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Factors Influencing Spring Distribution, Availability, and Recreational Catch of Atlantic Mackerel *(Scomber scombrus)* in the Middle Atlantic and Southern New England Regions

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Northeast Region
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Factors Influencing Spring Distribution, Availability, and Recreational Catch of Atlantic Mackerel *(Scomber scombrus)* in the Middle Atlantic and Southern New England Regions

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ABSTRACT

The relationship between the spring distribution of Atlantic mackerel *(Scomber scombrus)*, environmental factors, and the recreational fishery for mackerel in the Mid-Atlantic - Southern New England region was investigated. The Northwest Atlantic stock of Atlantic mackerel is highly migratory, with the southern spawning contingent showing a pronounced inshore and northward migration during the spring and early summer, and the northern spawning contingent moving north into the Gulf of St. Lawrence at this time. We examined catch distribution maps constructed from spring research vessel bottom trawl surveys; results indicated that the center of abundance of the stock shifts toward the south in years with cool-to-moderate shelf temperatures and shifts northward in warmer years. Catches of mackerel in the Northeast Fisheries Science Center's spring bottom trawl surveys are usually at bottom water temperatures of 5°C or greater; mackerel tend to actively avoid cooler water. Recreational catch in the Mid-Atlantic - Southern New England region is positively, but weakly, correlated with stock size, and is probably highly influenced by the thermal regime in the early spring. Recreational catch may also be related to wind direction and intensity during March; this is probably an indication that regional meteorological conditions heavily influence the inshore environment at this time.

INTRODUCTION

Atlantic mackerel *(Scomber scombrus)* in the Northwest Atlantic have been fished commercially along the coast of the eastern United States since the early 1800s (Sette and Needler 1934; Hoy and Clark 1967; Anderson and Paciorkowski 1980; Overholtz and Parry 1985; Figure 1). Since 1960, a major commercial and recreational fishery developed in the Mid-Atlantic (Massachusetts to Virginia) region (Figure 1) during the winter and spring when the transient mackerel stock is abundant there. A large distant-water fleet began fishing for mackerel in the Mid-Atlantic region in the late 1960s, and annual catches averaged 310,000 metric tons (mt) during 1970-76 (Anderson and Paciorkowski 1980). These large catches were not sustainable and the stock collapsed. Catches declined dramatically, and coincident with extension of U.S. management responsibility to 200 miles offshore, the Mid-Atlantic Fishery Management Council (MAFMC) established controls on the fishery in the early 1980s under authority of the Magnuson Fishery Conservation and Management Act. During the 1980s, the MAFMC utilized annual catch quotas, established a target minimum spawning stock size (600,000 mt), and -- to the extent possible -- minimized foreign fishing on the mackerel stock to enhance the spring recreational fishery.

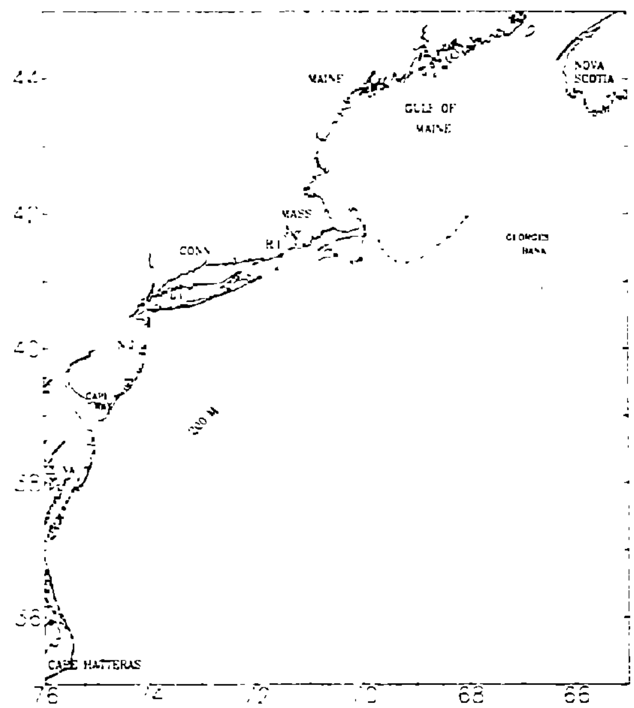

Figure 1. Map of the eastern United States from North Carolina to Maine with place names mentioned in the text, and with the 200-m isobath.

During the late 1960s, an intense recreational fishery for mackerel also developed in the springtime. Catches from this fishery have been highest along the nearshore areas of New Jersey and New York, locations where the fish form spawning congregations in April and May (Sette 1950; Murray *et al.* 1983). Recreational catch declined in the late 1970s and early 1980s coincident with the collapse of the stock, but clear trends before that time are difficult to discern because of sparse data.

The waters on the Mid-Atlantic - Southern New England continental shelf exhibit a large seasonal cycle in temperature (Colton and Stoddard 1972; Mountain and Holzwarth 1989). In winter, the water column is vertically well mixed with temperatures of less than 4°C near the coast and increasing to above 8°C near the shelf edge. In the spring, the surface layers begin to warm and temperatures continue to increase through the summer, with the warming progressing from south to north. The annual maximum surface-layer temperatures are above 25°C over the southern part of the shelf and decrease to the north, with maximum values south of Nantucket of about 18°C. In the early fall, the surface-layer temperature begins to decrease, and cooling continues until reaching minimum values in late February or early March (Han and Niedrauer 1981).

Mackerel are sensitive to temperature both in terms of physiological and behavioral responses and also in relation to timing of migration and spawning activity (Sette 1950; Olla *et al.* 1976; Anderson and Almeida 1977; Berrien 1982; Murray et al. 1983). Laboratory and field studies have shown that mackerel are intolerant of water temperatures less than 5-6°C, or greater than about 15-16°C (Olla *et al.* 1976; Overholtz and Anderson 1976). During the winter and early spring, mackerel are distributed in the warmer waters along the shelf-slope break from Hudson Canyon to Cape Hatteras (Sette 1950; Anderson and Almeida 1977). In April and early May, they begin a northward and inshore migration to form spawning aggregations. There are two spawning contingents (Sette 1950): (1) a southern contingent that spawns off New Jersey and New York, and (2) a northern contingent that spawns in the Gulf of St. Lawrence. Meteorological events or regional climatic conditions are probably important in determining the range, timing, and extent of these inshore spring migrations for the southern contingent (Murray *et al.* 1983). Thus, low temperatures in the spring could delay inshore migrations significantly and also affect their duration (Murray 1984). Changes in the temperature regime of the inshore area could be caused by the frequency or intensity of winter or spring storms, colder-than-normal winters, shifts in water masses, variations from normal wind patterns, and/or other factors.

