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Changes in the distribution of marine animals in New England and Middle Atlantic waters in relation to changes in temperature.*

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INTRODUCTION

A summary of evidence showing a marked warming of arctic and subarctic areas in recent years, accompanied by significant floral and faunal changes, has been presented by Rollefsen and others (Rollefsen, Fridriksson, Jespersen, Lysgaard, Smed, Tåning, 1948). Since slight changes in air temperatures have pronounced effects on ice formation, it is apparent that the first indications of a general warming of climate will be noted in northern latitudes and that the presence or absence of ice will, in general, be related to presence or absence of plants and animals.

In temperate regions, slight fluctuations in climate may pass unnoticed because accompanying floral and faunal changes may be absent or, if present, may be of such small magnitude that they are obscured by normal variations.

The warming of arctic areas and the accompanying ecological changes have been so marked, however, that it seems reasonable to suppose that similar changes have taken place on a smaller scale in more southern latitudes. It is the purpose of this paper to examine the evidence indicating fluctuations in temperatures in recent years, and to explore the relations which may exist between these fluctuations and the apparent abundance and distribution of marine animals along the eastern coast of the United States and in the New England area in particular.

The examination of available meteorological data and of records which may indicate floral and faunal changes requires, in its initial stages at least, a direct approach to the major features which may be inherent in the details of the data. In some species the mechanisms of temperature influence may be at least as complex as the steps by which the organism is removed from the base of the food chain. In other species the influence of temperature may be direct. A change in temperature may be expected to alter the whole ecological situation. The presence or relative abundance of a particular species may be influenced directly by the change in temperature or by one or more other factors in the new environment.

In the following pages we have gathered some of the available data on trends in temperature and trends in the distribution of certain species of fish and other marine invertebrates.

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While the interpretation to be placed on these data doubtless will be controversial, it is hoped that the presentation of these relationships may stimulate others, especially specialists in particular fields, to examine more critically the data they may have at hand. A great deal of the theory of fishery science is based on the premise that the environment is unchanging and that the fluctuations which do occur take place within certain limits on either side of a stable norm. We find, therefore, that changes in abundance are frequently attributed to the effects of exploitation. If the premise of a stable environment is not valid, it will be required, at least, to re-examine the over-fishing explanation of such fluctuations.

Trends in air temperature:

Extensive evidence of an upward trend in air temperatures over the United States and Canada was presented by Kincer as early as 1933 (Kincer, 1933). In addition to a general upward trend in annual means, Kincer's analysis showed that winters, springs, and falls were becoming milder, while summer temperatures were remaining about the same. Similarities in trends, as well as in the patterns of fluctuations, are evident in Kincer's diagrams for stations at Philadelphia, Pa., St. Paul, Minn., St. Louis, Mo., Washington, D.C., New Haven, Conn., Lynchburg, Va., Dale Enterprise, Va., Baltimore, Md., Portland, Oregon, Winnipeg, Canada, and Toronto, Canada. Kincer also showed similar trends for Paris, Vienna, Greenwich, Santiago, Buenos Aires, Capetown, Bombay, and Batavia.

Kincer's data encourages one to believe that air temperature records at one point on the eastern seaboard will reflect the general trend of air temperatures for latitudes north and south, although of course not in level or in magnitude of fluctuations.

Monthly mean temperatures are available for New Haven, Conn. since 1780 and for Eastport, Maine, since 1874 (Clayton, H.H., 1927, 1934; Clayton, H.H. and Clayton, F.L., 1947). Annual deviations from the mean (48.3°F.) at New Haven for the period 1780-1938 are presented in Figure 1 and a smoothed curve has been drawn through them. An upward trend is discernable since about 1850, becoming pronounced after about 1885. Since 1900, 44 of the 51 annual means show positive deviations. Over half of the positive deviations are greater than 1°F.

Figure 2 presents similar data for Eastport, Maine, for the period 1874-1951. The upward trend is somewhat less marked than that for New Haven but it is clearly evident after 1925.

