Newfoundland and in Labrador.

Stock Assessment

<u>Canadian Contingent</u>

A spawning biomass index of individuals from the northern contingent has been evaluated since 1983 using an egg survey (Maguire 1979, 1980, 1981; Ouellet 1987; Grégoire et al. 2008). Compared with the 1980s, a significant decrease of this index's values was observed beginning in the mid-1990s. Canadian landings alone, although not all accounted for, cannot explain the extent of this decrease, which has also occurred when the water in the Gulf of St. Lawrence, i.e. the cold intermediate layer (CIL), has gotten colder (DFO 2008). Demographically, the late 1990s were characterized by the arrival of the strong 1999 year-class. Individuals from this year-class alone accounted for nearly half of the 330,000 t of mackerel landed in Canadian waters between 2000 and 2007. The arrival of this year-class increased the landings in Newfoundland from 2,000 in 2000 to over 40,000 t in 2007 (DFO 2008). Although the 1999 year-class has almost all disappeared, the vast majority of Canadian landings are still from Newfoundland. It is unlikely that this year-class was measured in the egg survey as was done for the strong 1982 year-class, which suggests that most of the fish from this year-class would have used a different spawning site than the traditional site in the southern Gulf.

Canadian and US Contingents

On the American side, catches from a scientific bottom-trawl survey conducted in the spring were used to calibrate various sequential population analysis models (Overholtz 1991; NEFSC 1996, 2000, 2006). This survey covers the entire U.S. east coast, from Cape Hatteras to Georges Bank. According to the work carried out by Sette (1950) on mackerel distribution and migration in the northwest Atlantic, both contingents could be well covered by this survey.

Objectives of the Present Study

The primary objective of this study is to determine whether the U.S. spring survey successfully represents the abundance fluctuations of the northern contingent by calculating the proportion of the American abundance index which is located east of the meridian 70° west, which is west of where Sette (1950, P.270) observed no individuals from the northern contingent. To do this, the aggregated abundance index (number/set) was recalculated by kriging. This approach helped divide the U.S. index into two components located on both sides of the meridian 70° west.

MATERIAL AND METHODS

Data Source

Catch data in numbers and weight (kg) per set from the scientific bottom-trawl survey in spring are from the National Fisheries Science Center (NEFSC) in Woods Hole, MA (Dr. Jon Deroba, NOAA Fisheries, pers. comm.). The other variables associated with these data are: (1) survey name, (2) strata identification, (3) station number, (4) set number, (5) date, (6) time, (7) position (latitude and longitude), (8) depth (m) trawled, and (9) water temperature (°C) at the bottom. The numbers and average annual weights per set were calculated from these data by the swept area method and by kriging.

Data Analysis

Catch Distribution

For each survey, mackerel catches (number/set) were displayed on maps created with the software Surfer (Golden Software Inc. 2008). Bottom temperatures were interpolated using the same software and the results were superimposed on catch maps. The geographic center of the catches was calculated for each survey using the position of the sets. Geographic centers of all the surveys were presented on the same map in order to compare annual catch concentrations.

Kriging

Variograms were produced for each survey from the numbers per set and their respective positions. The semivariance calculations were done using the GS^+ software (Robertson 1998). The choice of a variogram model was based on the coefficient of determination (r^2) results (Robertson 1998) and the parameters of the model chosen, on the results of the RSS statistics (residual sum of squares) as calculated by GS^+. For a given model, the parameters chosen were those that produced the lowest value of this statistic.

Ordinary point kriging was conducted using the corresponding parameters of the variograms. A correction factor was applied to the variograms that were produced without the occurrence of extreme values. The number of points to include in the search area was set at 16 and no restrictions were applied to the research range. For each survey, point estimates were made to the grid nodes of a 7,247 cell grid measuring 5X5 km covering the entire area sampled. The new abundance index was defined as the average of all point estimates. This index was compared with the index using the swept area method. Subsequently, averages were calculated for the grid-cells located on either side of the meridian 70° west to obtain two abundance indices associated with the distribution ranges of both mackerel contingents.

RESULTS

Set Characteristics

Between 151 and 251 stations were sampled annually by the scientific bottom-trawl survey (Table 1). The number of stations or sets with mackerel catches ranged between 16 (8.7%) and 75 (46.9%) for an annual average (1968-2008) of 44 (25.2%) stations. To the east of the meridian 70° west, mackerel were caught at a maximum of 40 (25.0%) stations in 2001 for an annual average of 11.5 (6.6%) stations. The maximum number of mackerel caught during a set was 15,619 in 1973 for an annual average of 24.4 mackerel per set. The average depths of the sampled stations ranged between 82.8 and 106.3 m and average temperatures at the bottom were between 2.9 and 8.6°C.

Catch Distributions

During the period covered by the survey (1968-2008), mackerel were caught over the entire continental shelf as well as at its edge (Figures 1 and 2). However, the catch distribution pattern varied from year to year. For example, for some surveys, catches were concentrated in a given region. With the exception of four years (1999, 2000, 2001 and 2007), very few catches were made east of the meridian 70° west, i.e. in the region between Cape Cod and Georges Bank. The temperature regime at the bottom has changed dramatically over the years. On some occasions, the highest temperatures were observed only at the edge of the continental shelf, and on other occasions, in the southern portion and/or the median of the sampled area.

Mean Catch and Weight per Survey

The annual abundance index, expressed as mean numbers per set, reached a minimum value of 0.19 in 1969 and a maximum value of 59.11 in 2001 (Table 2). With the exception of 1968 and 1987, very low values were measured until 1990. The index rose slightly between 1990 and 1996 and following a drop in 1997, it increased again until 2001. Subsequently, changes were observed with values above 25 mackerel per set in 2003, 2004 and 2006. The same annual variations were observed in mean weight per set.

Kriging

For most surveys, the choice of variogram was based on the spherical model (Table 3). The exponential model was used a few times but no model has helped describe the spatial structure of catches in 1969, 1978, 1980 and 1981 due to an insufficient number of catches. All models selected adjusted well to the semivariance data with coefficients of determination ranging from 0.76 to 1.00 (Table 3).

The annual kriged index reached a low of 0.54 mackerel per set in 1979 and a maximum of 117.45 in 2001 (Table 4). The kriged index, while higher than the swept area index, showed the same annual variations (Figure 3). The relationship between these two indices can be described using a linear regression ($F=294.75$, $r^2=0.89$, $p<0.0001$) (Figure 4). With the exception of the surveys conducted in 1975, 1997, 1999, 2000 and 2001, all geographic catch centers were found west of 70° west (Figure 5A).

The annual index associated with the grid-cells of the kriging grid located west of the meridian 70° west (Figure 5B) ranged between 0.67 (1979) and 119.77 (2004) mackerel per set (Table 4). For the area east of this meridian, the index ranged from 0 (2005) to 217.98 (2001) mackerel per set. The mean numbers per set were generally higher for the region west of the meridian 70° west. They were higher on the east side in 1999, 2000 and 2001 and slightly higher in 1973, 1975 and 1976, 1985 and 1997 (Figures 6A and 6B).

DISCUSSION

In the U.S. spring bottom trawl surveys, the most numerous and most significant mackerel catches were generally made west of the meridian 70° west (Cape Cod). The results from the kriging analyses also show that mackerel were more abundant in this region. Considering, based on observations by Sette (1950), that this meridian is the winter limit separating the two mackerel contingents in the northwest Atlantic, the results presented in this study suggest that the southern contingent, with some exceptions, is more abundant than the northern contingent in the area covered by the survey. However, it is possible that (1) individuals from the northern contingent are found west of the meridian 70° west, or (2) a portion of the northern contingent winters in Canadian waters and thus remains inaccessible to the U.S. survey. Should this last statement be true, the U.S. index could not be considered representative of the abundance of the two contingents.

The presence of individuals of the northern contingent in the Cape Cod region and in particular west of it is not well documented and most mackerel distribution and migration patterns in Canadian waters have changed significantly over recent years. Most Canadian landings are now in Newfoundland. Fishing in this province, both on the west and east coast, sometimes continues until late October and early November.

Sette mentions two schools of thought regarding mackerel migration (Sette 1950). The first stipulated that mackerel traveled great distances every year between fall fishing sites and wintering sites. The second believed that migrations were much shorter and that mackerel schools, in the fall, headed out to sea to winter in deep waters. Sette (1950) mentioned that it is likely a combination of both. This is probably what occurs in Newfoundland. The deep waters at the edge of the continental shelf, off the Grand Banks of Newfoundland, could serve as wintering areas such as those found off the Scotian Shelf (Grégoire 2006). Mackerel that do not have time to reach this region could be affected by rapid drops in temperature which sometimes occur in late fall. These falling temperatures could be the reason for the mortalities observed occasionally on the beaches of Newfoundland. The presence of mackerel in winter off the Grand Banks of Newfoundland, and not off the Scotian Shelf and Georges Bank, could explain the almost simultaneous arrival of mackerel on the east and west coasts of Newfoundland (Grégoire et al. 2009). This change in wintering grounds could also be the reason for the substantial drop in commercial catches which has been observed in recent years in Nova Scotia (Grégoire et al. 2009). In addition to this decrease, the bottom trawl surveys conducted in winter on the Scotian Shelf and Georges Bank have yielded very few mackerel, as though they were wintering elsewhere (Grégoire et al. 2009).