The purpose of this study is to investigate changes in the distribution and recreational catch of Atlantic mackerel from the Northwest Atlantic stock in relation to environmental conditions. Relative abundance data from spring bottom trawl surveys conducted by the Northeast Fisheries Science Center (NEFSC) during 1968-87, wind stress estimates for the Mid-Atlantic region, and catch-effort information from recreational fishery surveys conducted by the National Marine Fisheries Service (NMFS) were utilized. Since none of these data were collected from studies that were specifically designed to monitor changes in mackerel distribution and catch, they are used in an exploratory sense, with the hope of defining important relationships that are broad enough in extent to be clearly defined. Additionally, the results should be useful for identifying possible causal factors and the limitations of the fisheries and environmental data.

METHODS

INITIAL HYPOTHESES

Prior to attempting analysis, we formulated a set of working hypotheses to focus our work so that our study would not resemble a random search of all possible variables to obtain the best model fit. To facilitate this approach, we discussed a conceptual model of the mackerel migration, its environmental determinants, and implications for recreational fishing success. We felt that spring inshore temperature was probably one of the dominant factors responsible for changes in mackerel distribution. This was based on previous work suggesting that mackerel were intolerant of temperatures less than about 5-6°C (Olla *et al.* 1976), and that the spring behavioral and physiological changes such as aggregation for spawning and maturation of gonads were keyed at least partly to the thermal regime during this time period.

We identified the need for a mechanistic model of factors influencing nearshore conditions in the spring. Regional meteorology, variation in seasonal climatic factors, and changes in coastal oceanography may all be important in determining the spring temperature regime off the Mid-Atlantic region. For example, southward winds off the Virginia Capes in the early spring could cause cold water to be trapped along the shore, or a severe spring storm off New Jersey could mix cold nearshore bottom water with warmer surface waters. We used meridional (north-south) wind stress, a measure of seasonal wind direction and intensity, as a proxy variable for many of the aforementioned processes. We also were interested in finding out if recreational catch was related to stock size.

DATA

After formulating these initial hypotheses, we attempted a series of correlation analyses, relating recreational catch to stock size, water temperature, and wind stress. Temperature data were collected during each cruise and at almost every station of the NEFSC's spring bottom trawl surveys conducted from 1968 through 1987. The design and protocol of these annual research surveys have been described in detail by Grosslein (1969) and Azarovitz (1981). The surveys are based on a stratified random design with appropriate statistical methods and sampling schedules applied throughout. The Mid-Atlantic survey starts in mid-March each year; the region has been sampled consistently each spring. Temperature records from these cruises were used to produce two different sets of data: (1) average bottom temperature for the entire Southern New England - Mid-Atlantic area representing minimum winter temperature conditions, and (2) average surface temperature for the inshore area from Cape May, New Jersey, to Long Island, New York, representing spring conditions (Table 1; Figure 2).

Monthly mean values of the meridional component of wind stress for a standard grid point representative of the central portion of the Middle Atlantic Bight (39°N, 75°W) were acquired from the wind-driven flow indices generated by the NMFS's Pacific Fisheries Environmental Group, and based on the surface atmospheric pressure analyses of the U.S. Navy Fleet Numerical Oceanographic Center. The wind stress data were used in correlation analyses to see if this measure of regional climatic energy was appropriate for explaining any of the variation in recreational catch that was observed over the 1979-87 period.

Table 1. Recreational catch, age 3+ stock size, average spring inshore surface temperature, average spring bottom temperature, and March wind stress data used in this study

Year	Recreational Catch (000s mt)	Age 3+ Stock Size (million fish)	Average Spring Inshore Surface Temp. (°C)[a]	Average Spring Bottom Temp. (°C)[a]	March Wind Stress (000s dyn/cm²)[b]
1962	3,565.0	531.0			
1963	3,981.0	635.0			
1964	4,343.0	705.0			
1965	4,292.0	645.0			
1966	4,535.0	606.0			
1967	4,498.0	629.0			
1968	7,781.0	939.0	2.55	6.32	
1969	13,050.0	1,898.0	2.50	6.29	
1970	16,039.0	4,453.0	6.12	7.73	
1971	16,426.0	4,232.0	3.91	7.09	
1972	15,588.0	3,762.0	4.94	8.43	
1973	10,723.0	2,886.0	4.76	9.79	
1974	7,640.0	2,171.0	6.32	9.22	
1975	5,190.0	1,560.0	5.39	7.03	
1976	4,202.0	1,536.0	5.98	8.01	
1977	522.0	1,399.0	4.89	6.24	
1978	6,571.0	1,204.0	4.08	5.81	
1979	3,588.0	1,017.0	5.35	6.47	48
1980	2,364.0	815.0	5.17	6.58	-65
1981	8,505.0	837.0	5.67	6.47	-556
1982	1,162.0	683.0	4.33	6.24	7
1983	3,280.0	664.0	5.33	6.87	-227
1984	2,618.0	1,385.0	4.52	6.79	-216
1985	3,287.0	5,136.0	5.07	6.90	-86
1986	3,943.0	4,238.0	6.00	7.08	11
1987	5,567.0	3,653.0	5.75	6.63	-93

[a]From NEFSC spring bottom trawl surveys.
[b]Meridional component of wind stress. Positive values are northward. Data from NMFS Pacific Fisheries Environmental Group based on U.S. Navy surface pressure analysis.

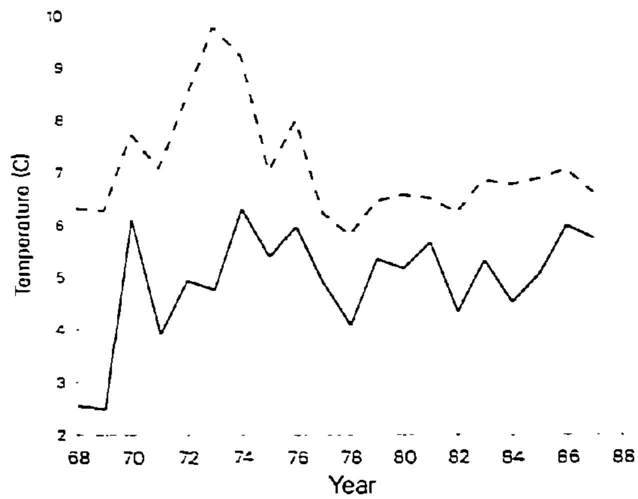

Figure 2. Average March-April bottom water temperature (°C, dashed line) for the Southern New England - Mid-Atlantic region, and average spring inshore surface water temperature (°C, solid line) for the New Jersey - Long Island area, from bottom trawl surveys conducted by the Northeast Fisheries Science Center during 1968-87.

