Correlations of Fish Catch and Environmental Factors in the Gulf of Maine[1]

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In an investigation of catches of 17 commercial marine species of fish and shellfish from the Gulf of Maine, 10 showed statistically significant correlations with sea temperatures at St. Andrews, N.B., or Boothbay Harbour, Maine. Most fish records contained at least 40 yr of data. Descriptive equations are produced for four species based first on the correlation between catch and sea temperature and second on the correlation between catch and sea temperature allowing for fishing effort. Inclusion of fishing effort, not surprisingly, improved the correlations for all of the species so examined. The equations permitted the "prediction" of later parts of the records from earlier parts.

Considering the fish species collectively, the Gulf of Maine system from 1940 to 1959 appeared to be in equilibrium with little fluctuation in the total commercial biomass. We interpret the large fluctuations in individual species abundance as resulting from a combination of fishing pressure and to a significant degree oceanic climate as represented by sea temperature. The small fluctuations in the total biomass displays the species variation, with their differing climatic "preferences," as well as possible predator (including man)–prey relationships. Environmentally imposed patterns underlie at least 50% of the fluctuations in catch of many species and the understanding of these fluctuations is basic to effective management.

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Une étude des prises de 17 espèces commerciales de poissons et de coquillages de mer dans le golfe du Maine démontre pour 10 d'entre elles des corrélations significatives avec les températures de la mer à St. Andrews, N.-B., ou Boothbay Harbour, Maine. Les données pour la plupart des poissons couvrent une période d'au moins 40 a. Nous formulons des équations descriptives pour quatre espèces, fondées d'abord sur la corrélation entre les prises et la température de l'eau, et ensuite en tenant compte de l'effort de pêche. Le fait d'inclure l'effort de pêche améliore les corrélations pour toutes les espèces étudiées, ce qui n'est pas surprenant. Les équations nous ont permis de « prédire » les périodes plus récentes de données à partir des périodes antérieures.

Si l'on considère toutes les espèces de poissons collectivement, on constate que le système du golfe du Maine, entre les années 1940 et 1959, semblait être en équilibre avec très peu de fluctuations dans la biomasse commerciale totale. A notre avis, les grandes fluctuations dans l'abondance d'espèces individuelles seraient le résultat de la pression exercée par la pêche et, à un degré significatif, du climat océanique représenté par la température de l'eau. Les petites fluctuations dans la biomasse totale reflètent la variation des espèces, avec leurs « préférences » climatiques différentes, de même que des relations possibles prédateur (y compris l'homme)–proie. L'environnement est responsable d'au moins 50% des fluctuations dans les prises de ces espèces et qu'il est essentiel pour une gestion efficace de comprendre ces fluctuations.

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IN a preceding paper (Sutcliffe et al. 1976) the role of coastal circulation, especially that of the St. Lawrence River system, on the water properties of the Scotian Shelf and the Gulf of Maine was discussed. That study was initiated when correlations were found between fish catches from these areas and both the environmental factors of local sea temperatures and St. Lawrence River discharge. Evidence was presented to show that events originating within the Gulf of St. Lawrence eventually gave rise to, or were associated with, temperature perturbations on the Scotian Shelf and in the Gulf of Maine. It was thought that the St. Lawrence River system was important, although not necessarily the major influence, in the sequence of events.

With the association between the St. Lawrence River discharge and sea temperatures on the

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TABLE 1. Data series and sources. New England = N.E.; ICNAF subarea 5 = 5; Nova Scotia and Bay of Fundy = N.S.; Southern New England = S.N.E.

Species	Region	Yr	Source[a]
Alewife	N.E.	1928–71	1–2, 5–9, 12–16
Butterfish	N.E.	1928–71	1–2, 5–9, 12–16
Clams			
Hard	N.E.	1928–71	1–2, 5–9, 12–16
Soft	N.E.	1928–71	1–2, 5–9, 12–16
Atlantic cod	5	1893–1973	11–12
Cusk	N.E.	1928–73	1–2, 5–9, 12–16
Haddock	5	1893–1973	11–12
Hake			
Silver	N.E.	1928–71	1–2, 5–9, 12–16
Red	N.E.	1944–71	1–2, 5–9, 12–16
Atlantic halibut	5	1893–1973	11–12
Atlantic herring	N.E.	1928–71	1–2, 5–9, 12–16
Atlantic mackerel	N.E.	1928–71	1–2, 5–9, 12–16
	N.S.	1893–1964	10
Atlantic menhaden	N.E.	1929–71	1–2, 5–9, 12–16
Pollock	N.E.	1928–71	1–2, 5–9, 12–16
Redfish	5	1936–73	11–12
Sea scallops	N.E.	1928–73	1–2, 5–9, 12–16
Striped bass	N.E.	1930–71	1–2, 5–9, 12–16
Yellowtail flounder	S.N.E.	1935–74	3–4

[a]These follow the bibliographic references at the end of this paper.

Scotian Shelf and in the Gulf of Maine considered, albeit far from understood, we now wish to turn our attention towards the fish. Correlations between the long-term records of commercial fish catch in the Gulf of Maine and sea temperatures and St. Lawrence discharge are presented in an attempt to show the possible effects of the environment on several major fish stocks.

Following the discussion of correlations of individual species with temperature, "predictions" of cod, haddock, and yellowtail flounder catch from temperatures are presented. These consist of estimating one section of the data record based on a relationship derived from another section.

As pointed out in an earlier paper (Sutcliffe et al. 1976), several environmental influences have been considered by a number of investigators with temperature being the most frequently used (e.g. Iselin 1939; Redfield 1939; Carruthers 1951; Templeman and Fleming 1953; Chase 1955; Taylor et al. 1957; Colton and Temple 1961; Martin and Kohler 1965; Flowers and Saila 1972; Sutcliffe 1972; Dickson and Lee 1972; Iles 1973; Gulland 1965; Lett and Kohler 1976). Temperature is not necessarily the most important influence, but it has the best and longest continuous records. Temperature serves only as an indicator of the local oceanographic climate and while the effect may be direct, further investigation is required to determine the actual variable(s) of importance to the fish and its mode of influence.

Methods

Environmental data used here are all mentioned and sources listed in Sutcliffe et al. (1976). These are used with annual commercial catch or landing statistics (Table 1) in correlation analysis almost identical to the method used for correlating environmental data (Sutcliffe et al. 1976).

The annual catch data were first correlated with the mean monthly temperatures of the year corresponding to the year of catch, thus giving 12 correlation coefficients. This was then repeated with the monthly temperature data lagged back a year (e.g. if fish data spanned 1939–73, temperature data was correlated from 1938–72) and so on until an obvious peak (or trough) appeared, to produce a correlation matrix (Table 2). The lag and time of year with the highest coefficient (r) was chosen for presentation. Keeping in mind that much of the environmental effect is in the 1st yr of life (discussed later), the lag was compared with published data on age at commercial size. For all species considered significant, the correlations chosen were not isolated or random events in the matrices (Table 2); several adjacent months or years showed correlations nearly as high. This will be discussed later. Smoothing was done usually by 2- or 3-yr running means and the year shown in the figures is always the 1st yr of the group.