The commercial catch pattern in Canadian waters, the very low catches by bottom trawl surveys on the Scotian Shelf and Georges Bank, and the low catches from the U.S. survey in the region between Cape Cod and Georges Bank may be the result of a shift by the Canadian contingent to more northerly regions. This phenomenon was observed recently in Europe (ICES 2008, Jacobsen 2008, Nøttestad 2008).

To ensure proper management of the mackerel fishery, it is essential to improve knowledge about mackerel migration and distribution patterns in the northwest Atlantic. It is also important to consider the role that certain environmental variables could have on recent changes in migration and distribution that have been observed in Canadian waters. A tagging program should also be introduced to study the mixing between the two contingents during the winter fishery in U.S. waters.

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Table 1. Set characteristics of the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

YEAR	Nb. STRATA	Nb. AREA	STATION TOTAL			STATION EAST OF 70° W		MACKEREL (nb/set)		
			Nb.	Nb. With Mackerel	% With Mackerel	With Mackerel	% With Mackerel	Min.:	Mean	Max.:
1968	41	23	180	38	21.1	5	2.8	0	53.8	3 538
1969	41	23	184	16	8.7	2	1.1	0	0.9	107
1970	41	23	193	58	30.1	12	6.2	0	11.9	448
1971	41	22	191	44	23.0	1	0.5	0	11.2	736
1972	41	23	194	51	26.3	15	7.7	0	8.2	331
1973	41	25	216	67	31.0	13	6.0	0	79.9	15 619
1974	41	23	159	58	36.5	29	18.2	0	6.3	253
1975	37	19	163	32	19.6	11	6.7	0	7.4	738
1976	41	22	191	39	20.4	11	5.8	0	7.9	494
1977	41	23	191	36	18.8	3	1.6	0	1.3	80
1978	41	23	194	28	14.4	0	0.0	0	3.8	256
1979	41	23	251	25	10.0	7	2.8	0	0.4	15
1980	41	24	231	31	13.4	5	2.2	0	2.0	220
1981	40	23	169	43	25.4	10	5.9	0	15.8	1 120
1982	41	23	180	30	16.7	1	0.6	0	5.1	420
1983	41	20	175	27	15.4	16	9.1	0	0.7	23
1984	41	23	178	20	11.2	0	0.0	0	11.2	603
1985	41	25	172	39	22.7	11	6.4	0	9.2	595
1986	41	21	178	33	18.5	8	4.5	0	3.5	379
1987	41	23	179	48	26.8	2	1.1	0	26.8	1 470
1988	40	22	160	33	20.6	0	0.0	0	14.0	579
1989	41	25	155	31	20.0	2	1.3	0	9.3	316
1990	40	23	157	30	19.1	0	0.0	0	8.6	632
1991	41	23	160	46	28.8	15	9.4	0	15.3	910
1992	39	23	156	44	28.2	7	4.5	0	18.3	692
1993	39	23	157	42	26.8	11	7.0	0	21.6	974
1994	40	21	158	42	26.6	11	7.0	0	32.4	1 064
1995	41	22	156	59	37.8	18	11.5	0	19.7	859
1996	41	23	167	55	32.9	22	13.2	0	37.4	2 222
1997	39	24	158	48	30.4	20	12.7	0	20.3	1 168
1998	40	23	163	64	39.3	26	16.0	0	19.8	681
1999	41	24	160	68	42.5	25	15.6	0	45.8	1 521
2000	41	24	160	61	38.1	32	20.0	0	70.4	2 067
2001	41	22	160	75	46.9	40	25.0	0	114.8	5 792
2002	41	24	159	53	33.3	22	13.8	0	28.7	1 232
2003	41	23	151	54	35.8	11	7.3	0	41.6	1 103
2004	41	22	160	47	29.4	7	4.4	0	80.5	2 536
2005	41	23	159	31	19.5	0	0.0	0	27.5	1 944
2006	40	22	161	49	30.4	8	5.0	0	52.8	2 590
2007	41	23	186	61	32.8	20	10.8	0	26.6	2 511
2008	41	21	167	46	27.5	13	7.8	0	57.9	3 946
1968-2008										
Min.:	37	19	151	16	8.7	0	0	0	0.4	15
Mean[1]:	40.6	22.8	174.1	44.0	25.2	11.5	6.6	0.0	24.4	1 531.3
Max.:	41	25	251	75	46.9	40	25.0	0	114.8	15 619

[1] Based on all the sets pooled together

Table 1. (Continued.)

YEAR	DEPTH (m)			BOTTOM TEMP. (°C)		
	Min.:	Mean	Max.:	Min.:	Mean	Max.:
1968	20.0	106.0	329.5	0.0	5.4	11.4
1969	21.5	102.4	379.5	0.0	5.7	13.3
1970	28.5	104.8	333.5	0.0	6.6	15.8
1971	19.0	100.2	329.0	0.0	5.7	14.3
1972	26.0	106.0	370.5	0.0	7.5	16.1
1973	0.0	84.9	494.0	0.0	6.4	15.5
1974	26.0	106.3	417.0	0.0	7.8	15.3
1975	0.0	99.4	329.0	0.0	6.5	12.5
1976	18.0	97.8	470.0	0.0	7.9	14.8
1977	19.0	98.5	410.0	0.0	6.6	11.3
1978	23.0	96.0	348.0	2.3	5.8	13.1
1979	19.0	89.3	281.0	0.0	6.5	12.0
1980	22.0	89.6	424.0	3.3	7.1	13.0
1981	25.0	93.9	359.0	0.0	7.0	14.5
1982	24.0	103.5	393.0	0.0	4.2	12.3
1983	24.5	103.1	334.0	0.0	6.9	16.7
1984	22.0	100.7	455.5	0.0	7.1	16.2
1985	19.5	98.8	430.5	0.0	2.9	12.9
1986	19.5	105.1	382.5	0.0	3.6	18.2
1987	24.0	103.1	358.5	0.0	4.1	12.2
1988	27.0	86.8	374.0	0.0	4.2	11.8
1989	19.0	88.7	342.0	0.0	2.9	13.5
1990	18.5	86.9	399.5	0.0	3.6	12.6
1991	26.0	92.7	343.0	0.0	7.3	17.8
1992	12.5	84.0	312.5	0.0	6.6	13.9
1993	18.0	84.2	344.5	2.5	5.9	14.8
1994	23.0	87.1	304.0	0.0	6.9	13.4
1995	24.0	88.9	323.0	0.0	7.8	14.0
1996	16.5	88.8	327.5	0.0	6.6	14.2
1997	20.5	85.6	284.5	3.7	7.5	13.4
1998	22.5	86.6	313.0	0.0	6.4	14.4
1999	24.5	86.8	309.0	0.0	7.8	16.2
2000	19.0	82.8	267.5	0.0	8.0	13.3
2001	23.0	92.0	358.0	3.8	7.1	14.4
2002	16.0	90.2	378.0	5.1	8.6	14.5
2003	21.0	87.2	323.0	0.0	5.6	11.6
2004	16.0	89.4	375.0	0.0	5.3	11.9
2005	22.0	87.6	355.0	0.0	6.2	13.0
2006	18.0	88.5	354.0	4.2	7.7	14.0
2007	22.0	99.0	366.0	3.2	6.9	11.8
2008	23.0	85.1	293.0	0.0	7.3	13.0
<u>1968-2008</u>						
Min.:	0	82.8	267.5	0	2.9	11.3
Mean[1]:	20.3	93.9	357.9	0.7	6.3	13.9
Max.:	28.5	106.3	494.0	5.1	8.6	18.2

[1] Based on all the sets pooled together

Table 2. Standardized stratified mean catch per set in numbers and weight (kg) for Atlantic mackerel in the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