Mackerel catches from the spring bottom trawl surveys were plotted on maps of the region to evaluate changes in distribution over the 1970-87 period (Figures 3a-c). Although these research surveys were not specifically designed for sampling pelagic fishes such as mackerel, they are still useful for defining fish distributions. We were interested in whether the distribution patterns of the Northwest Atlantic mackerel stock had changed over these two decades because stock size had undergone dramatic fluctuations over this period and temperatures were much more variable during the 1970s. These data were also converted to percent of catch by one degree of latitude on an annual basis and plotted to give another perspective on changes in the distribution of mackerel (Figure 4). Spring survey temperature data were used to produce contour maps for the area from Cape Hatteras, North Carolina, to southern Georges Bank for 1981 and 1982 in order to compare the years with the highest and lowest recreational catch (Figures 5a,b). In addition, trawl survey bottom temperature and catch of Atlantic mackerel were plotted for 1970, 1975, and 1981 (Figure 6) to ascertain if any mackerel were caught at temperatures less than their normal lower tolerance limit of 5°C (Olla *et al.* 1976). Since a previous study indicated that few mackerel are ever caught below 5°C (Overholtz and Anderson 1976), we only picked a few years in the time series to confirm this assertion.

A telephone recall survey of the recreational fishery was conducted in 1960, 1965, and 1970 to estimate recreational catch of Atlantic mackerel (Clark 1967; Deuel and Clark 1968; Deuel 1973). From 1979 to present, the NMFS has conducted the Marine Recreational Fishery Statistics Survey (MRFSS), a program of complementary telephone and intercept (on-site angler interviews) surveys that provides catch and effort estimates for the coastwide recreational fishery (U.S. Department of Commerce 1984, 1985a, 1985b, 1986, 1987, 1988). The intercept portion of the survey collects information on the numbers, weights, and length frequencies of the catches.

Direct estimates of recreational catch were only available for 1960, 1965, 1970, and 1979-87; the rest of the years were interpolated (Anderson 1981). We therefore restricted our analyses to recent years, 1979-87, when direct estimates of recreational catch were available and consistent data collection procedures had been employed. Interview sampling data from the MRFSS, 1979-87, were examined to identify trends in the recreational fishery. March, April, and May interviews of fishermen in the Mid-Atlantic region were studied to determine average catch per angler, arrival date (date of first interview), departure date (date of last interview), and duration of stay (days between first and last interview) on a state-by-state basis (Table 2). The

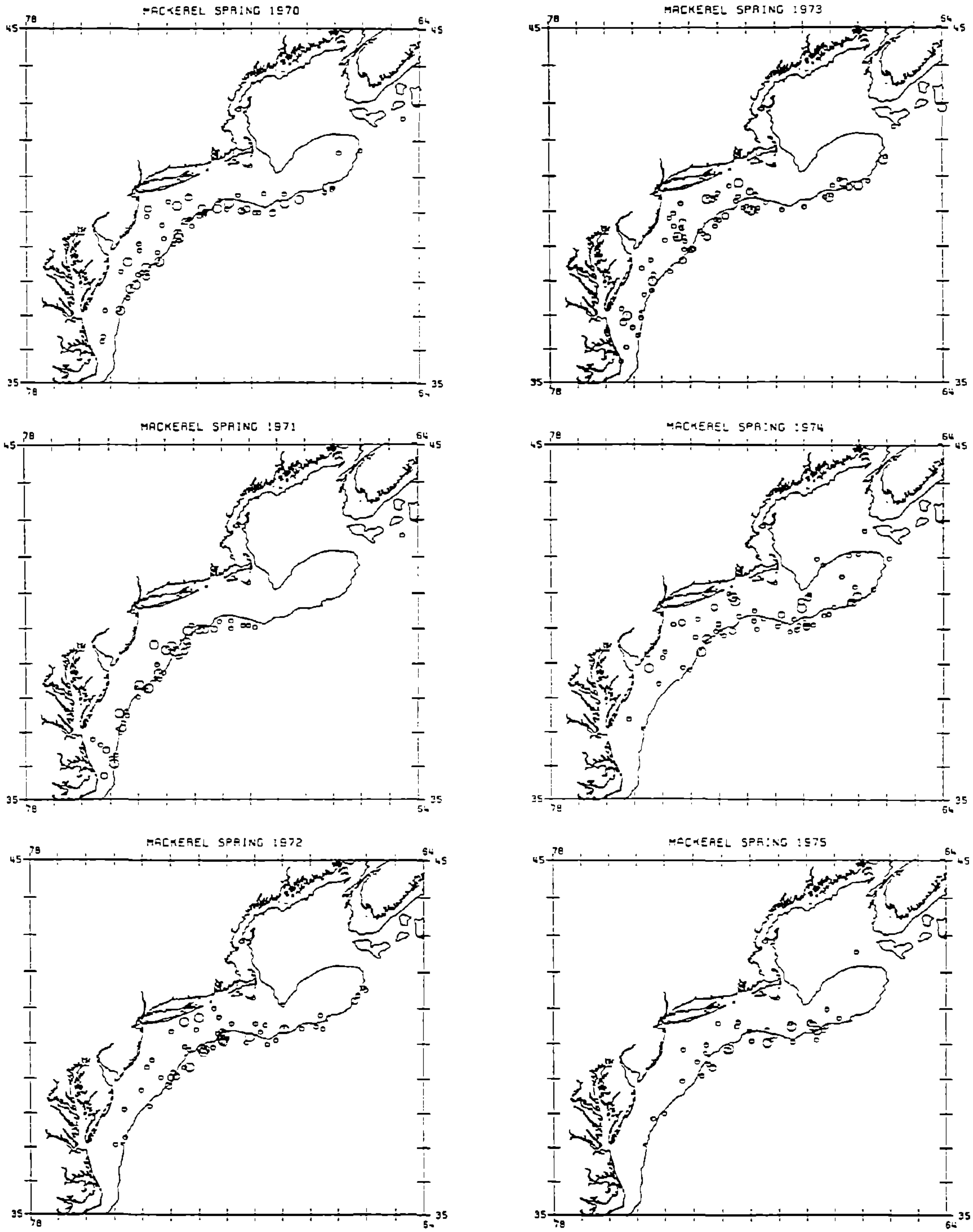

Figure 3a. Catches of Atlantic mackerel from spring bottom trawl surveys conducted by the Northeast Fisheries Science Center from Cape Hatteras, North Carolina, to Nova Scotia during 1970-75.