Because a single catch datum for a given year

TABLE 2. Computer generated correlation table of the principle type used in this paper. Files used are monthly mean temperatures for St. Andrews, N.B. and cod, ICNAF subarea 5 (1929–73 used), 3-yr running means. Highest correlation coefficient (r) occurs for August, 4 yr lag. Outline contains values significant at 0.05 level, values underlined significant at 0.02 level, with 6 df. See text.

Yr lag no.	r for mo of 1	2	3	4	5	6	7	8	9	10	11	12
0	−.476	−.586	−.557	−.558	−.488	−.443	−.344	−.33	−.347	−.328	−.446	−.426
1	−.545	−.649	−.593	−.647	−.588	−.535	−.514	−.526	−.519	−.5	−.598	−.563
2	−.561	−.653	−.599	−.692	−.677	−.631	−.654	−.682	−.662	−.637	−.714	−.667
3	−.531	−.641	−.611	−.701	−.716	−.678	−.747	−.785	−.738	−.704	−.789	−.718
4	−.453	−.575	−.581	−.678	−.681	−.667	−.796	−.817	−.749	−.74	−.802	−.714
5	−.372	−.501	−.535	−.635	−.613	−.61	−.784	−.791	−.707	−.724	−.746	−.652
6	−.3	−.407	−.471	−.578	−.532	−.535	−.74	−.744	−.659	−.698	−.662	−.57
7	−.252	−.316	−.388	−.493	−.453	−.446	−.677	−.685	−.607	−.651	−.578	−.494
8	−.193	−.204	−.266	−.366	−.335	−.344	−.589	−.622	−.553	−.587	−.502	−.432

usually includes more than one year-class (although often one year-class predominates), the catch data cannot be considered as independent points; for other reasons the same is true for temperature (Sutcliffe et al. 1976). This is further compounded by smoothing. In determining level of statistical significance we have tried to take these factors into account in the same way we handled the environmental data in the previous paper (Sutcliffe et al. 1976). We believe our estimates of significance to be conservative.

In the following presentation most of the fish statistics are compared and correlated with the sea surface temperatures at St. Andrews, N.B. (TEMPSA). This particular environmental data series was chosen because of its time span and geographic location; information was also derived from Boothbay Harbor (BOOTHT) records and a signal representative of the St. Lawrence River system (RIVSUM) for comparison.

Though somewhat distant in space from the actual areas in which the fish have been caught, the sea surface temperature trends at St. Andrews have been shown to be representative of surface and subsurface temperature variations through the Scotian Shelf and the Gulf of Maine (see Lauzier 1972). For those fish statistic records beginning prior to St. Andrews sea temperatures, correlations were run with sea temperatures at Boothbay Harbor, Maine, or air temperatures at Eastport, Maine. Comparisons between Eastport air and St. Andrews sea temperatures can be found in Sutcliffe et al. (1976).

In choosing catch records for analysis and presentation, few particualr criteria were observed other than the necessity that a given record be for one species only, the data derived from a fairly limited area (in the ecological sense) and contain a reasonably long series. Convenience also influenced our choices. For example, while the fisheries statistics of Nova Scotia are available for many years, these include catches inside the Gulf of St. Lawrence and outside on the Shelf, quite different habitats in our opinion, and would require much sorting out of landing data by fisheries districts of the province. Fisheries of New Brunswick presented the same problem. Thus, confining our attention to the area of the Shelf from Cape Breton, N.S., to a little past Cape Cod, Mass., our presentation is mostly centered in the New England fisheries (from Fisheries Statistics of the United States) and International Commission for the Northwest Atlantic Fisheries (ICNAF) subarea 5 (from ICNAF publications).

Results and Discussion

The following species taken individually were run through our programs and are presented as they occurred. We did not attempt to go into each in any great detail for reasons given later. Some have already been noted or indications given in the literature that stocks are susceptible to environmental fluctuations (e.g. alewife, Leim and Scott 1966; striped bass, Merriman 1941) so we do not pretend originality in this respect; we have merely updated them and added longer records (Fig. 1).

ALEWIFE (*Alosa pseudoharengus*)

Although frequently spawning in fresh water near the sea (Leim and Scott 1966), stocks of this anadromous species appear to be related to sea temperature. Figure 1A shows the New England catch from 1928 to 1971 and temperatures for the month of April with a lag of 6 yr (r = 0.850). In 1972 commercial catches were mostly 2–8 yr old (ICNAF 1973), dominated by ages 4 and 5 (5th and 6th growing season).

BUTTERFISH (*Peprilus triacanthus*)

Figure 1B shows the New England commercial catch of butterfish from 1928 to 1971 with St. Andrews temperatures (April and May) lagged by 4 yr (r = 0.735). From information in Bigelow and Schroeder (1953), the lag may be a little long although a 3-yr lag gave r = 0.717. Slightly higher correlation coefficients (but not significant) were observed for October–November and lags of 4–5 yr.

ATLANTIC COD (*Gadus morhua*)

Landings from ICNAF subarea 5 (from Coté 1952; Martin and Kohler 1965; and subsequent

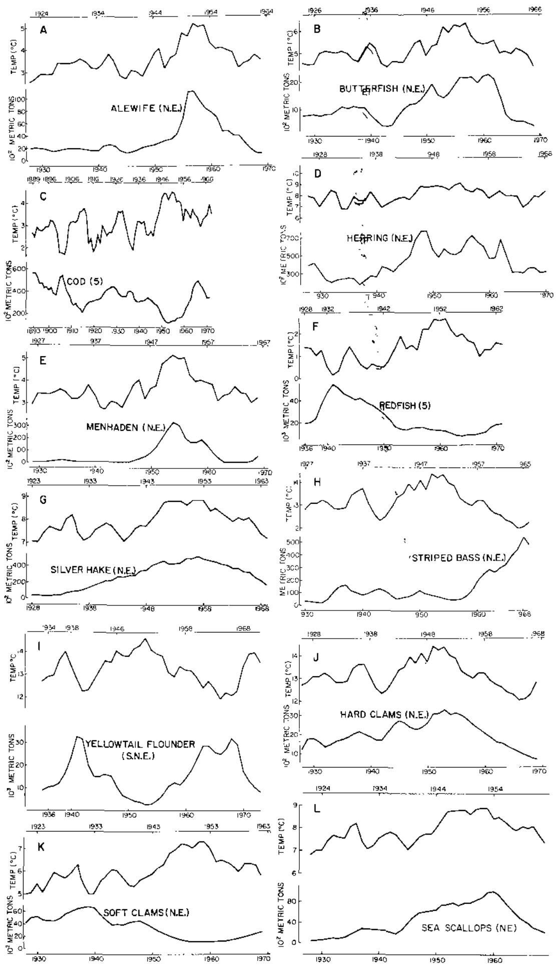

FIG. 1. Commercial fish landings and St. Andrews sea temperatures (except Fig. 1C). All are 3-yr running means except where indicated. For further details see Table 3. A, Alewife (*Alosa pseudoharengus*), New England; B, butterfish (*Peprilus triacanthus*), New England; C, Atlantic cod (*Gadus morhua*), ICNAF subarea 5 (3-yr means) and July–August Eastport air temperature (4-yr means); D, Atlantic herring (*Clupea harengus harengus*), New England; 2-yr running means; E, Atlantic menhaden (*Brevoortia tyrannus*); New England; F, redfish (*Sebastes marinus*), ICNAF subarea 5; G, silver hake (*Merluccius bilinearis*), New England; H, striped bass (*Morone saxatilis*), New England; I, yellowtail flounder (*Limanda ferruginea*), southern New England, 2-yr running means; J, hard clam (*Mercenaria mercenaria*) (meats), New England; K, soft-shell clam (*Mya arenaria*) (meats), New England; L, Sea scallop (*Placopecten magellanicus*) (meats), New England.