Annual means may not indicate all the significant changes which may be occurring in an area. Mild winters and cool summers may, for example, result in the same annual means as severe winters and very warm summers, the former being characteristic of a maritime climate, the latter of a continental climate. The difference between January and July temperatures provides an estimate of the degree of maritime influence. If winters become milder or summers cooler, the January-July difference will become less, while if winters become colder and summers warmer this difference will be greater. If the trend is in the same direction for both January and July, the difference will remain about the same but the change will be reflected in the annual mean.

January-July differences for the period 1874-1951 are plotted as deviations from their mean difference for New Haven and Eastport in Figure 3. A downward trend, indicating a general increase in mildness is evident from 1874 to 1932. A temporary reversal of this trend appears between 1932 and 1942. Figure 4, which shows smoothed January temperatures for New Haven and Eastport, indicates this reversal was caused by a decline in January temperatures over the same period. This decline appears to be only a periodic fluctuation and the general trend of January temperatures from 1874 to 1951 is upward. The actual increase in January temperatures at New Haven, for example, over the period since 1780 is greater than Figure 4 shows. The average January temperature for the period 1780-1873 is 26.5°F. For the period 1874-1951 it is 28.9°F., an increase of 2.4°.

The close correspondence of temperature conditions at New Haven and at Eastport over the period 1874 to 1951 shows that we may, with considerable assurance, use the longer New Haven series as indicative of air temperature changes generally in the New England coastal area.

Sea surface temperatures:

Surface temperature records covering periods of time sufficient to indicate significant trends are scarce for the Atlantic coast. Hachey and McLellan (1948) have published data for St. Andrews, New Brunswick, for the period 1921-1947. Annual means for St. Andrews for the years 1948-1951 are shown by Lauzier (1952). Surface temperature records taken at lightships are comparatively recent for the most part and frequently contain gaps for periods when the ships are off station.

Daily readings of surface temperature were taken at 8:00 a.m., 12:00 noon, and 4:00 p.m. at the fish hatchery which was in operation at Boothbay Harbor, Maine from 1905 to 1949. These data, as monthly means, are presented in Appendix I. Examination of the original records indicates that these temperatures, recorded to the nearest degree, were carefully taken for the most part. In some instances, however, temperatures below the freezing point of sea water were recorded. The trends and fluctuations in these temperatures are in good agreement with those appearing in the St. Andrews data (cf. Figures 5 and 6).

Annual deviations from the 43-year mean at Boothbay Harbor (1906-1948) are shown in Figure 5. There is little evidence of increase in the annual means over the period. For the 25 years 1906-1930 the annual means average 45.9°F. For the 18 years 1931-1948 the average is 46.4.

A striking amelioration of winter conditions in recent years is shown when the January-July difference in water temperature at Boothbay Harbor is plotted as a deviation from the mean difference for the period (Figure 7). The average January and July temperatures for various periods are shown below:

Period	January	July
1906-1920	33.3	61.1
1921-1930	33.0	61.6
1931-1940	34.6	60.7
1941-1949	35.2	60.5

January temperatures have increased about 2° while July temperatures have decreased about 1° since 1920. These opposite trends account, of course, for the magnitude of the phenomenon observed in Figure 7.

Temperature records exist for Woods Hole, Massachusetts, for the periods 1881-1914, 1932-1942, and 1945-1952. These data are presented in Appendix II. January, July, and annual means for various periods are presented below:

Mean Temperature

Period	January	July	Annual
1885-1894	34.2	69.2	51.1
1895-1904	33.0	68.3	50.5
1905-1914	33.8	69.6	51.1
1932-1941	34.7	67.8	50.5
1945-1951	35.1	70.3	52.5

The trend in January temperatures is similar to that for Boothbay Harbor, the temperatures for nearly comparable periods being of about the same magnitude. Except for the period 1932-1941, however, there does not appear to be any trend toward declining July temperatures comparable to that at Boothbay Harbor. The annual means for the years since 1945 are considerably higher than for the earlier periods. This increase is undoubtedly significant, for no other period of similar length is to be found in which the annual means average as high. These data indicate that winter conditions have been generally milder since 1932 and that a significant warming has occurred since 1945. A five-year moving average of the deviations of the January-July difference from the mean difference is shown in Figure 8, together with similar data for St. Andrews, New Brunswick and Boothbay Harbor, Maine.