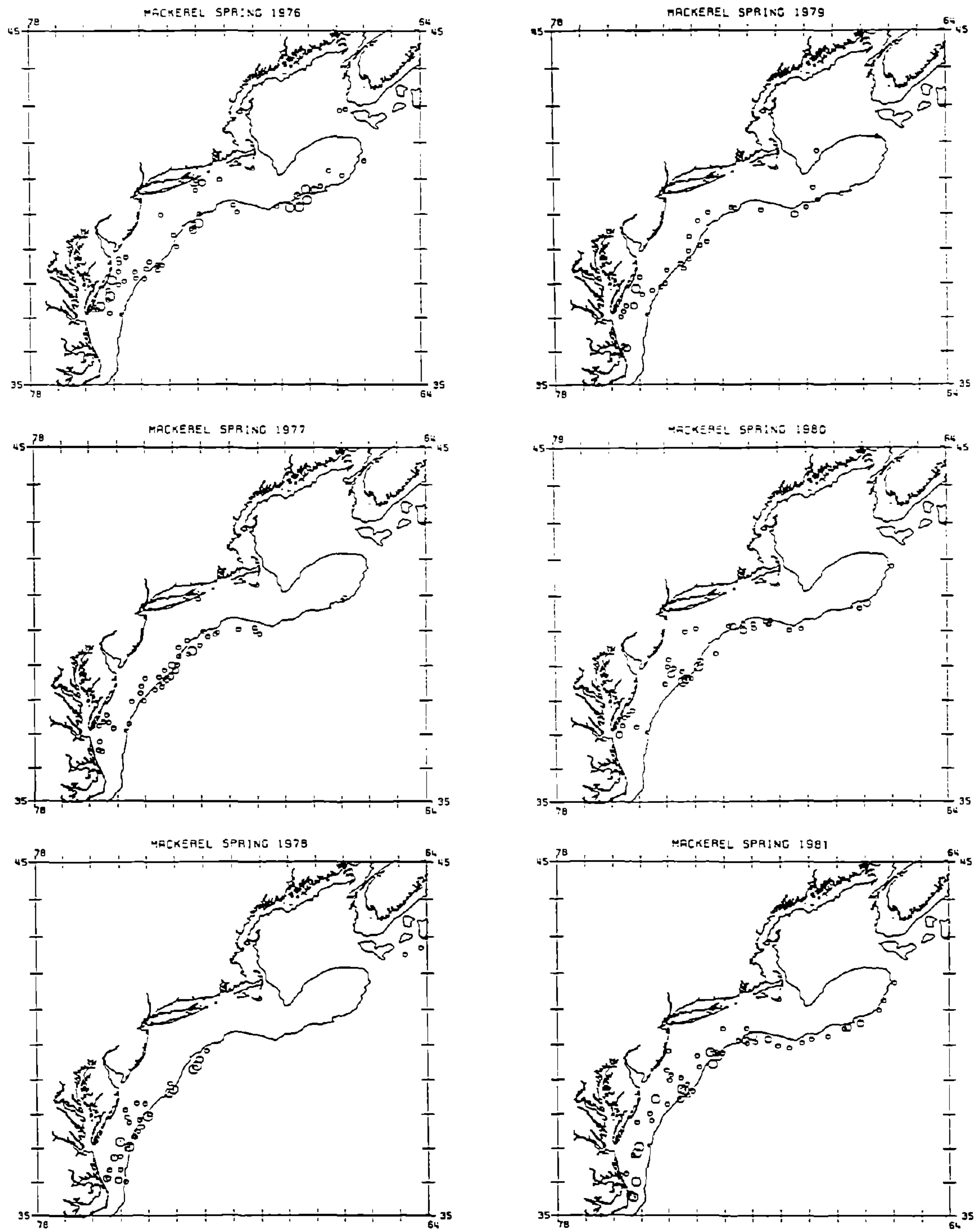

Figure 3b. Catches of Atlantic mackerel from spring bottom trawl surveys conducted by the Northeast Fisheries Science Center from Cape Hatteras, North Carolina, to Nova Scotia during 1976-81.