ICNAF Stat. Publ.) were plotted with Eastport air temperatures from 1893 to 1973. The results (Fig. 1C) have a correlation coefficient of −0.661. With St. Andrews surface temperatures (1921–73) and a lag of 4 yr, r assumed a value of −0.833 for July and August temperatures. In the 1920s most cod on Nantucket Shoals were 3–5 yr old (Schroeder 1930) as were those on Georges Bank 1956–70 (Brown and Heyerdahl 1972).

ATLANTIC HERRING (*Clupea harengus harengus*)

Plots of New England herring and temperature (November) with a 2-yr lag ($r = 0.604$) are shown in Fig. 1D. The lag time is short for adult fish in the commercial catch (ages 4 and 5, Boyar 1968); however, the New England landings include the inshore fishery for immature fish so the lag derived for the mixture given here may not be unreasonable. Clearly, any further work on these correlations should separate stocks and the fisheries.

ATLANTIC MENHADEN (*Brevoortia tyrannus*)

New England menhaden landings are correlated with St. Andrews sea temperatures (April, $r = 0.872$) with a 3-yr lag (Fig. 1E). Henry (1971) indicates the average age of specimens from the North Atlantic fishery (north of 40°) was 3.7 yr from 1955 to 1968.

REDFISH (*Sebastes marinus*)

Kelly and Wolf (1959) give the age composition for redfish in the Gulf of Maine for the early 1950s. The spread is wide, ranging from about 3 to over 20 yr. However, the "mean" age of 8 yr selected in our lagging program does not seem unlikely when looking at the Kelly and Wolf histograms. Redfish catch from subarea 5 and St. Andrews temperatures are correlated in Fig. 1F ($r = -0.728$). Data previous to 1936 were ignored because the fishery had not yet developed (E. Sandeman personal communication).

SILVER HAKE (*Merluccius bilinearis*)

The 5-yr lag found for the New England catch of silver hake (see Fig. 1G $r = 0.781$) is close according to the age estimate given by ICNAF (1964) for this species (3–4 yr, 4th–5th growing season). Correlations from 1928 to the early 1960s showed a lag of 4 yr.

STRIPED BASS (*Morone saxatilis*)

New England catches (mostly Massachusetts and Connecticut) and August temperatures ($r = -0.631$) for a 3-yr lag are shown in Fig. 1H. According to Merriman (1941) 2-yr-olds (entering or in the 3rd growing season) appear most prominently in the commercial catch.

Yellowtail Flounder (*Limanda ferruginea*)

Brown and Hennemuth (1971) have described the yellowtail flounder fisheries in subarea 5. We have used their tabulated data for the southern New England grounds and updated the catch and effort from Edwards and Hennemuth (1975). Correlating the catch from this stock with St. Andrews temperature, we obtained the highest negative correlation (−0.792) for August with a 2-yr lag. The data are plotted in Fig. 1I. Sissenwine (1974) also found strong correlations with temperature for this species.

Hard Clams (*Mercenaria mercenaria*)

The 2-yr lag for commercial catch of this species (Fig. 1J) seems reasonable (r = 0.805). Resently, most of the hard clams harvested are near the lower size limit in Maine (5.1 cm), according to E. S. Gilfillan (personal communication), and approximate 2-yr-olds.

Soft-Shell Clams (*Mya arenaria*)

A 7 yr lag and negative correlation (r = −0.798) were found between New England clam catch and St. Andrews temperatures (November and December) (Fig. 1K) with a secondary peak for a 5-yr lag with February and March temperatures (r = −0.745). Minimum size restrictions place limits at 5.1-cm shell size in Maine (the largest producer of the area), an average age of 5 yr (Dow and Wallace 1957), although growth rate is highly variable.

Sea Scallops (*Placopecten magellanicus*)

Dow (1964a) indicated the correspondence between spring and autumn sea temperatures (Boothbay Harbor) and Maine landings (1939–43) of this species. He noted that 6–9-yr-olds composed most of the catch in the late 1940s and 1950s.

Correlating New England scallop catches for 1928–71 with St. Andrews temperatures we obtained the highest correlation (0.796) for November with a lag of 6 yr (Fig. 1L). For Georges Bank catches (Caddy and Lord 1971) and St. Andrews temperature, the highest correlation (0.821) was for March and a lag of 8 yr, which is too long (J. F. Caddy personal communication). However, the character of the fishery changed considerably during the 1960s, perhaps contributing to the discrepancy (Bourne 1964; Caddy and Lord 1971).

Other Species

In addition to the foregoing, several other species in our area of interest have been correlated with temperature. Lobster (*Homarus americanus*) abundance–temperature correlations were shown by Flowers and Saila (1972), and indications given for northern shrimp (*Pandalus borealis*) and the blood worm (*Glycera dibranchiata*) by Dow (1964a, b). With Atlantic mackerel (*Scomber scombrus*), Taylor et al. (1957) showed positive correlations between New England landings and New Haven air temperatures (1810–1930) for a 3-yr lag.

Attempts were made to use Atlantic halibut records (*Hippoglossus hippoglossus*) for subarea 5 (1893–1973, ICNAF Sta. Bull.) which were compared with appropriate Eastport air temperatures. While significant at the 0.05 level (Table 3) we are inclined to question the statistical value of the low levels of catch (mean < 500 t/yr) and the table was somewhat confusing, perhaps because of the considerable spread in age found in the catches (McCracken 1958). For red hake (*Urophycis chuss*) correlations with Boothbay Harbor temperatures did not fit an easily recognizable pattern, although with St. Andrews and RIVSUM results were obtained with a 2-yr lag (not inconsistent with 2–3 yr age, Rickter 1972) (see Table 3). Efforts to derive useful associations from landings of cusk (*Brosme brosme*) and pollock (*Pollachius virens*) were not fruitful.

Other Environmental Records

Most of the species presented above for correlations with St. Andrews sea temperatures were tried also with Boothbay Harbor temperature records and RIVSUM. Table 3 gives the results of these and the levels of significance with all three signals. With one signal or another, 13 species showed significant (0.05 level or less) relations with the environmental records. There are some differences in year lags between Boothbay and St. Andrews series, but the significance of these is doubtful. In many cases, although the highest coefficient was chosen for presentation, neighboring ones in terms of adjacent months or years were almost as high and probably not significantly different statistically.