	SPRING SURVEY BACKTRANSFORMED GEOMETRIC MEAN	
YEAR	No/Set	Wt/Set
1968	17.921	1.831
1969	0.190	0.033
1970	2.908	0.972
1971	3.154	1.023
1972	2.566	0.657
1973	3.490	0.885
1974	3.444	0.866
1975	1.200	0.232
1976	1.353	0.345
1977	0.535	0.209
1978	1.068	0.482
1979	0.405	0.231
1980	0.797	0.368
1981	4.606	1.978
1982	1.112	0.396
1983	0.611	0.121
1984	2.819	0.971
1985	3.036	1.005
1986	1.334	0.484
1987	14.006	3.676
1988	7.095	2.469
1989	4.321	0.713
1990	4.104	0.883
1991	6.577	1.477
1992	12.719	2.267
1993	9.767	2.674
1994	15.604	3.045
1995	15.668	2.865
1996	15.555	2.669
1997	6.679	1.248
1998	13.389	1.736
1999	24.723	3.723
2000	30.193	3.446
2001	59.106	6.022
2002	11.387	2.615
2003	44.151	5.177
2004	32.741	3.063
2005	7.761	1.611
2006	38.982	4.917
2007	15.602	2.606
2008	9.166	1.893

Table 3. Parameters of the isotropic variograms calculated from the number of Atlantic mackerel per set for the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

YEAR	MODEL*	Nugget (C0)	Sill (C0+C)	*Range* (A_0)	R^2	RSS**
1968	Spherical	10	5775	36	0.96	1.77E+05
1969	*Spatial structure of the data doesn't allow the construction of a variogram*					
1970	Spherical	1	3058	33	0.94	9.92E+04
1971	Spherical	1	355	38	0.93	1.69E+03
1972	Exponential	334	1620	29	0.82	9.56E+04
1973	Spherical	0	133	45	0.94	9.29E+02
1974	Spherical	0	126	92	0.96	4.47E+02
1975	Spherical	1	8	137	0.98	8.44E-01
1976	Spherical	10	34	138	1.00	1.74E-01
1977	Spherical	3	8	100	0.91	1.74E+00
1978	*Spatial structure of the data doesn't allow the construction of a variogram*					
1979	Spherical	1	3	368	0.93	1.52E-01
1980	*Spatial structure of the data doesn't allow the construction of a variogram*					
1981	*Spatial structure of the data doesn't allow the construction of a variogram*					
1982	Spherical	349	1614	65	0.93	2.73E+04
1983	Spherical	4	9	84	0.89	1.70E+00
1984	Spherical	11	43	82	0.89	5.33E+01
1985	Spherical	1	623	41	0.86	2.04E+04
1986	Spherical	8	25	70	0.95	6.84E+00
1987	Spherical	1	2596	52	0.96	4.46E+04
1988	Spherical	580	4075	50	0.90	3.70E+05
1989	Spherical	365	1221	37	0.97	5.14E+03
1990	Spherical	0	102	34	0.97	1.33E+02
1991	Spherical	12	208	109	0.93	2.09E+03
1992	Spherical	10	5551	80	0.86	1.81E+06
1993	Spherical	1	1144	50	0.87	9.47E+04
1994	Spherical	1	1738	27	0.87	4.34E+04
1995	Spherical	10	6825	53	0.91	4.46E+06
1996	Spherical	100	35960	58	0.90	8.39E+07
1997	Exponential	1183	2367	102	0.85	5.65E+04
1998	Exponential	620	7243	6	0.97	5.27E+04
1999	Spherical	10	8624	63	0.95	1.68E+06
2000	Spherical	10	5724	80	0.95	4.02E+05
2001	Spherical	10	13920	38	0.98	7.08E+05
2002	Spherical	720	8021	53	0.91	1.57E+06
2003	Spherical	10	20810	51	0.91	2.43E+07
2004	Spherical	10	12940	54	0.96	3.07E+06
2005	Spherical	1	590	42	0.84	1.82E+04
2006	Spherical	1	2702	38	0.76	7.54E+05
2007	Exponential	100	54010	34	0.94	6.04E+07
2008	Spherical	84	186	171	0.90	8.41E+02

* Spherical $$\gamma(h) = \begin{cases} C0 + C\left[1.5\left(\frac{h}{A_0}\right) - 0.5\left(\frac{h}{A_0}\right)^3\right] & \text{if } h \le A_0, \text{ and } C0 + C \text{ otherwise} \end{cases}$$

Exponential $$\gamma(h) = C0 + C\left[1 - \exp\left(-\frac{h}{A_0}\right)\right]$$

** Residual sum of squares

Table 4. Mean number per set of Atlantic mackerel calculated by kriging for the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

YEAR	MEAN NUMBER PER SET		
	TOTAL	East of 70° W	West of 70° W
1968	56.988	14.730	82.920
1969	n/a	n/a	n/a
1970	13.688	1.190	21.357
1971	12.514	0.047	20.164
1972	7.987	4.280	10.262
1973	5.161	6.375	4.416
1974	7.197	4.400	8.914
1975	5.471	11.598	1.710
1976	7.312	8.534	6.562
1977	0.858	0.067	1.343
1978	n/a	n/a	n/a
1979	0.535	0.314	0.670
1980	n/a	n/a	n/a
1981	n/a	n/a	n/a
1982	4.910	0.028	7.906
1983	0.952	0.903	0.982
1984	12.311	0.001	19.866
1985	8.728	9.027	8.545
1986	4.272	0.464	6.609
1987	30.670	0.093	49.435
1988	16.106	0.790	25.505
1989	11.276	1.097	17.522
1990	11.005	0.003	17.756
1991	30.573	0.734	48.885
1992	32.594	0.776	52.120
1993	24.288	8.853	33.761
1994	35.930	2.833	56.241
1995	30.208	8.660	43.431
1996	40.075	6.875	60.449
1997	19.909	22.473	18.335
1998	24.570	11.798	32.407
1999	41.283	73.022	21.805
2000	59.865	120.431	22.697
2001	117.453	217.983	55.761
2002	34.711	7.480	51.422
2003	56.231	3.283	88.724
2004	74.516	0.769	119.773
2005	38.659	0.000	62.382
2006	68.686	0.176	110.729
2007	30.228	49.055	18.674
2008	22.716	2.743	34.973

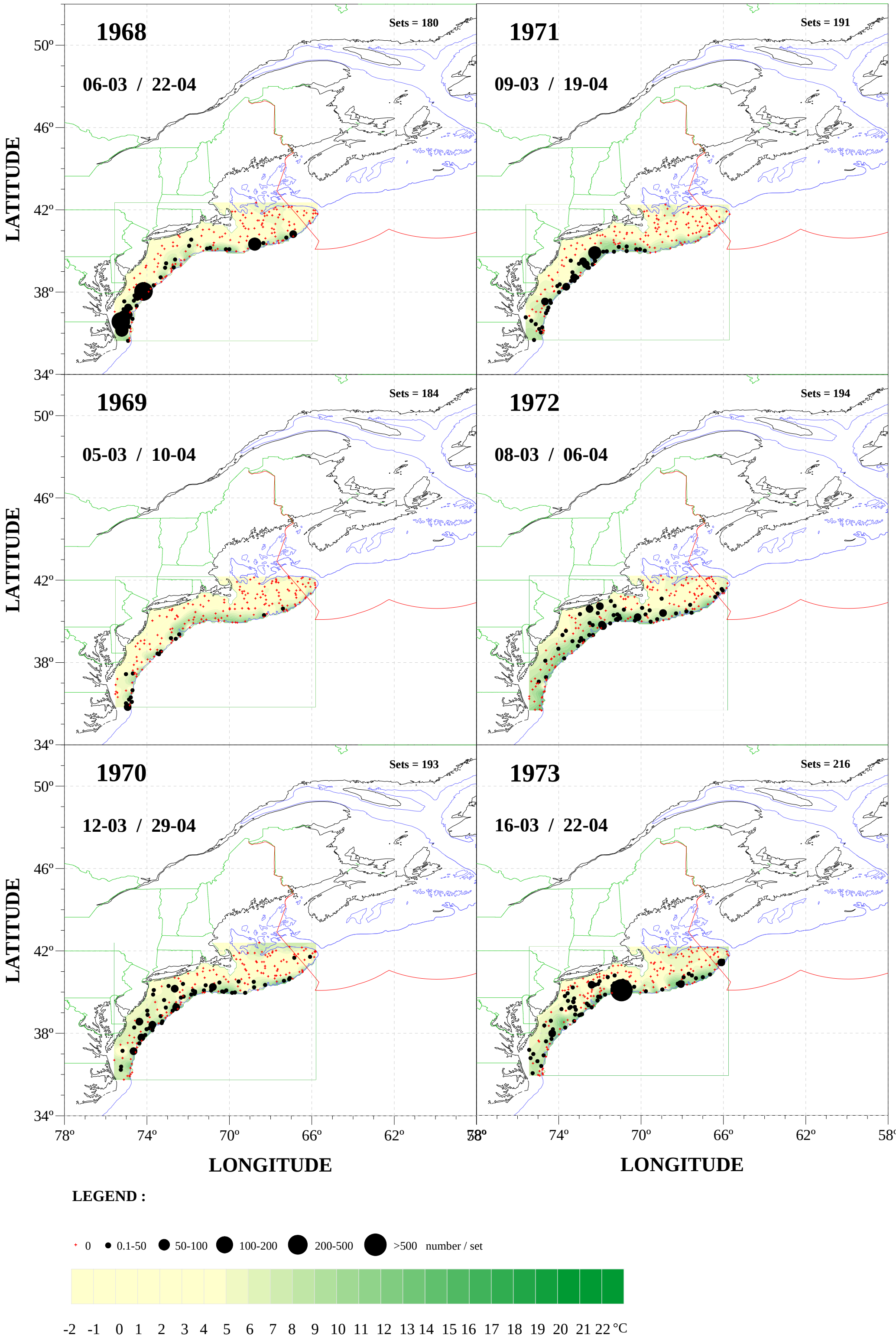


Figure 1. Spatial distribution of Atlantic mackerel (nb/set) and bottom temperature (°C) for the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