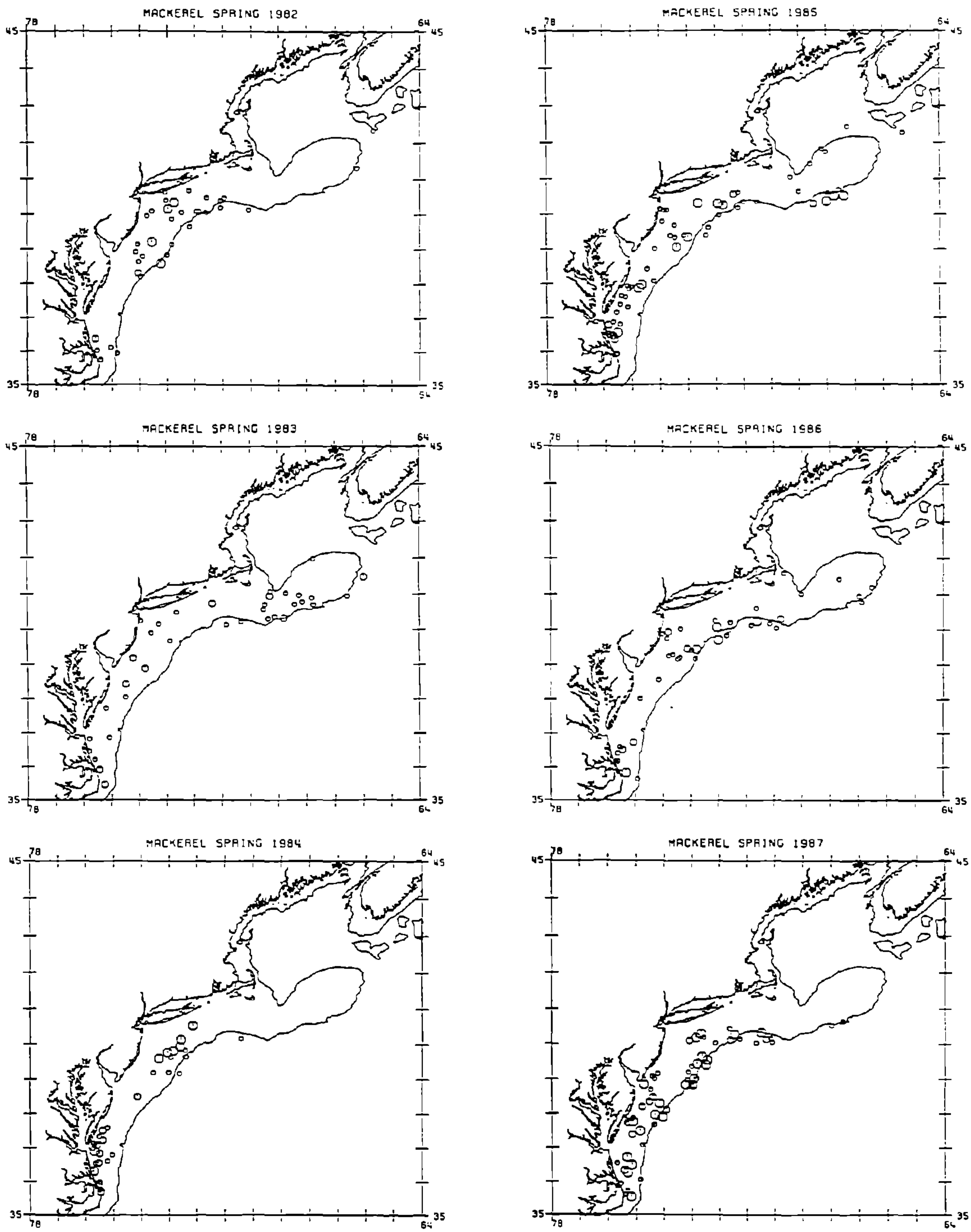

Figure 3c. Catches of Atlantic mackerel from spring bottom trawl surveys conducted by the Northeast Fisheries Science Center from Cape Hatteras, North Carolina, to Nova Scotia during 1982-87.

values for these last three measures of availability are imprecise, because daily interviews were not conducted, but they should give some indication of trends by state.

The Northwest Atlantic mackerel stock has been studied extensively for five decades (Sette 1950; Anderson and Paciorowski 1980). Recent analytical assessments (Anderson and Paciorowski 1980), which have been updated annually, provide a time series of estimates of stock size from 1962 to 1987. Since most fish caught and kept by recreational anglers tend to be large (*i.e.*, greater than 30 cm) (Christensen and Clifford 1980), age 3+ population size (in numbers of fish) was used as an estimate of exploitable stock for the recreational fishery. These estimates (Table 1) were available from a recent update of a virtual population analysis that was described in detail in Anderson and Paciorowski (1980).

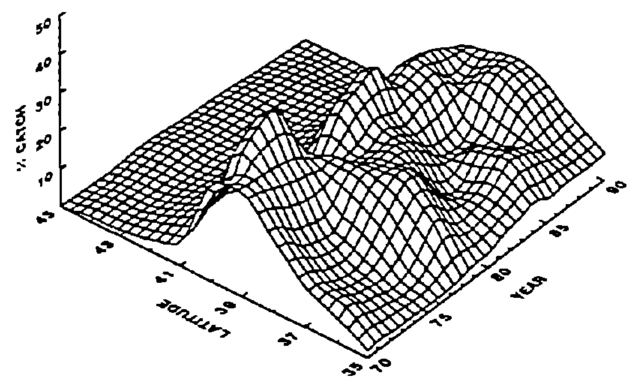

Figure 4. Annual catches of Atlantic mackerel from spring bottom trawl surveys conducted by the Northeast Fisheries Science Center from Cape Hatteras, North Carolina, to Nova Scotia during 1970-87. Catches are expressed as percent of total catch (in numbers of fish) by latitude, collapsed over longitude.

RESULTS

Bottom temperature data from NEFSC spring bottom trawl surveys for 1968-87 show a period of pronounced warming in the 1970s followed by a relatively stable cooler trend in the 1980s (Figure 2). Temperatures reached a high of 9.8°C in 1973, dropped to 5.8°C in 1978, and hovered around 6.5°C during the 1980s. Plots of spring trawl survey mackerel catches indicate that in 1970 and 1971 mackerel were distributed along the shelf-slope break, but during 1972-76 were found in shallower water and further north (Figure 3a,b; Anderson and Almeida 1977). This shift in distribution coincides with the warmer temperatures measured on the bottom trawl surveys during the 1972-76 period (Figure 2; Anderson and Almeida 1977). During the late 1970s, mackerel were again found in the shelf-slope break region. During 1978, the year with the lowest trawl-survey bottom temperature, the stock was distributed along the outer shelf-slope area and in the southern half of the Middle Atlantic Bight. In contrast, during 1973 and 1974, the bulk of the stock had shifted much farther to the north, with some of the largest catches being taken on eastern Georges Bank.

These patterns are clearer if the information is converted to percent of catch by one degree of latitude, collapsed over longitude (Figure 4). In the early to middle 1970s, very little of the stock appeared to be in southern waters, while in the late 1970s, the stock seemed to be spread out over a much greater area, with a major portion of it south of 38°N latitude (Figure 4). Formost of the 1970s, the mackerel stock was confined to the area between 38° and 40°N latitude.

In the 1980s, it appears that Atlantic mackerel were generally in shallower water, as opposed to being primarily along the shelf-slope break in the 1970s. During the 1980s, the mackerel stock occupied more of the continental shelf from 35° to 40°N latitude (Figures 3b,c). In general, there seemed to be a split in distribution at 37°-38°N, with part of the stock to the north and part to the south.

Temperature patterns on the shelf, developed from the spring trawl survey data base, were useful for interpreting changes in mackerel distribution and recreational catches for 1981 and 1982. In 1981, recreational catch rates off the New Jersey coast were the highest in the 1979-87 period (Table 2), coincident with the warm shelf temperatures that were present in that region at the time (Figure 5a). In 1982, when recreational catches were the lowest in the 1979-87 period, shelf temperatures during the spring were noticably colder than in 1981 (Figure 5b). The overall distribution of the mackerel stock in these years was also quite different with most of the fish found much farther south in 1981 (Figures 3a,b).

Survey catch data and bottom temperatures from specific sites indicate that the largest mackerel catches occur at temperatures greater than about 5°C. Plots of mackerel catches from spring surveys in 1970, 1975, and 1981 illustrate that mackerel were consistently captured at bottom temperatures greater than 5°C, and virtually all the larger catches (*i.e.*, greater than 100 fish) occurred at temperatures greater than 6°C (Figure 6).

An examination of MRFSS intercept survey catch data from the recreational fishery for 1979-87 suggested some interesting generalities about the spring mackerel fishery, even though there are some inconsistences in sampling over this time period. Summaries of the Virginia and Maryland fisheries indicate that when the fish are available, they usually arrive in late March in Virginia and mid-April in Maryland (Table 2). Little, if any, catch occurred from 1979 to 1982 in either of these states; however, sampling in March was poor for the period. The fishery off Delaware, New Jersey, and New York is much more stable from year to year, and catch per unit of effort (CPUE) is more consistent than in southern waters (Table 2). Fish apparently arrive in mid-April off Delaware and New Jersey, and the duration of the migration is longer there. CPUE off