We are reluctant to put great importance on the particular month indicated in Table 3 for the highest coefficient. It is more likely that a span of months is involved, as encountered when going into cod, haddock, yellowtail flounder, and menhaden in greater detail (see below), and that this span (representing the first growing season?) is possibly more important biologically to the species in question.

Gulland (1953, 1965) has advised caution with the use of correlations to relate environment to

TABLE 3. Statistical data for some of the correlations of environmental factors and catches of various species. Environmental signal = Env. Sig.; Running mean = RM; New England = N.E.; St. Andrews, N.B. = S.A.; Boothbay Harbour, Me. = B.H.; RIVSUM = R; ICNAF subarea 5 = 5 (under "area"); Eastport, Me., air temperatures = EPATEM; Southern New England = S.N.E.

Species	Area	Yr	Env. Sig.	RM	Mo for Env. Sig.	Yr Lag	*r*	No. of ind. points[a] Fish	No. of ind. points[a] Env. Sig.	df[a]	Significance
Alewife	N.E.	1928–71	S.A.	3×3	4	6	.850	8	10	6	.01–.001
		1928–71	B.H.	3×3	2	5	.841	8	8	6	.01
					12	7	.867	8	6	4	.05–.02
		1928–71	R	3×3	4	6	.850	8	14	6	.01–.001
Butterfish	N.E.	1928–71	S.A.	3×3	4, 5	4	.735	8	11	6	.05–.02
				3×3	10	5	.750	8	10	6	.05–.02
		1928–71	R	3×3	3	5	.788	8	9	6	.02
		1928–71	B.H.	3×3	4	5	.786	8	9	6	.02
Clams											
Hard	N.E.	1928–71	B.H.	3×3	10	3	.744	7	8	5	.05
		1928–71	R	3×3	4	2	.696	7	14	5	.1–.05
		1928–71	S.A.	3×3	8	2	.805	7	10	5	.05–.02
Soft		1928–71	S.A.	3×3	11, 12	7	−.798	6	8	4	.1–.05
				3×3	2, 3	5	−.745	6	9	4	.1–.05
		1928–71	R	3×3	1	5	−.800	6	9	4	.05
		1928–71	B.H.	3×3	11	7	−.886	6	6	4	.02
Atlantic cod	5	1914–73	B.H.	3×3	10	4	−.668	9	12	7	.05
		1925–73	S.A.	3×3	7–12	4	−.850	7	8	5	.02–.01
		1919–73	R	3×3	3	4	−.778	8	10	6	.02
		1925–73	S.A.	3×3	7, 8	4	−.833	7	10	5	.02
		1893–1973	EPATEM	3×4	10–12	4	−.661	12	25	10	.02–.01
Cusk	N.E.	1928–71	S.A.	3×3	12	7	−.543	7	10	5	> .1
		1928–71	B.H.	3×3	12	7	−.680	7	6	4	> .1
		1928–71	R	3×3	12	1	−.731	7	10	5	.1–.05
Haddock	5	1893–1923	EPATEM	3×3	11–2	2	−.548	7	12	5	> .1
Hake											
Silver	N.E.	1928–71	S.A.	3×3	11	5	.781	5	9	3	> .1
		1928–71	R	3×3	3	6	.771	5	9	3	> .1
		1928–71	B.H.	3×3	11	4	.880	5	6	3	.05
Red	N.E.	1944–71	B.H.	3×3	8	0	.522	12	6	4	> .1
		1944–71	S.A.	3×3	8	2	.507	12	7	5	> .1
		1944–71	R	3×3	6	2	.847	12	8	6	.01
Atlantic halibut	5	1893–1973	EPATEM	3×3	3	11	−.537	17	39	15	.05–.02
Atlantic herring	N.E.	1928–71	B.H.	2×2	11	2	.737	10	8	6	.05–.02
		1928–71	R	2×2	3	4	.648	10	12	8	.05–.02
		1928–71	S.A.	2×2	11	2	.604	10	10	8	.1–.05
Atlantic menhaden	N.E.	1929–71	S.A.	3×3	4	3	.872	7	11	5	.01
		1929–71	R	3×3	3	3	.796	7	9	5	.05–.02
		1929–71	B.H.	3×3	2	2	.881	7	8	5	.01–.001
					12	3	.870	7	6	4	.05–.02
Pollock	N.E.	1928–71	S.A.	3×3	8	2	.463	8	10	6	> .1
		1928–71	B.H.	3×3	8	2	.458	8	11	6	> .1
		1928–71	R	3×3	12	2	−.453	8	11	6	> .1
Redfish	5	1936–73	B.H.	3×3	11	8	−.846	6	5	3	.1–.05
		1936–73	S.A.	3×3	3	8	−.728	6	9	4	.1
		1936–73	R	3×3	2	8	−.867	6	6	4	.05–.02
				3×3	12	10	−.861	6	7	4	.05–.02
Sea scallops	N.E.	1928–71	R	3×3	3	7	.820	6	9	4	.05
		1928–71	S.A.	3×3	11	6	.796	6	8	4	.06
		1928–71	B.H.	3×3	11	5	.885	6	10	4	.02
Striped bass	N.E.	1930–71	B.H.	2×3	7	3	−.644	6	9	4	> .1
		1930–71	S.A.	2×3	8	3	−.631	6	9	4	> .1
		1930–71	R	2×3	5	5	−.763	6	18	4	.1–.05
Yellowtail flounder	S.N.E.	1935–74	S.A.	2×2	8	2	−.792	10	12	8	.007
		1935–74	B.H.	2×2	8	1	−.797	10	12	8	.007
		1935–74	R	2×2	4	2	−.586	10	17	8	.08

[a]For method of determining independent points and degrees of freedom see Sutcliffe et al. (1976).

fluctuations in populations because of the chance of spurious relations. Some presented here may be fortuitous. Redfish is certainly a possibility as is silver hake with only one main peak of catch correlated with one main peak in temperature; only more years of data with further and detailed study will tell. The choice of variables — four different environmental signals, month, year lag, and running average — is not as great as would appear. In a previous paper (Sutcliffe et al. 1976) we reviewed the great similarity among a number of signals along the coast (including the ones used here) and it is not surprising that the monthly components would show basic similarities. The fact that the year lags we found are not greatly dissimilar to the likely mean ages of the various species at commercial size since the 1920s supports our thesis since strength of year-class is thought to be largely determined in the 1st yr of life (Gulland 1965; Templeman 1972; Cushing

TABLE 4. Data and statistical information for species considered with effort (see text). ICNAF subarea 5 = (5); Southern New England = (S.N.E.); North Atlantic = (N.A.). y = catch (10^3t), x_1 = temperature, x_2 = effort, days fished ($\times 10^3$).