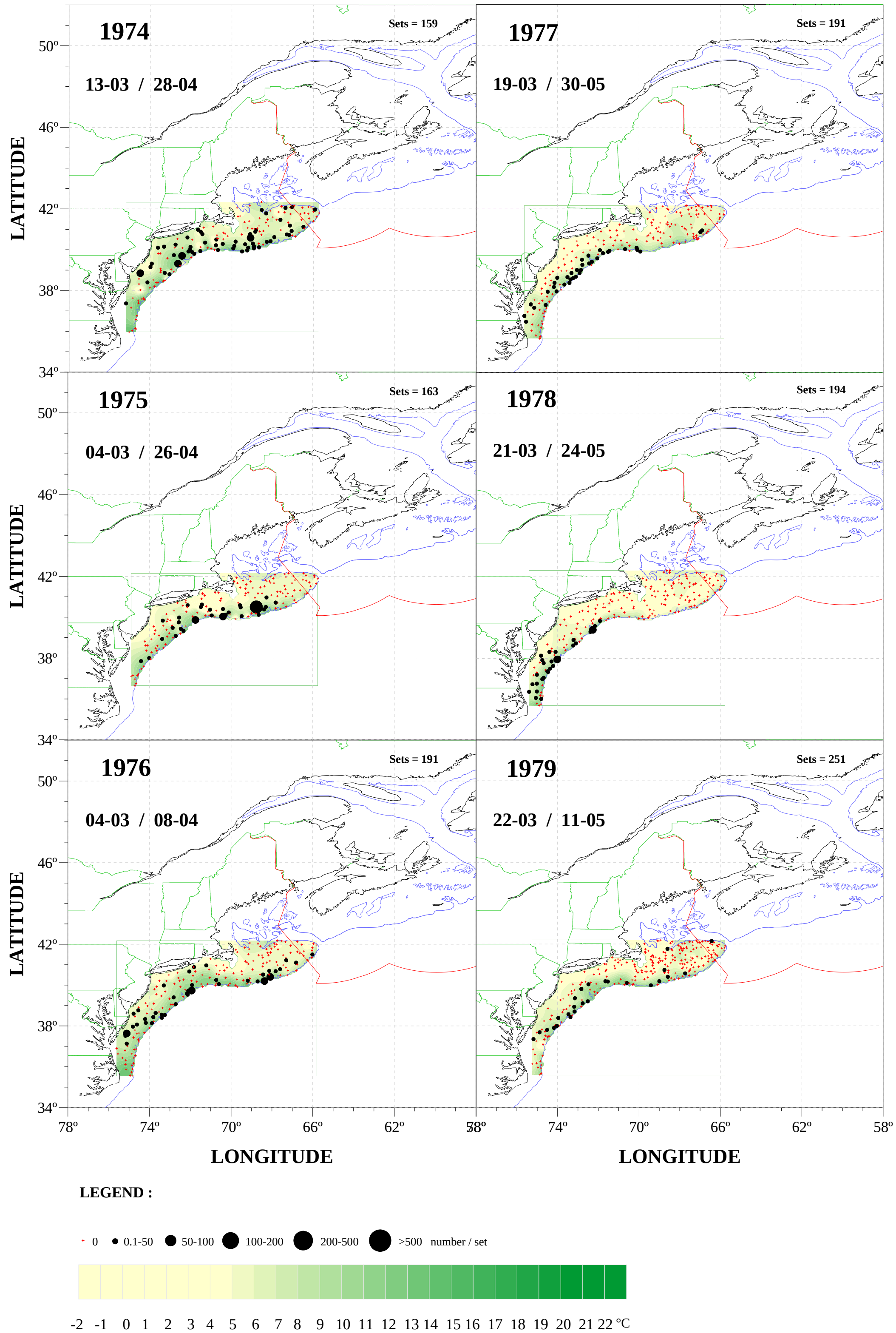


Figure 1. (Continued.)

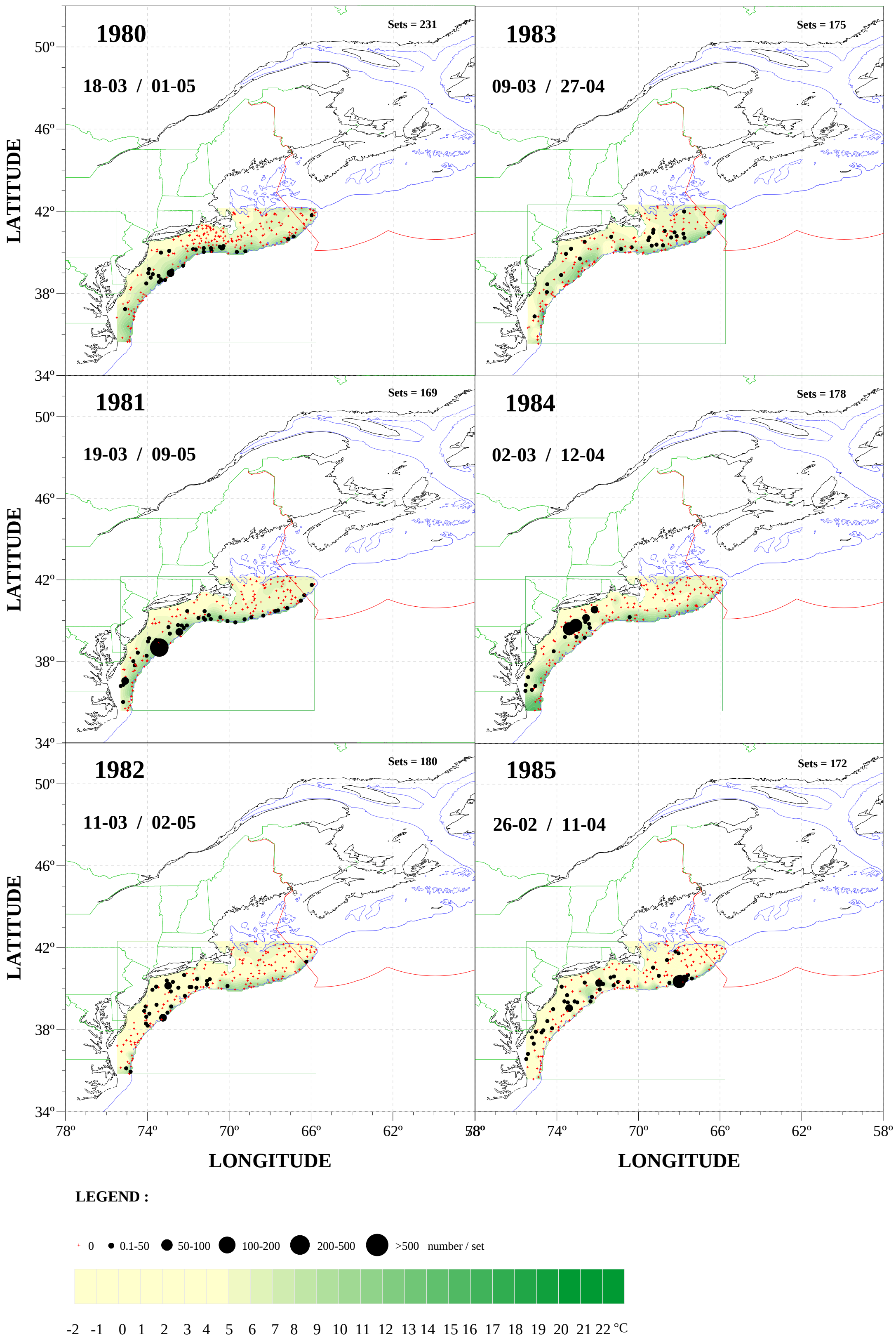


Figure 1. (Continued.)