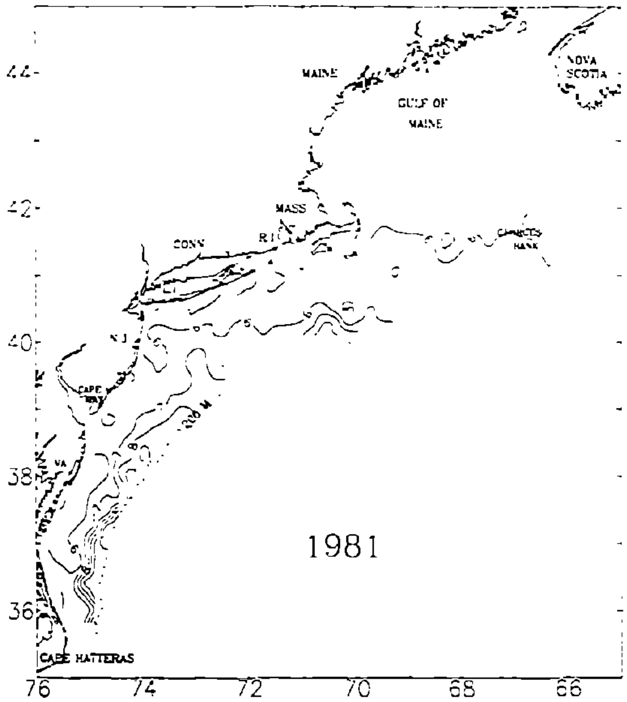

Figure 5a. Surface temperature contours (1°C interval) from a spring bottom trawl survey conducted by the Northeast Fisheries Science Center from Cape Hatteras, North Carolina, to Georges Bank in 1981.

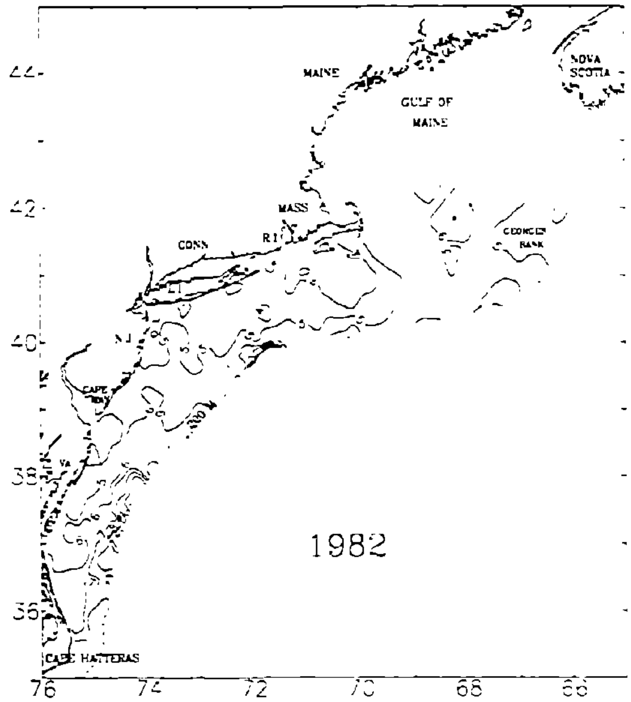

Figure 5b. Surface temperature contours (1°C interval) from a spring bottom trawl survey conducted by the Northeast Fisheries Science Center from Cape Hatteras, North Carolina, to Georges Bank in 1982.

Delaware and New Jersey is generally higher than the other states. The New York catch is characterized by fish arriving in early to mid-May, a fairly consistent pattern of annual catch over the period, and variable CPUE (Table 2). The Delaware, New Jersey, and the New York fisheries are apparently more reliable in terms of mackerel being available to fishermen (Table 2).

Correlations between recreational catch and water temperature, wind stress, and stock size during the 1979-87 period were used to investigate various hypothesized relationships. The correlation between recreational catch and stock size from this period was positive, but the relationship was rather weak (r^2=0.32, not significant), and it was necessary to drop the 1981 data point from the analysis to explain this amount of variation (Table 3; Figure 7). Even though the recreational catch in 1981 was high relative to stock size, there is probably no good reason for removing this data point from the model.

A much stronger [r^2=0.47, P=0.043 (significant at the 0.05 level of confidence)] relationship was found between recreational catch and survey inshore temperature for 1979-87, and there appeared to be no patterning in the residuals (Table 3; Figure 8). We also correlated recreational catch and March meridional wind stress for 1979-87. Results suggested a statistically significant, negative relationship [r^2=0.52, P=0.028 (significant at the 0.05 level of confidence)] with independent error terms (Table 3; Figure 9). The correlation and strength of the wind stress model depended highly on one data point, the 1981 observation (Figure 9).

Several multiple regression models were also fitted to see if there might be important combinations of independent variables that would enhance the simple relationships suggested by the univariate models. A model relating recreational catch to stock size and surface-water temperature for the 1979-87 period was only marginally better than the model with temperature alone (Table 3). If the 1981 data point were dropped from the analysis, however, a measurable improvement in the model results occurred, but, again, this is not justified based on any objective criteria (Table 3). The overall coefficient of determination increased to 0.84 for this model, but stock size was still the least important of the two independent variables. A model relating recreational catch to inshore surface temperature and wind stress for 1979-87 was also fit and proved to be highly significant [r^2=0.86, P=0.0028 (significant at the 0.01 level of confidence)] (Table 3). An examination of error structure indicated that the residuals from this model were independent and unpatterned. The independent variables in this model also appeared to be uncorrelated, and each accounted for a significant amount of the variation in the model fit.

DISCUSSION

Temperature is apparently one of the dominant factors influencing the spring distribution and the rate of northward