Fish	Equation	Yr RM	Period	Constants a	b	c	r
Atlantic cod (5)	$y = a + bx_1$	3	1925–71	107.55	−7.3792	—	.850
(Brown and Heyerdahl 1972)	$y = a + bx_1 + cx_2$	3	1931–71	117.83	−9.8425	.82792	.896
	″	1		118.79	−9.6235	.45425	.833
Haddock (5)	″	3	1917–68	69.599	−6.2417	4.4543	.776
(Grosslein and Hennemuth 1973)	″	1		64.579	−4.3132	3.6125	.751
Yellowtail flounder (S.N.E.)	$y = a + bx_1$	2	1935–74	147.79	−11.436	—	.811
(Brown and Hennemuth 1971;	$y = a + bx_1 + cx_2$	2	1937–74	132.89	−10.441	1.3832	.882
Edwards and Hennemuth 1975)	″	1	1937–74	76.539	−5.9172	2.0516	.828
Atlantic menhaden (N.A.) (Henry 1971)	″	1	1941–68	−107.13	12.19	.05663	.924

1974; Daan 1975). The method of running the correlations is an averaging process in terms of year lag. Actually, using earlier or later segments of some of the records, we find somewhat longer or shorter lags indicating catch composition of older or younger fish. As to running means, increased smoothing results in greater correlation coefficients indicating the importance of low frequencies and long-term trends. This, however, decreases statistical significance; less smoothing increases significance and decreases the magnitude of r.

With some of the species presented in Table 3, lags with RIVSUM are longer than those of the temperature records. This is consistent with the notion presented in the earlier paper that the St. Lawrence River system has some influence further south months later. Again, however, it is difficult to assign significance to the actual difference in year lags or months involved between RIVSUM and the other two records for reasons given above.

Records with Effort Data

Results so far have dealt only with "raw" catch or landing statistics and make no attempt to take into account changes in fishing effort in terms of time or equipment expended. Four records that included considerable time series of standardized effort statistics were examined in more detail – cod, haddock (*Melanogrammus aeglefinus*), yellowtail flounder, and menhaden (see Table 4).

Figure 2A (upper part) shows the cod catch of ICNAF subarea 5 from 1925 to 1973. For the period 1925–50 an equation was derived from annual data (least squares fit) of the form $y = a + bx$ from the relationship between cod (y) and St. Andrews sea temperatures (x_1), $r = 0.640$. The second part of the middle graph (Fig. 2A) extending to 1971 was "predicted" from this equation. The occurrences of major peaks and troughs are reasonable except for the reduced relief of the fitted curves and a 2-yr difference of the peak in the late 1960s ($r = 0.850$). At the

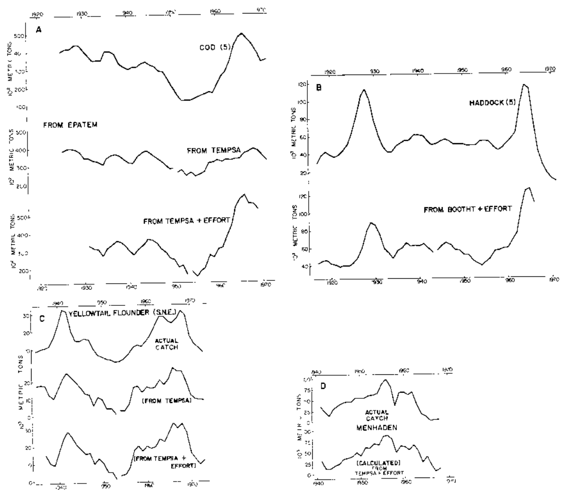

FIG. 2. A, *Upper* — ICNAF Subarea 5 cod catch; *middle* — calculated catch from temperature record (St. Andrews sea July–December); *lower* — calculated catch from sea temperature and effort. All 3-yr running means. B, *Upper* — ICNAF subarea 5 haddock catch; *lower* — catch calculated from temperature (Boothbay January–August) and effort. All 3-yr running means. C, *Upper* — southern New England yellowtail flounder catch; *middle* and *lower* — calculated from temperature (St. Andrews June–October) and effort. All 2-yr running means. D, *Upper* — annual North Atlantic menhaden catch; *lower* — annual catch calculated from temperature (St. Andrews May–December) and effort.

bottom of Fig. 2A is a graph of catch (y) derived from $y = a + bx_1 + cx_2$ (x_1 = temperature St. Andrews, x_2 = days fished $\times 10^{-3}$) for 1931–55. From this the remainder was calculated to the end of the effort record (1971). Similarities (and differences) with the actual catch record are obvious. The correlation coefficient of the entire cod–temperature–effort relationship is 0.896 (see Table 4).

With haddock, Eastport air temperatures for the early part of the record (starting in 1893) gave indifferent confusing results, explaining only about 25% (r^2) of the variation, and failed completely to account for the considerable rise in catch in the late 1920s. A large influence on this peak was greatly increased effort (Hennemuth 1969; Grosslein and Hennemuth 1973). So, using Boothbay temperatures (x_1), effort (x_2), and annual catch (y), we fitted the equation $y = a + bx_1 + cx_2$ for 1917–43 and extrapolated catch for the remainder using only temperature and effort (10^{-3} days). The results are shown in Fig. 2B (3-yr means); the correlation coefficient for the entire relationship was 0.776 (see Table 4).

The same approach used for cod was employed for yellowtail flounder (southern New England). The results (Fig. 2C) show, top, catch from 1935 to 1972; middle, catch and temperature fitted for 1935–53, catch predicted from the first period by temperature 1954–74; and bottom, catch fitted with temperature and effort (10^{-3} days) for 1937–53 to predict catch for 1954–74, all 2-yr running means. Details for catch–temperature and catch–temperature–effort equations for the entire series are given in Table 4.

Figure 2D shows plots of (upper) annual catch of North Atlantic menhaden and (lower) calculated catch from St. Andrews temperatures and standard vessel days, $r = 0.924$ (Table 4). For temperature alone, $r = 0.760$. The use of running means apparently did not introduce any spurious correlations in the other three species discussed above as seen in Table 4 when annual catch was used.

We realize the equations we have used here are not the usual ones found in mathematical treatments of fish stocks. Catch and effort might ideally have a curvilinear relationship and the relations to temperature might more properly be some function of the reciprocal of the absolute temperature. Clearly, if effort declines to zero, so must the catch, whereas once effort exceeds some optimal value, the catch should eventually go down. However, for the ranges of effort and temperature encountered here, the linear function did nearly as well as (or a little better than) more complicated ones that were tried and no purpose seemed to be served by making the presentation more complex. With these empirically derived equations we wish to make no further point than that environment should be considered when dealing with these populations.

No attempt was made to extend these catch–temperature–effort relationships with quite recent data for two reasons: 1) we feel the best catch and effort data available for a species result from a single investigator or group that has spent considerable time evaluating and collecting the data for that species, and 2) we are unsure of the effect of quotas on recent data. Ideally, some of the calculations presented here should be redone for the catch of a single country for which all the factors are well known.

Without more attention to the details of the biology and life histories of the various species considered here, it is difficult to say much about the underlying causes for positive or negative correlations. For instance Welch (Anon. 1975) notes that a negative correlation for soft-shell clams is likely through the agency of a predaceous crab that is more plentiful in warm years. Except for striped bass all species of fin fish showing negative correlations in this report are near the southern limit of commercial abundance (Bigelow and Schroeder 1953; Leim and Scott 1966).