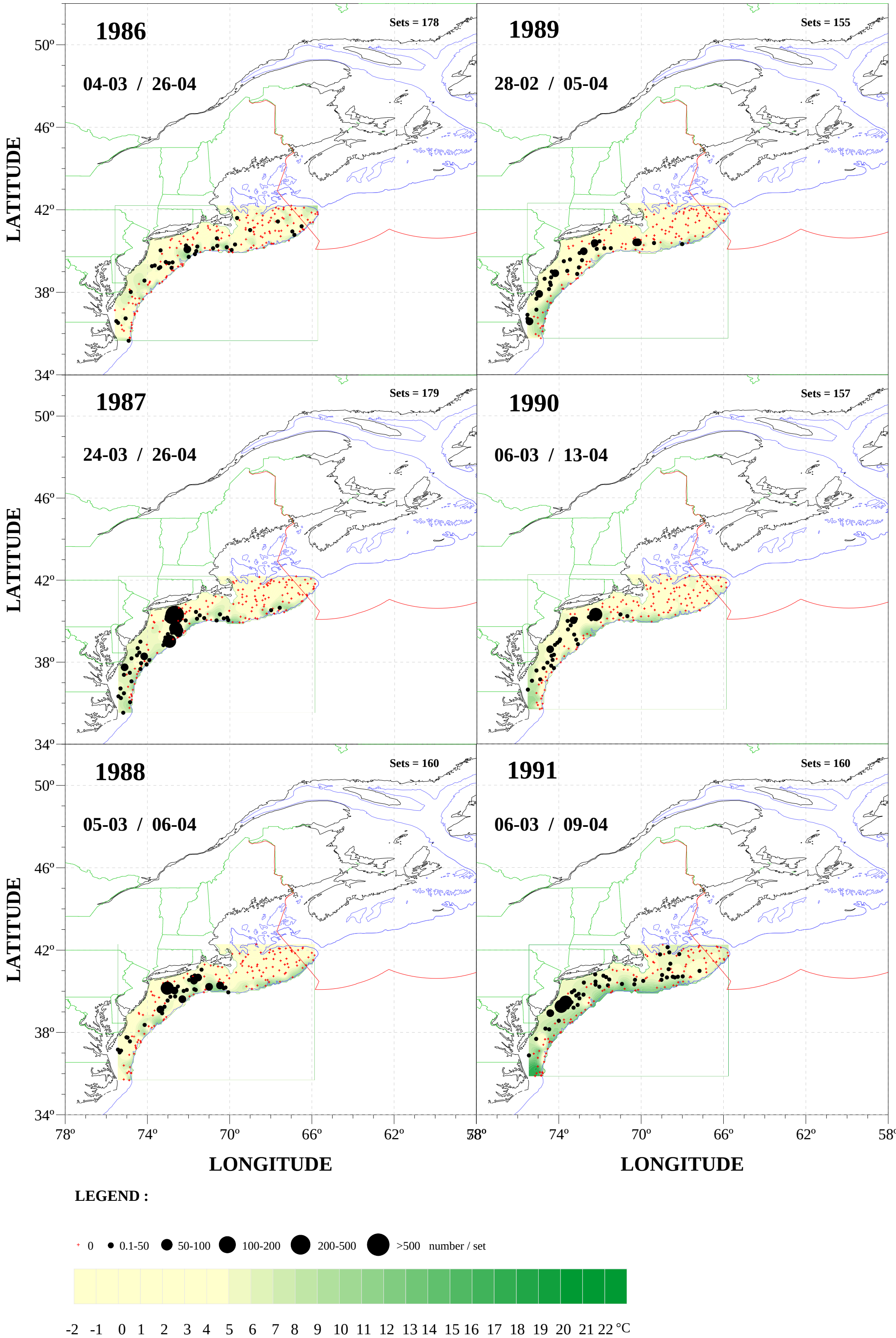


Figure 1. (Continued.)

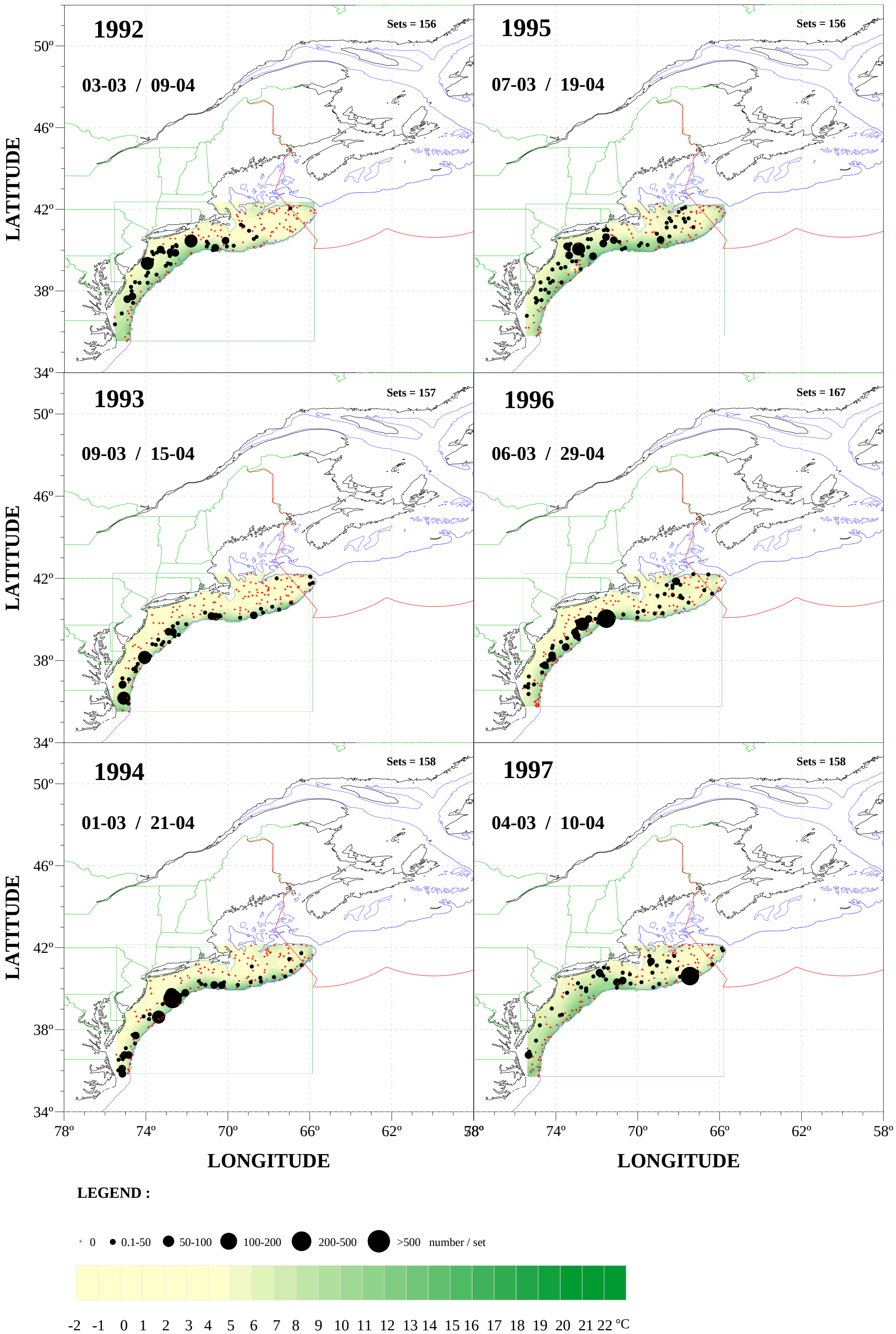


Figure 1. (Continued.)