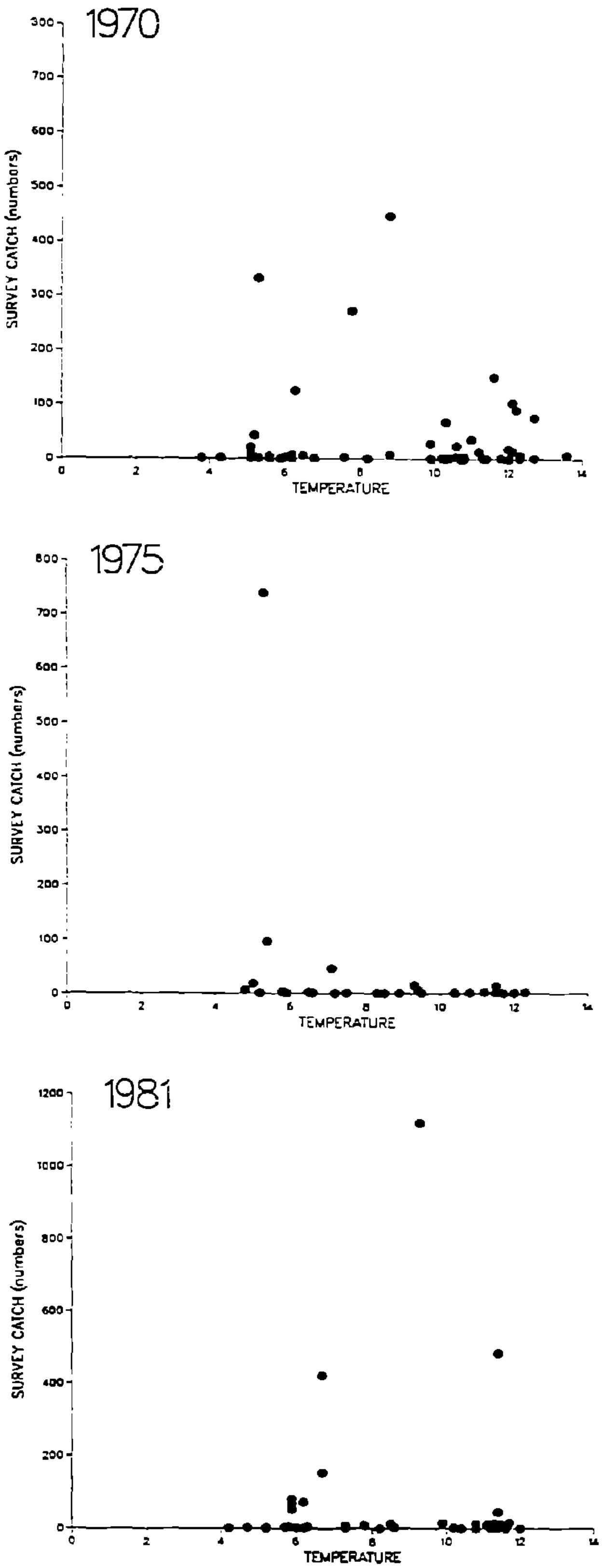

Figure 6. Catches of Atlantic mackerel versus bottom temperature from spring bottom trawl surveys conducted by the Northeast Fisheries Science Center for 1970, 1975, and 1981. (Null tows are not included in these plots.)

Table 2. Arrival date, departure date, duration of stay, and average catch per angler -- all from interviews -- for the Atlantic mackerel spring recreational fishery by state and year during 1979-87

State	Year	Arrival Date	Departure Date	Duration of Stay (days)	Avg. Catch per Angler (# fish)
Virginia	1979				
	1980				
	1981				
	1982				
	1983	03/20			322.0
	1984	04/14			0.8
	1985	03/31			12.8
	1986	03/05	03/31	27	95.4
	1987	03/28			13.2
Maryland	1979				
	1980				
	1981				
	1982				
	1983	04/17	04/29	13	175.5
	1984	04/07	04/22	16	60.5
	1985				
	1986	04/12			206.7
	1987	04/11	04/12	2	26.9
Delaware	1979	04/15	04/28	14	126.2
	1980	04/19			230.9
	1981				
	1982				
	1983	03/02	04/03	33	50.0
	1984	04/11	04/29	19	293.9
	1985	04/20			141.7
	1986	04/12	04/20	9	100.6
	1987	03/28			13.2
New Jersey	1979	04/29			500.0
	1980	04/22	04/23	2	61.9
	1981	04/11	05/13	34	137.3
	1982	04/16	05/02	17	122.5
	1983	04/09	04/30	22	192.2
	1984				
	1985	04/07			188.0
	1986	04/12	05/04	23	134.8
	1987	04/14	05/09	25	74.6
New York	1979	05/15			84.4
	1980	05/31	06/01	2	59.6
	1981	04/25	05/09	15	11.25
	1982	05/16			13.0
	1983				
	1984	05/13	05/19	7	1.4
	1985	04/27	04/28	2	145.8
	1986				
	1987	05/03	05/09	7	256.1

Table 3. Results of correlation analyses of recreational catch versus stock size, average spring inshore surface temperature, and meridional March wind stress during 1979-87

Independent Variable	r	r^2	F	P	Significance Level[a]	D-W Statistic[b]
Stock size[c]	0.57	0.32	2.863	0.1416	NS	1.694
Surface temperature	0.68	0.47	6.116	0.0426	*	2.572
Wind stress	-0.72	0.52	7.575	0.0284	*	1.283
Surface temperature & stock size	0.71	0.50	2.978	0.1264	NS	2.675
Surface temperature & stock size[c]	0.84	0.71	6.089	0.0457	*	2.098
Surface temperature & wind stress	0.93	0.86	18.293	0.0028	**	2.466

[a] $P \leq 0.05$ = *; $P \leq 0.01$ = **; and not significant = NS.
[b] Durbin-Watson statistic; test of autocorrelation.
[c] Excluding the 1981 data point.

migration of mackerel in the Northwest Atlantic. Bottom trawl survey data from selected years indicate that mackerel are seldom captured at temperatures less than 5°C, and almost all of the larger catches that occur in surveys are taken at bottom temperatures greater than 6°C (Figure 6). A previous study summarizing survey data for all stations in the Southern New England - Mid-Atlantic region for 1968-76 (N=777) showed that 46 percent of the stations that were occupied had bottom temperatures less than 5°C, and only five percent of the stations where catches were made were below 5°C (Overholtz and Anderson 1976). Thus, mackerel in the Mid-Atlantic region apparently seek temperature conditions during the winter and spring that may limit their spatial distribution. Laboratory studies show that swimming speeds of mackerel increase at low temperature, suggesting that this 5°C threshold is important (Olla *et al.* 1976).

Results from correlation analyses suggest that spring recreational catches in the Mid-Atlantic region are positively related to inshore surface temperatures in the late March to mid-April period. This means that a cool spring is likely to inhibit the northward and inshore migration of mackerel, resulting in a smaller recreational catch. Previous work by other researchers suggested that Julian arrival dates of mackerel at specific points along the Mid-Atlantic coast were negatively related to March surface temperature (Murray 1984). The study also found that duration of stay at these coastal locations was negatively related to arrival date. Thus, if mackerel arrive early at a point along the coast due to favorable (warm) surface-water temperatures, they will likely stay longer. This should have a positive impact on recreational catch because the fish will be available inshore for a longer period of time and thus more vulnerable to exploitation by anglers.

The positive relationship between temperature and recreational catch may only be valid over a short range in temperature. During the 1980s, the temperature remained rather stable, albeit rising (Figure 2). It appears that a major warming trend, such as occurred in the early to mid 1970s, may cause the stock to shift too far north, causing recreational catch from Virginia to New Jersey to decline (Figure 3a; Table 1). Although catch estimates for 1974-76 are uncertain, they suggest that during a period when temperatures were higher than observed in the 1980s, the recreational fishery waned along the entire Mid-Atlantic region (Table 1).