Periodicity

If, as this study suggests, trends in the catches of commercial fisheries are associated with trends in the sea temperatures then any periodic behavior in the latter becomes important in forecasting future oscillations. Such an occurrence was recently discussed by Southward et al. (1975), who observed an 11-yr cycle in the commercial catches of several species of fish off England. They related this perodicity to sunspot cycles through sea temperatures.

To investigate the periodicity within the environmental factors of this study autocorrelations and power spectra were run on the annual averages of the sea temperatures at Boothbay Harbor (1906–73) and St. Andrews (1921–73), the air temperatures at Eastport (1874–1972) and the St. Lawrence River discharge, RIVSUM (1914–73). In each case the autocorrelation showed similar curves to that of Boothbay Harbor (Fig. 3) with a peak occurring at a lag of around 22 yr. The lag at which the peak occurs, the correlation coefficient and its significance follows:

	r at peak	Yr lag at peak	P
Sea surface temp.			
Boothbay Harbor	.261	22	.10
St. Andrews	.180	22	.10
Air temp			
Eastport	.366	22	.10
River discharge			
RIVSUM	.373	26	.08

Significance was calculated in a manner similar to that found in Sutcliffe et al. (1976).

Power spectra of these same series showed, after trend removal, that most of the variance is explained by fluctuations on the order of 20 yr or greater. More variance, although still quite small, was observed at higher frequencies in the

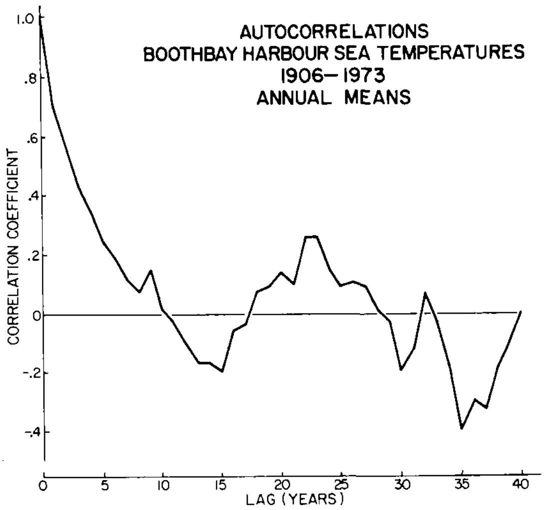

FIG. 3. Autocorrelations, Boothbay Harbor sea temperatures, see text.

air temperatures at Eastport than in the remaining series.

Although the environmental data series are too short to establish the stability of a 22-yr periodicity it is interesting that other investigators have also noted such a period, e.g. Roberts and Olsen (1975) for the occurrence of droughts in the Great Plains of North America.

SUBAREA 5

Figure 4 shows 3-yr running means of catch for the various species discussed above for subarea 5. ICNAF statistics were used back to 1954 (except for cod, haddock, and redfish for which the records were longer) and before this the New England landings (less Connecticut) were used. For a few years in the 1950s, before the influx of large mobile fleets, the numbers agreed fairly well so this combination of the two records does not seem unreasonable; for 1953–56, according to ICNAF records, the U.S. catch was at least 99% of the total in subarea 5, and presumably before this. In spite of wide variations of individual species and many factors affecting the data such as economic influences, the total is curiously flat for many years not unlike Lake Erie (Regier and Hartman 1973). While this is a log plot which would tend to flatten relief, the extremes are only about ±10% of the mean for the period of this plot. The picture from about 1940 to 1959 suggests a balanced system with man as an opportunistic predator taking whatever was in greatest abundance but with a relatively steady supply in toto. After 1960 the effect of large fleets with increased effort may be seen (discussed by Edwards (1968) and Brown et al. 1973). According to these authors the new level of catch constitutes overfishing of the major stocks involved.

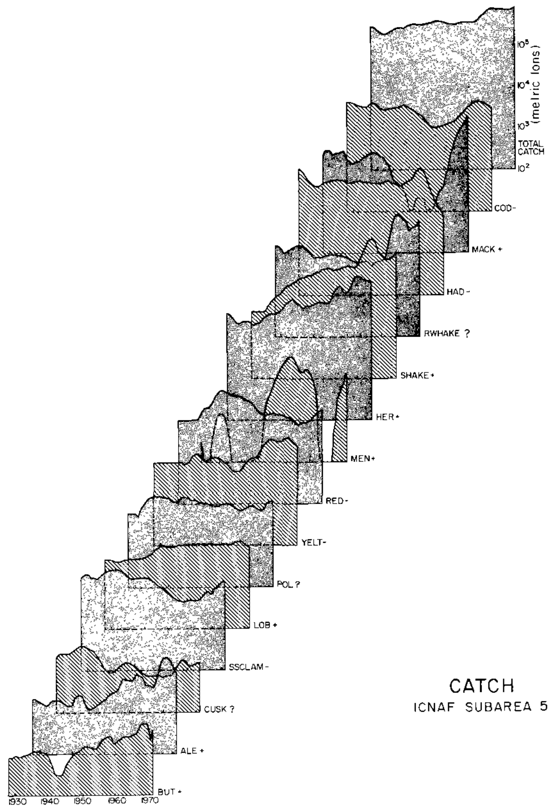

FIG. 4. ICNAF subarea 5 "catch" of various species (round fresh) and total (at top), see text, 3-yr running means,

Most of the species depicted in Fig. 4 have been shown above to undergo fluctuations correlated with environmental changes and the entire roster amounts to an average of about 84% of the total catch for the area. Further, the correlations with the environmental signals, in the majority of cases, explain at least 50% (r^2) of the variation. Clearly, a better understanding of the basic patterns of fluctuations, apparently imposed in part by the environment, would help in management policies and the imposition of quotas.

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ANON. 1975. The sea is warming up again. New Engl. Mar. Resour. Info. Prog., Univ. Rhode Island. 75: 4–5.

BIGELOW, H. B., AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. U. S. Fish Wildl. Serv. Fish. Bull. 53: 577 p.

BOURNE, N. 1964. Scallops and the offshore fishery of the Maritimes. Bull. Fish. Res. Board Can. 145: 60 p.

BOYAR, H. C. 1968. Age, length and gonadal stages of herring from Georges Bank and the Gulf of Maine. Int. Comm. Northwest Atl. Fish. Bull. 5: 49–61.

BROWN, B. E., J. A. BRENNAN, E. G. HEYERDAHL, M. D. GROSSLEIN, AND R. C. HENNEMUTH. 1973. An evaluation of the effect of fishing on the total finfish biomass in ICNAF sub-area 5 and statistical area 6. Int. Comm. Northwest Atl. Fish. Res. Doc. 73/8: 32 p.

BROWN, B. E., AND R. C. HENNEMUTH. 1971. Assessment of the yellowtail flounder fishery in sub-area 5. Int. Comm. Northwest Atl. Fish. Res. Doc. 71/14, Ser. No. 2599: 57 p.

BROWN, B. E., AND E. G. HEYERDAHL. 1972. An assessment of the Georges Bank cod stock (Div. 5Z). Int. Comm. Northwest Atl. Fish. Res. Doc. 72/117: 24 p.