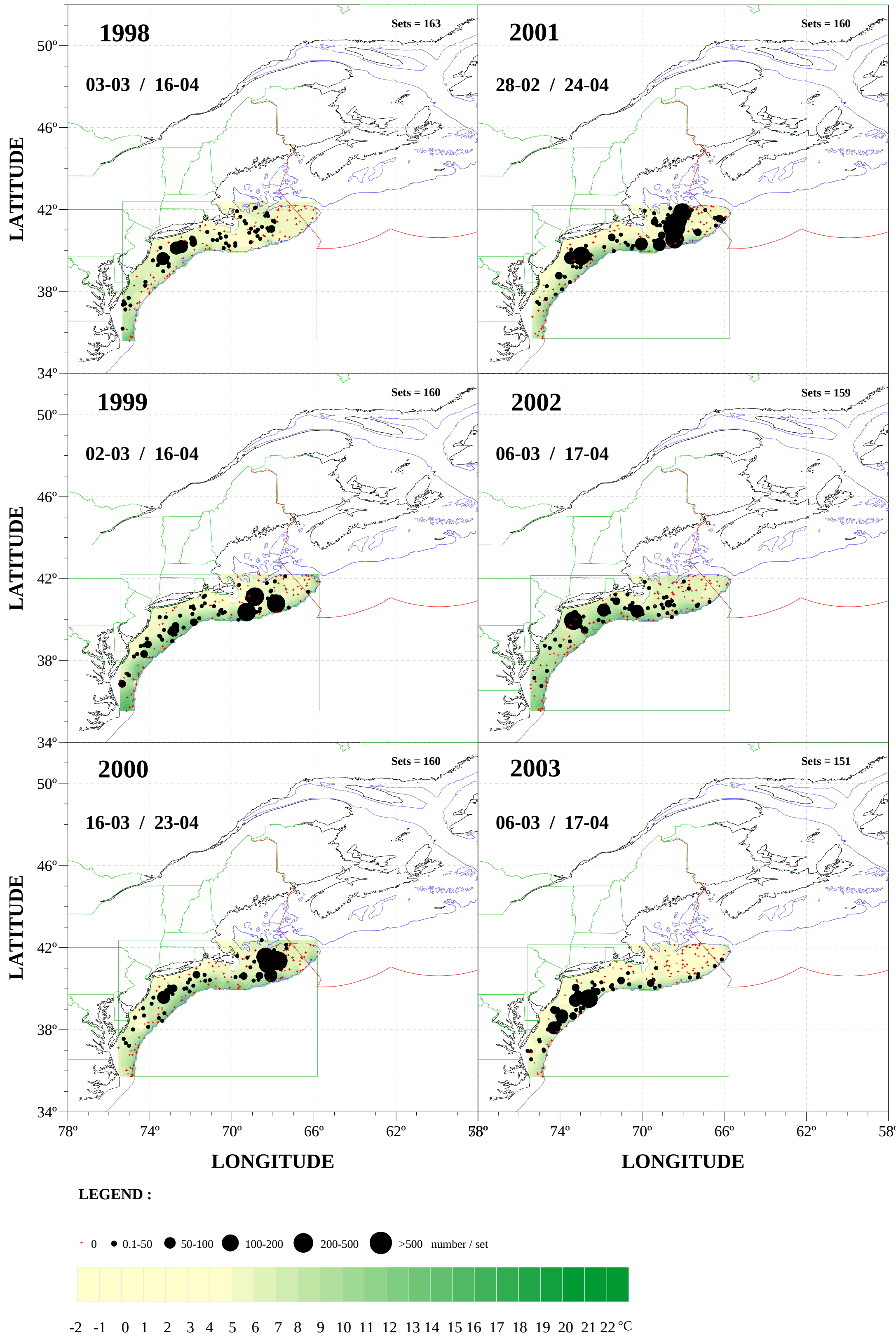


Figure 1. (Continued.)

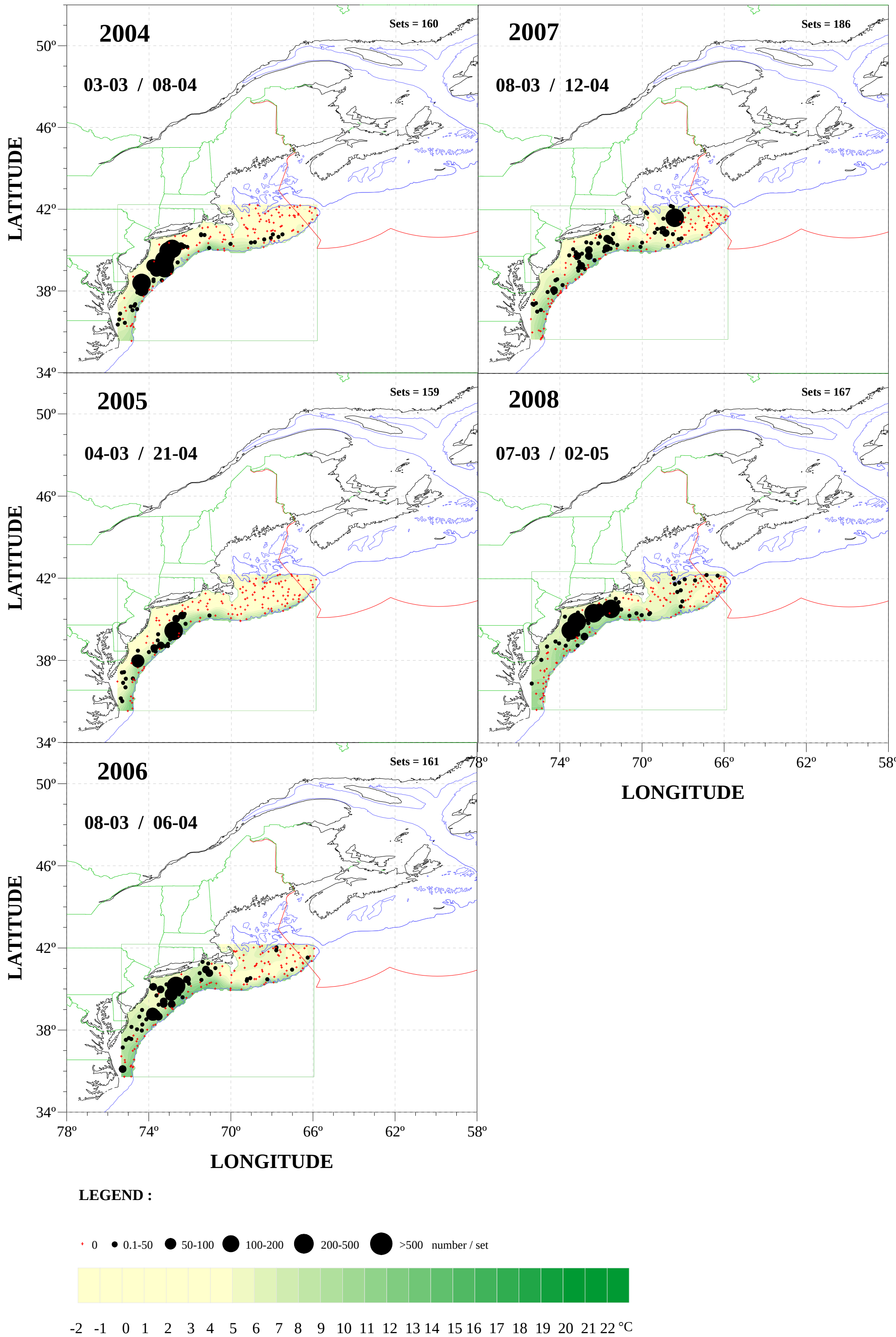


Figure 1. (Continued.)