The negative relationship between recreational catch and March wind stress that was found in the correlation study suggests that meteorological events that occur just prior to and during the arrival of the fish may be important. Other studies have indicated that seasonal winds have a major impact on the coastal oceanography of this region (Swanson and Parker 1988; Swanson and Zimmer 1990). Southward winds during March may serve to retain warm surface water near the shore, thereby preserving optimal thermal conditions and prolonging fish availability to the recreational fishery. We caution that the relationship between catch and wind stress is a proxy for several factors that may influence the thermal pattern in the spring in this region. Factors such as river discharge, frequency of storm events, and other environmental conditions may also be important and are certainly very prominent in this region (Swanson and Parker 1988). In a given year, however, it appears that recreational catch is probably related to the

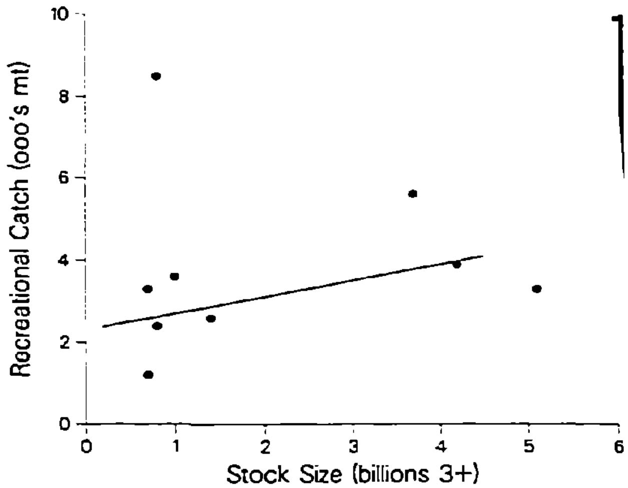

Figure 7. Recreational catch versus stock size (in numbers of fish) for 1979-87 with linear regression line, computed without the 1981 data point.

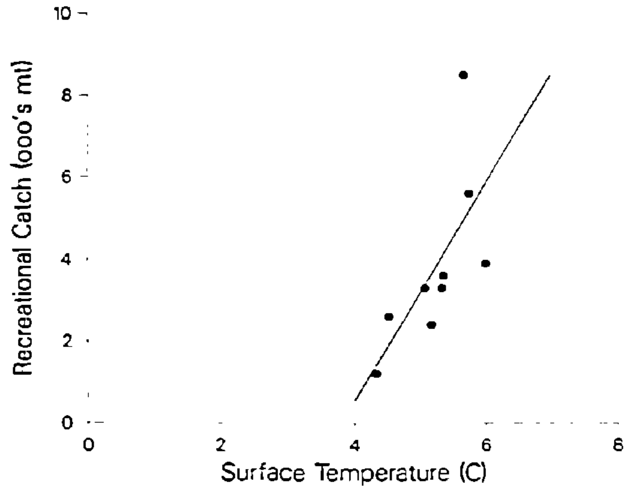

Figure 8. Recreational catch versus average surface temperature from spring bottom trawl surveys for 1979-87 with linear regression line.

temperature of inshore surface water and the factors that maintain this in the short term. The large catch that occurred in 1981 may have resulted from a combination of relatively warm temperature and wind conditions that maintained this thermal pattern, even though abundance of mackerel at this time was rather low.

Analyses from this study also suggest that recreational catches along the Mid-Atlantic coast are only weakly related to stock size (Table 3). This is somewhat counterintuitive since it is often assumed that stock sizes must be maintained at high levels to achieve high catch rates with inefficient angling gear. However, since the catch (in numbers of fish) in any given year is relatively small when compared to the overall stock size, local variations in fish availability determine catch even when the stock is very low (Table 1). In 1981, a year with a large catch relative to estimated total stock size, the amount removed by the recreational fishery was only about one percent of the exploitable stock. In 1987, only about 0.1 percent of the estimated total stock was removed by the recreational fishery. This implies that environmental cues and influences are probably more important in determining the magnitude of the spring fishery since the catch can be relatively large even if the exploitable stock is small.

The time series of sport fishery catches from the states of Virginia and Maryland are not adequate for correlation analyses. Therefore, we could not perform fine-scale studies of relationships within these areas to quantify the local environmental events that may be important at this time of the year. It is likely, however, that temperature plays an important role in determining whether mackerel move inshore and are available to the fishermen in Virginia and Maryland. These two areas do not appear to be in the normal migratory corridor of this species, as evidenced by

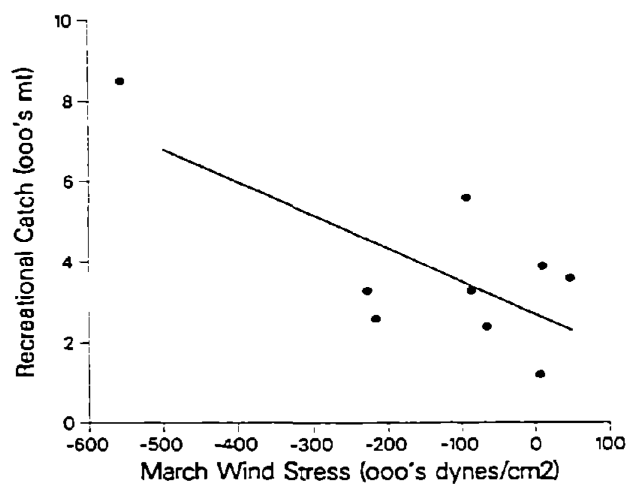

Figure 9. Recreational catch versus meridional component of March wind stress for 1979-87 with linear regression line.

the patterns in the bottom trawl survey distributions and statistics from the recreational catch surveys. Therefore, the fish only occasionally show up along shore in quantity and do not stay long (Figures 3b,c; Table 2). The fishery in this area can be expected to be highly variable since the mackerel appear to be heading northward rather quickly at this time of the year to aggregate for spawning in the area off New Jersey and New York (Sette 1950).

Our analysis should not be considered definitive, but more appropriately, suggestive of possible relationships and causal factors that may be important in determining the spring distribution and catch of mackerel in the Mid-

Atlantic region. Other factors may be important, and certainly the underlying mechanisms causing shifts in distribution and availability are still an enigma. A more thorough analysis of available data would certainly be valuable, especially if fairly detailed sets of environmental observations could be matched with coincident catches or catch rates of mackerel. An analysis of commercial catch data and environmental variables might be revealing since, typically, catches are larger and more frequent in these operations. Additional field sampling of the short-term and long-term distributional changes in the stock with accompanying environmental data would be useful as would detailed records of recreational catches by state. A tagging study would not only be useful in determining the proportion of northern *versus* southern components in the stock, but would also help detail fish movements and changes in distribution. Remote sensing technology may also be useful for studying this problem and would be important in providing short-term forecasts of probable changes in distributions of mackerel on a real-time basis.

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