CADDY, J. T., AND E. I. LORD. 1971. High price of scallop landings conceals decline in offshore stocks. Fish. Can. 23(5): 3–7.

CARRUTHERS, J. N. 1951. An attitude on fishery hydrography. J. Mar. Res. 10: 101–118.

CHASE, J. 1955. Winds and temperatures in relation to the brood-strength of George's Bank haddock. J. Cons. Cons. Int. Explor. Mer 21: 17–24.

COLTON, J. B. JR., AND R. F. TEMPLE. 1961. The enigma of Georges Bank spawning. Limnol. Oceanogr. 6: 280–291.

COTÉ, J. 1952. Statistics of landings of groundfish from the convention area. Int. Comm. Northwest Atl. Fish. 2nd Annu. Rep. 1951–52, Part 4: 35–68.

CUSHING, D. H. 1974. The possible density-dependence of larval mortality and adult mortality in fishes, p. 103–111. *In* J. H. S. Blaxter [ed.] The early life history of fish. Springer-Verlag, New York, N.Y. 765 p.

DAAN, N. 1975. Consumption and production in North Sea cod, *Gadus morhua*: an assessment of the ecological status of the stock. Neth. J. Sea Res. 9: 24–55.

DICKSON, R., AND A. LEE. 1972. Recent hydrometeorological trends on the North Atlantic fishing grounds. Fish. Int. Rev. 2: 4–11.

DOW, R. L. 1964a. A comparison among selected marine species of an association between sea water temperature and relative abundance. Extr. J. Cons. Cons. Int. Explor. Mer 28: 425–431.

1964b. Changes in abundance of the marine worm *Glycera dibranchiata*, associated with seawater temperature fluctuations. Commer. Fish. Rev. 26(8): 7–9.

DOW, R. L., AND D. E. WALLACE. 1957. The Maine clam (*Mya arenaria*). Bull. Dep. Sea Shore Fish. Maine. p. 3–35.

EDWARDS, R. L. 1968. Fishery resources of the North Atlantic area, p. 52–60. *In* DeWitt Gilbert [ed.] The future of the fishing industry of the United States. Univ. Wash. Publ. Fish. New Ser. 4: 346 p.

EDWARDS, R., AND R. HENNEMUTH. 1975. Maximum yield: assessment and attainment. Oceanus 18(2): 3–9.

FLOWERS, J. M., AND S. B. SAILA. 1972. An analysis of temperature effects on the inshore lobster fishery. J. Fish. Res. Board Can. 29: 1221–1225.

GROSSLEIN, M. D., AND R. C. HENNEMUTH. 1973. Spawning stock and other factors related to recruitment of haddock on Georges Bank. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 164: 77–88.

GULLAND, J. A. 1953. Correlations on fisheries hydrography. J. Cons. Cons. Int. Explor. Mer 18: 351–353.

1965. Survival of the youngest stages of fish, and its relation to year-class strength. Int. Comm. Northwest Atl. Fish. Environ. Symp., Int. Comm. Northwest Atl. Fish. Spec. Publ. 6: 363–371.

HENNEMUTH, R. C. 1969. Status of the Georges Bank haddock fishery. Int. Comm. Northwest Atl. Fish. Res. Doc. 69/90: 21 p.

HENRY, K. A. 1971. Atlantic menhaden (*Brevoorta tyrannus*) resource & fishery — analysis and decline. NOAA (Natl. Oceanic Atmos. Adm.) Tech. Rep. NMFS (Natl. Mar. Fish. Serv.) SSRF (Spec. Sci. Rep. Fish.)-642: 32 p.

ILES, T. D. 1973. Interaction of environment and parent stock size in determining recruitment in the Pacific sardine as revealed by analysis of density-dependent O-group growth, p. 228–240. *In* B. B. Parish [ed.] Fish stocks and recruitment symposium. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 164: 372 p.

INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES. 1964. Int. Comm. Northwest Atl. Fish. Redbook Part II: 129 p.

1973. Int. Comm. Northwest Atl. Fish. Redbook Part II: 109 p.

ISELIN, C. O'D. 1939. Some physical factors which may influence the productivity of New England's coastal waters. J. Mar. Res. 2: 74–85.

KELLY, G. F., AND R. S. WOLF. 1959. Age and growth of the redfish (*Sebates marinus*) in the Gulf of Maine. U. S. Fish Wildl. Serv. Fish. Bull. 60(156): 1–31.

LAUZIER, L. M. 1972. Climatic change in the marine subarctic. Trans. R. Soc. Can. Ser. 4 10: 297–307.

LEIM, A. H., AND W. B. SCOTT. 1966. Fishes of the Atlantic Coast of Canada. Bull. Fish. Res. Board Can. 155: 485 p.

LETT, P. F., AND A. C. KOHLER. 1976. Recruitment: a problem of multispecies interaction and environmental perturbations, with specific reference to the Gulf of St. Lawrence Atlantic herring (*Clupea harengus harengus*). J. Fish. Res. Board Can. 33: 1353–1371.

MCCRACKEN, F. D. 1958. On the biology and fishery of the Canadian Atlantic halibut, *Hippoglossus hippoglossus* L. J. Fish. Res. Board Can. 15: 1269–1311.

MARTIN, W. R., AND A. C. KOHLER. 1965. Variation in recruitment of cod (*Gadus morhua*) in southern ICNAF waters, as related to environmental changes. Int. Comm. Northwest Atl. Fish. Spec. Publ. 6: 833–846.

MERRIMAN, D. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. U. S. Fish Wildl. Serv. Fish. Bull. 50: 1–77.

REDFIELD, A. C. 1939. The history of a population of *Limacina retroversa* during its drift across the Gulf of Maine. Biol. Bull. 76: 26–47.

REGIER, H. A., AND W. L. HARTMAN. 1973. Lake Erie's fish community: 150 years of cultural stresses. Science 180 (4092): 1248–1255.

RICKTER, Y. A. 1972. An estimate of the stock abundance of red hake (*Urophycis chuss*) in 1965–72. Int. Comm. Northwest Atl. Fish. Redbook Part III: 49–58.

ROBERTS, W. O., AND R. H. OLSON. 1975. Great plains weather. Nature 254: 380.

SCHROEDER, W. C. 1930. Migrations and other phases in the life history of the cod off southern New England. Bull. U. S. Bur. Fish. 46: 1–135.

SISSENWINE, M. P. 1974. Variability in recruitment and equilibrium catch of the southern New England yellowtail flounder fishery. J. Cons. Cons. Int. Explor. Mer 36: 15–26.

SOUTHWARD, A. J., E. I. BUTLER, AND L. PENNYCUICK. 1975. Recent cyclic changes in climate and in abundance of marine life. Nature 253: 714–717.

SUTCLIFFE, W. H. JR. 1972. Some relations of land drainage, nutrients, particulate material and fish catch in two eastern Canadian bays. J. Fish. Res. Board Can. 29: 357–362.

SUTCLIFFE, W. H. JR., R. H. LOUCKS, AND K. F. DRINKWATER. 1976. Coastal circulation and physical oceanography of the Scotian shelf and the Gulf of Maine: J. Fish. Res. Board Can. 33: 98–115.