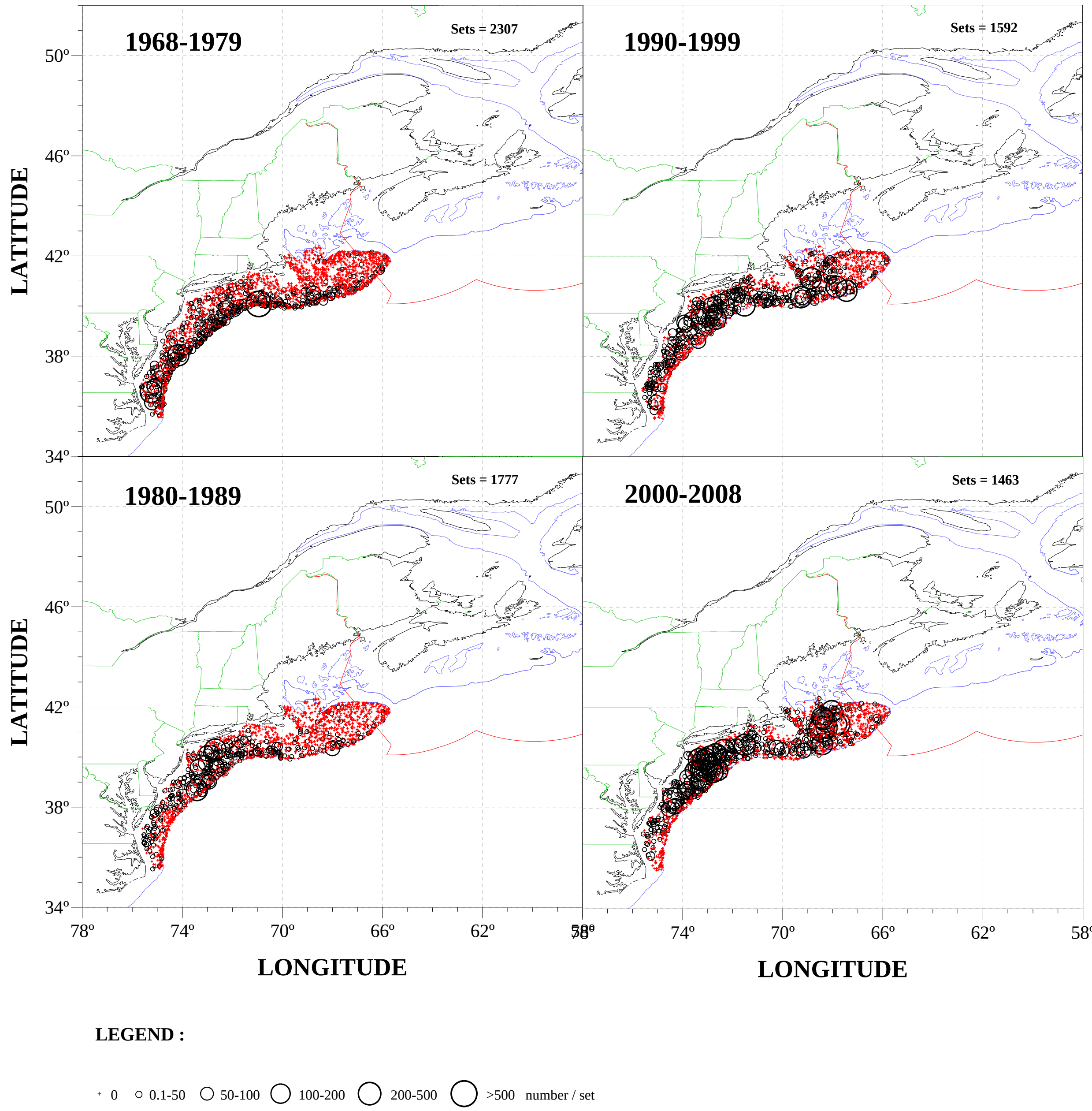


Figure 2. Composite maps of the spatial distribution of Atlantic mackerel (nb/set) for the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

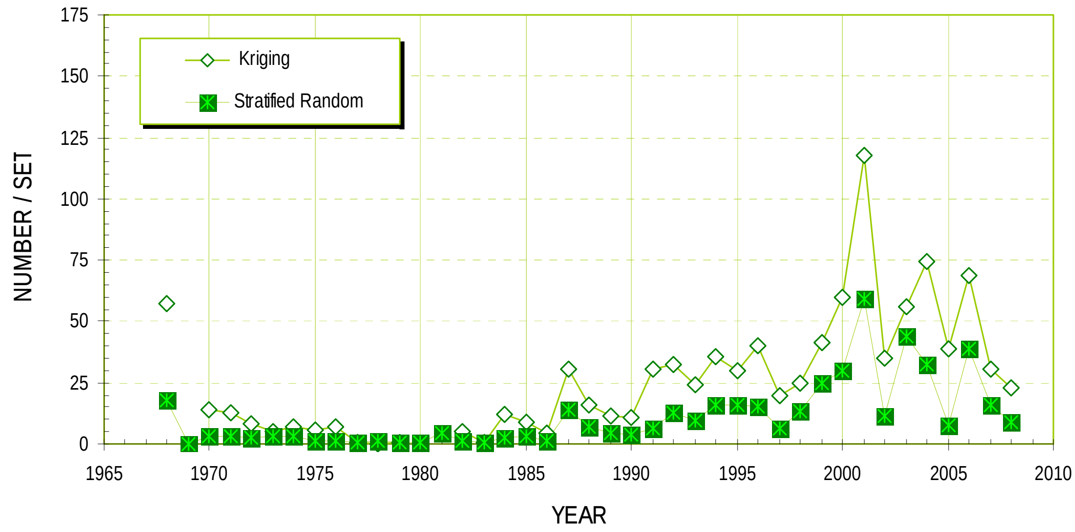


Figure 3. Mean number of Atlantic mackerel per set calculated by kriging and from a stratified random design survey for the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

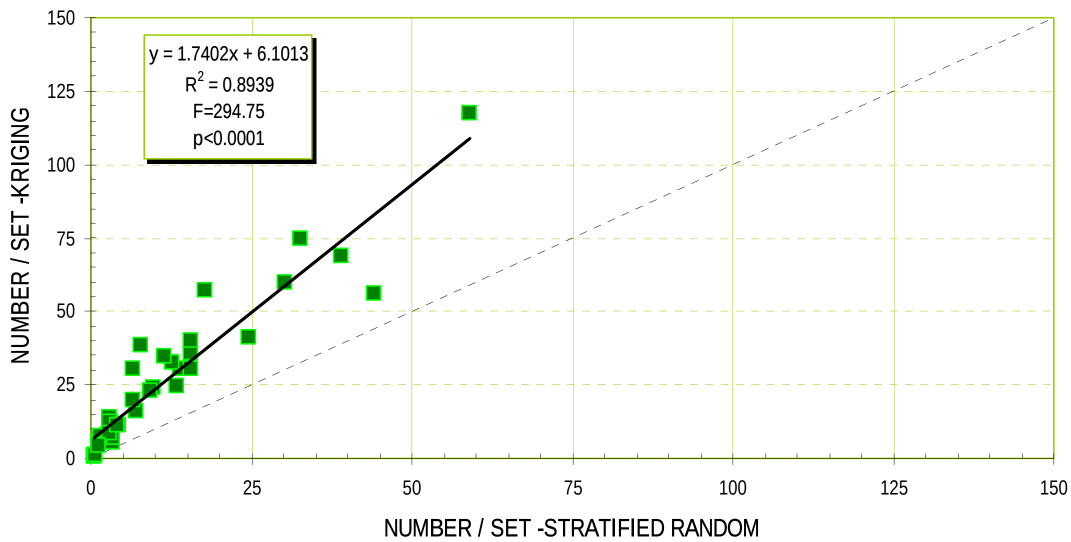


Figure 4. Relationship between the mean numbers of Atlantic mackerel per set calculated by kriging and from a stratified random design survey for the NEFSC spring research vessels bottom trawl surveys conducted from 1968 to 2008.