TAYLOR, C. C., H. B. BIGELOW, AND H. W. GRAHAM. 1957. Climatic trends and the distribution of marine animals in New England. U. S. Fish Wildl. Serv. Fish. Bull. 57: 293–345.

TEMPLEMAN, W. 1972. Year-class success in some North Atlantic stocks of cod and haddock. Symp. Environ. Conditions Northwest Atl. Int. Comm. Northwest Atl. Fish. Spec. Publ. 8: 223–239.

TEMPLEMAN, W., AND A. W. FLEMING. 1953. Long-term changes in hydrographic conditions and corresponding changes in abundance of marine animals. Int. Comm. Northwest Atl. Fish. Annu. Proc. 3: 79–86.

Data References

1. ANDERSON, A. W., AND E. A. POWER. Fishery statistics of the United States. U. S. Dep. Inter., Fish Wildl. Serv., U. S. Gov. Print. Off., Washington.
   1942. Stat. Dig. 11: 248 p.
   1943. Stat. Dig. 14: 241 p.
   1944. Stat. Dig. 16: 283 p.
   1945. Stat. Dig. 18: 372 p.
   1946. Stat. Dig. 19: 265 p.
   1947. Stat. Dig. 21: 283 p.
   1948. Stat. Dig. 22: 305 p.
   1952. Stat. Dig. 34: 345 p.
   1953. Stat. Dig. 36: 338 p.
   1954. Stat. Dig. 39: 374 p.
   1955. Stat. Dig. 41: 446 p.
2. ANDERSON, A. W., AND C. E. PETERSON. Fishery statistics of the United States. U. S. Dep. Inter., Fish Wildl. Serv., U. S. Gov. Print. Off., Washington.
   1949. Stat. Dig. 25: 298 p.
   1950. Stat. Dig. 27: 492 p.
   1951. Stat. Dig. 30: 341 p.
3. BROWN, B. E., AND R. C. HENNEMUTH. 1971. Assessment of the yellowtail flounder fishery in sub-area 5. Int. Comm. Northwest Atl. Fish. Res. Doc. 71/14: 57 p.
4. EDWARDS, R., AND R. HENNEMUTH. 1975. Maximum yield: assessment and attainment. Oceanus 18(2): 3–9.
5. FIEDLER, R. H. Fishery industries of the United States. U. S. Dep. Commer., Bur. Fish., U. S. Gov. Print. Off., Washington.
   1930. 552 p.
   1931. 440 p.
   1932. 449 p.
   1934. 330 p.
6. FIEDLER, R. H., J. R. MANNING, AND F. F. JOHNSON. Fishery industries of the United States. U. S. Dep. Commer., Bur. Fish. U. S. Gov. Print. Off., Washington. 1933 — 237 p.
7. FIEDLER, R. H. Fishery industries of the United States. U. S. Dep. Commer., Bur. Fish., U. S. Gov. Print. Off., Washington.
   1935. Adm. Rep. 24: 348 p.
   1936. Adm. Rep. 27: 276 p.
   1937. Adm. Rep. 32: 460 p.
   1938. Adm. Rep. 37: 554 p.
8. FIEDLER, R. H. Fishery industries of the United States. U. S. Dep. Inter., Bur. Fish., U. S. Gov. Print. Off., Washington. 1939 — Adm. Rep. 41: 554 p.
9. FIEDLER, R. H. Fishery statistics of the United States. U. S. Dep. Inter., Fish Wildl. Serv., U. S. Gov. Print. Off., Washington.
   1939. Stat. Dig. 1: 220 p.
   1940. Stat. Dig. 4: 225 p.
   1941. Stat. Dig. 7: 174 p.
10. HOY, D. L., AND G. M. CLARK. 1967. Atlantic mackerel fishery, 1804–1965. U. S. Fish Wildl. Serv. Fish. Leafl. 603: 9 p.
11. INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES. 1952. Second annual report for the year 1951–52. Dartmouth, N.S. 68 p.
12. INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES. Dartmouth, N.S.
   1953. Stat. Bull. 3: 55 p.
   1954. Stat. Bull. 4: 58 p.
   1955. Stat. Bull. 5: 52 p.
   1956. Stat. Bull. 6: 58 p.
   1957. Stat. Bull. 7: 67 p.
   1958. Stat. Bull. 8: 69 p.
   1959. Stat. Bull. 9: 70 p.
   1960. Stat. Bull. 10: 75 p.
   1961. Stat. Bull. 11: 90 p.
   1962. Stat. Bull. 12: 78 p.
   1963. Stat. Bull. 13: 87 p.
   1964. Stat. Bull. 14: 84 p.
   1965. Stat. Bull. 15: 95 p.
   1966. Stat. Bull. 16: 104 p.
   1967. Stat. Bull. 17: 115 p.
   1968. Stat. Bull. 18: 141 p.
   1969. Stat. Bull. 19: 121 p.
   1970. Stat. Bull. 20: 115 p.
   1971. Stat. Bull. 21: 135 p.
   1972. Stat. Bull. 22: 239 p.
   1973. Stat. Bull. 23: 277 p.
13. LYLES, C. H. Fishery statistics of the United States. U. S. Dep. Inter., U. S. Fish Wildl. Serv., Bur., Commer. Fish., U. S. Gov. Printing. Off., Washington.

1963. Stat. Dig. 57: 522 p.
1964. Stat. Dig. 58: 541 p.
1965. Stat. Dig. 59: 756 p.
1966. Stat. Dig. 60: 679 p.
1967. Stat. Dig. 61: 490 p.

14. POWER, E. A. Fishery statistics of the United States. U. S. Dep. Inter., Fish Wildl. Serv., Bur. Commer. Fish., U. S. Gov. Print. Off., Washington.
1956. Stat. Dig. 43: 476 p.
1957. Stat. Dig. 44: 429 p.
1958. Stat. Dig. 49: 424 p.
1959. Stat. Dig. 51: 457 p.
1960. Stat. Dig. 53: 529 p.
1961. Stat. Dig. 54: 460 p.

15. POWER, E. A., AND C. H. LYLES. Fishery statistics of the United States. U. S. Dep. Inter., Fish Wildl. Serv., Bur. Commer. Fish., U. S. Gov. Print. Off., Washington. 1962 — Stat. Dig. 56: 466 p.

16. UNITED STATES DEPARTMENT OF COMMERCE. Fishery statistics of the United States. Nat. Oceanic Atmos. Adm., Nat. Mar. Fish. Serv., U. S. Gov. Print. Off., Washington.
1968. Stat. Dig. 62: 578 p.
1969. Stat. Dig. 63: 474 p.
1970. Stat. Dig. 64: 489 p.
1971. Stat. Dig. 65: 424 p.

Added in proof: We wish to cite an independent but parallel investigation which has been brought to our attention (Dow personal communication). Although the approach differs somewhat, the primary conclusions agree with ours: R. L. Dow. 1977. Effects of climatic changes on the relative abundance and availability of commercial marine and estuarine species. J. Cons. Cons. Int. Explor. Mer 37(3). (In press)