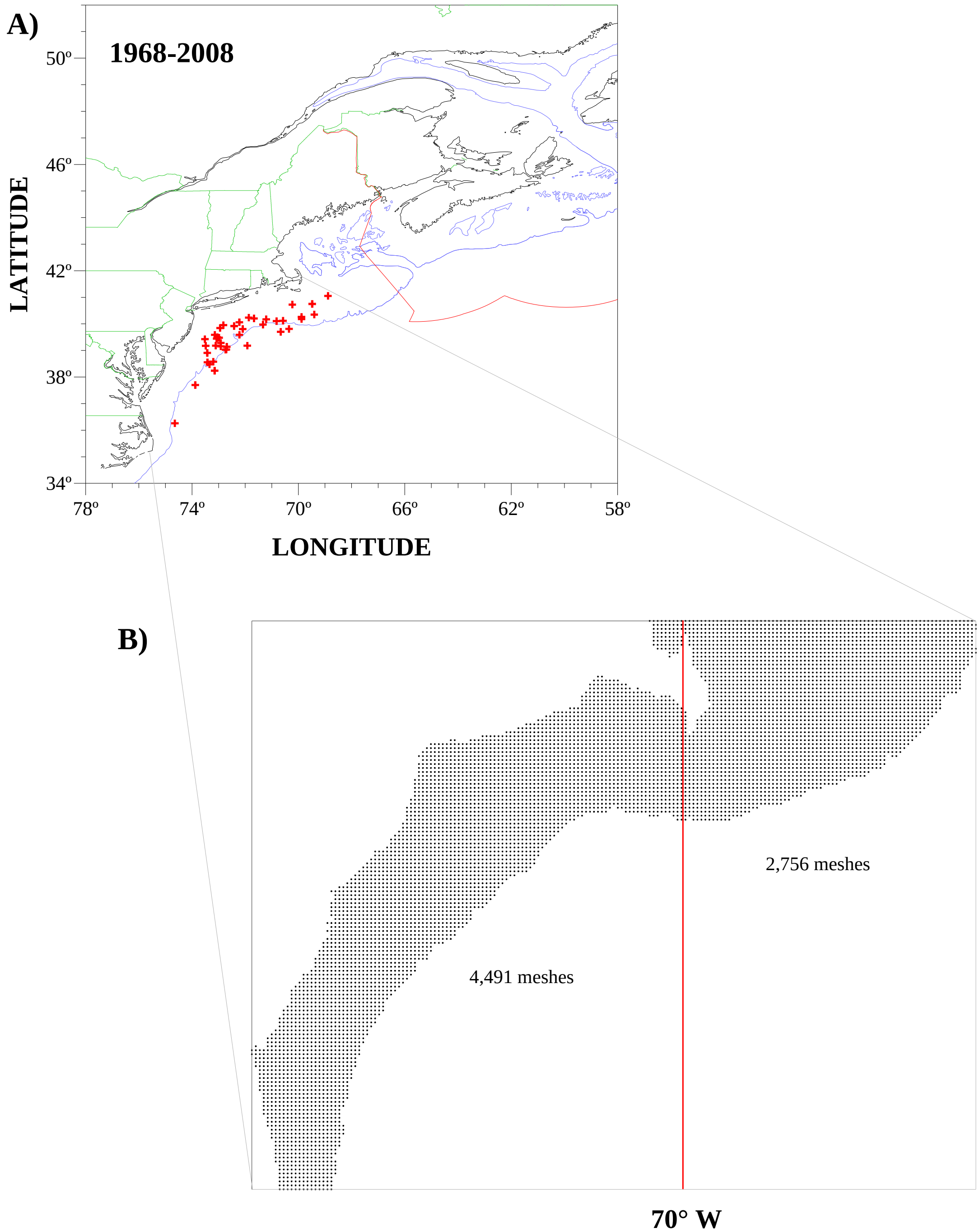


Figure 5. Mean longitude and latitude of Atlantic mackerel catches for each NEFSC spring research vessels bottom trawl survey conducted between 1968 and 2008 (A) and locations of 7,247 meshes used for kriging the numbers per set of Atlantic mackerel (the points are 5 km apart) (B).

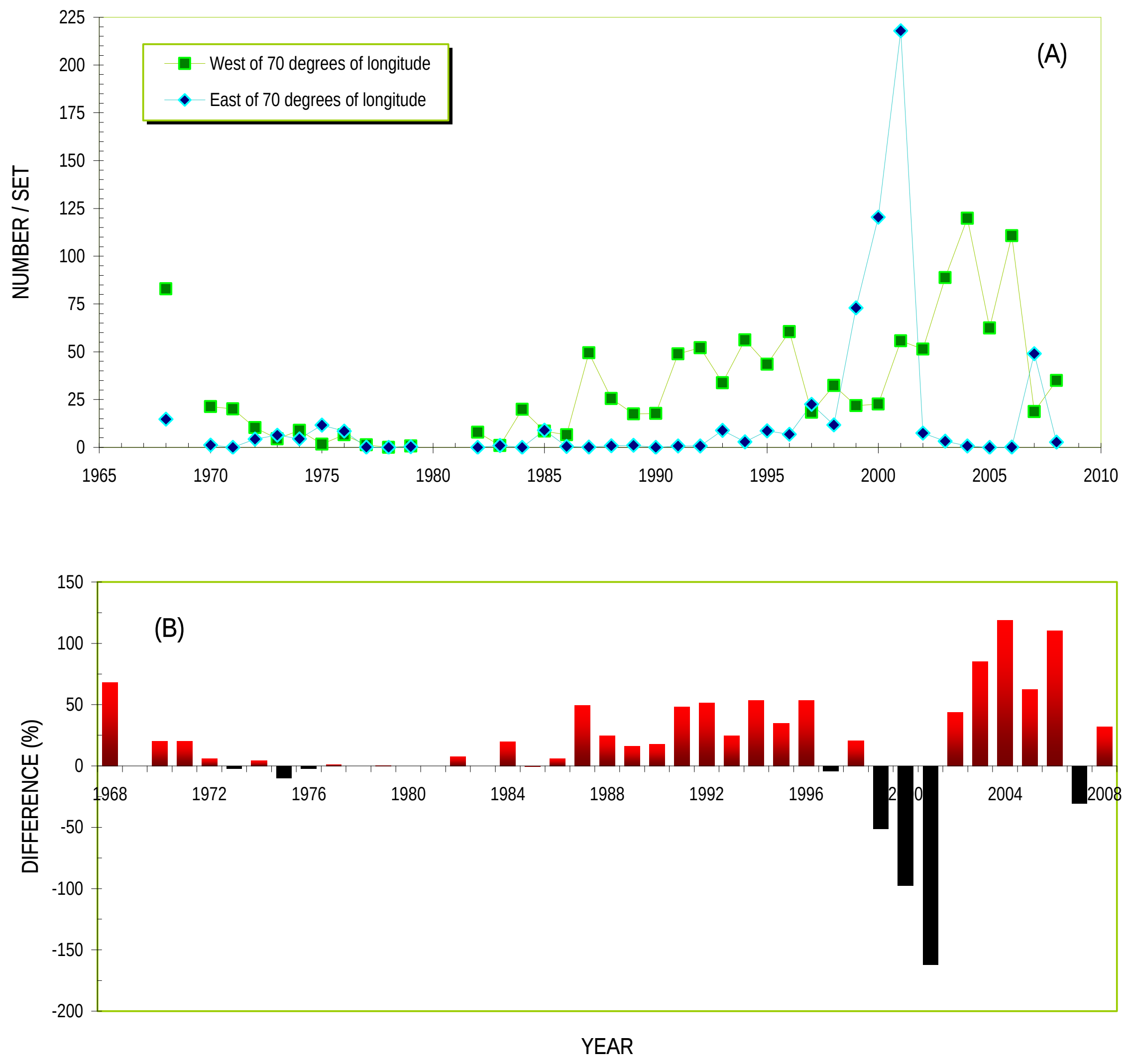
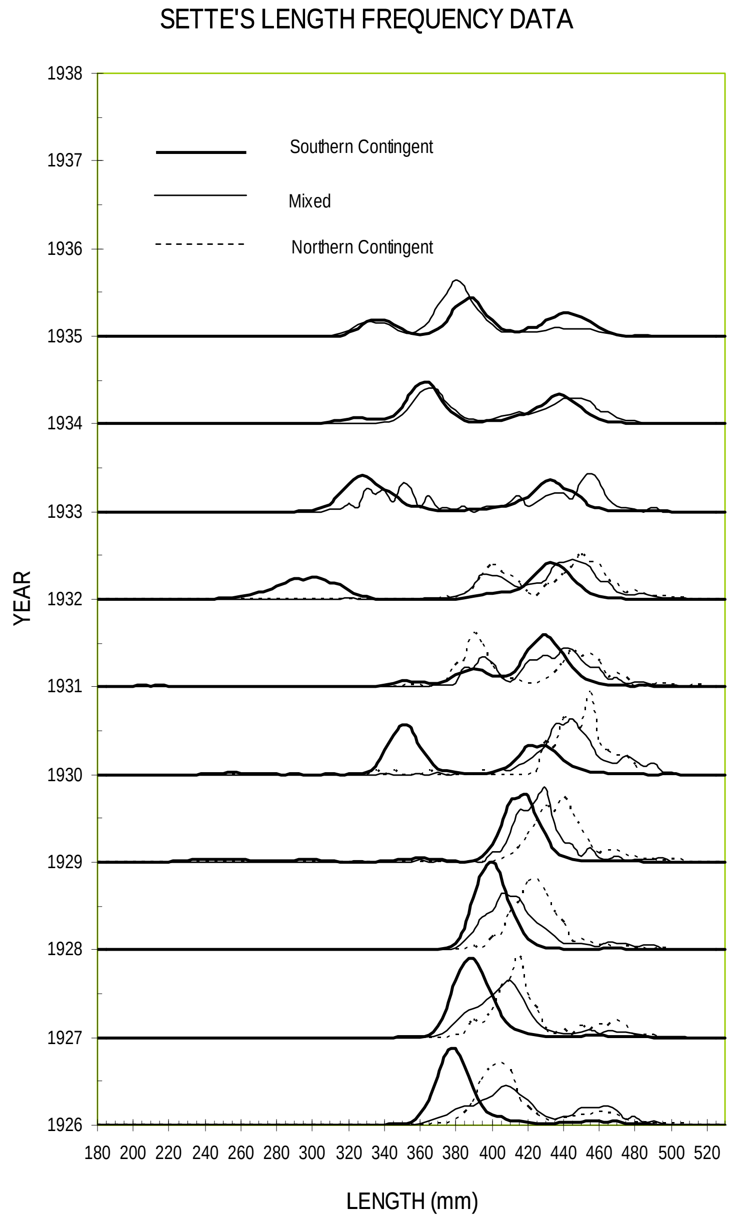


Figure 6. Mean number of Atlantic mackerel per set (A) calculated by kriging for the areas located to the west and east of 70° of longitude W and difference (%) between the west and east areas (B).

Appendix 1. Mackerel length distributions in May and June for the years 1926 to 1935 and for three categories: southern contingent, mixed and northern contingent (from Sette, 1950).



Note: Between 1926 and 1932, two different (strong) year-classes characterized the southern and northern contingents. In 1934 and 1935, the southern contingent and mixed distributions were similar.