Changes in the abundance and distribution of marine species:

Although valuable statistics on the landings of many marine species have been collected since 1887, these records are not, for the most part, continuous prior to about 1930. It is not, therefore, possible to show long-term trends and fluctuations except for a few species. Changes in methods, efficiency, and fishing effort, as well as changes in market conditions tend to obscure the relations that may exist, so that one must frequently make general comparisons, looking for minor fluctuations which may be related to environmental conditions when the major upward or downward trends may be due to other factors.

Fluctuations in mackerel landings:

G.B. Goode, et al, (1881) presents data on barrels of mackerel inspected in Massachusetts for the period 1804-1881. Except for the initial years, these figures appear to reflect variations in the abundance or availability of mackerel. Statistics on landings of mackerel for the ports of Boston, Gloucester and Portland have been published since 1893, so that with the exception of the period 1882-1892, a nearly continuous record of trends in the mackerel fishery in the New England area is available.

Thousands of barrels of mackerel inspected in Massachusetts, smoothed by five-year moving averages, are plotted against smoothed New Haven annual deviations in air temperature occurring three years earlier than the landings in Figure 9. There is a marked tendency for rising temperatures to be associated with good catches three years later, while falling temperatures are associated with the opposite effect. The relationship is not perfect, indicating the probability of a complex of factors.

Landings at Boston, Gloucester and Portland, 1893-1951, are also shown in Figure 9. Here again, peaks in catch are associated with peaks in temperature three years earlier. The catch rises rapidly after 1922. During the same period the smoothed temperature deviations have all been positive. The depression in catch occurring about 1939 and the subsequent rise can hardly be accounted for, however, in terms of the magnitude of corresponding temperature changes.

A feature of the mackerel data (Figure 9) is the occurrence of peaks in the catch at intervals varying between 15 and 18 years. These apparently cyclic fluctuations are evident over the entire period since about 1820. Although only scattered records are available for the period 1882 to 1892, the marked high in New Haven temperatures in 1879 is associated with high catches. Landings in Massachusetts in 1882, for example, were the highest ever recorded. If these intervals between high catches continue to hold, the next peak in mackerel landings may be expected between 1959 and 1962.

It is interesting to note that the peaks in mackerel landings which occurred about 1916, 1930 and 1945 correspond with outbreaks of epidemic proportions of the fungus Ichthyosporidium in herring as reported by Scattergood (1948).

Fluctuations in lobster landings:

A complete record of annual lobster landings since 1904 is available for Rhode Island (Annual Reports, Rhode Island Commissioners of Inland Fisheries), and from federal statistics for recent years. These data, smoothed by five-year moving averages, are presented in Figure 10 together with Boothbay Harbor January-July differences in water temperatures (dotted line). The Boothbay Harbor data which are presented in Figure 7 have been given an additional smoothing in Figure 10 by three-point moving averages. The Boothbay Harbor temperatures are used for this comparison because they are the only ones available which cover the period of these lobster landings. It has already been pointed out that trends in both air and water temperatures are quite similar over an extensive range along the Atlantic coast.

The temperature and landing data indicate a direct relationship between water temperature and the availability of lobsters, a relationship recently pointed out by Martin (1953) for lobster catches in Canada. It is to be noted, however, that the curve of water temperatures in Figure 10 represents a tendency toward warming of water conditions in recent years, especially during the winter months, and that the catch of lobsters in Rhode Island has declined in the face of this warming. The relationship discovered by Marten is opposite in effect, Canadian lobster catches being greater in warm years.

Lobster landings for the Middle Atlantic States, for Massachusetts, and for Maine are presented for the years since 1918 in Figures 11, 12, and 13. It will be noted that the downward trend in landings for the Middle Atlantic States is similar to that occurring in Rhode Island, while the trends in Massachusetts and Maine have been upward over the same period.

Consideration of these data, together with the Canadian trend, suggests that there are optimum conditions for lobsters and that these optimum conditions were passed in the area south of Cape Cod about the middle of the 1920's. This hypothesis also implies that conditions began improving in the area north of Cape Cod about 1940 and that this improvement has continued to the present time.

Lobster landings have been reported by months in Maine since January, 1939. The availability of monthly surface temperatures at Boothbay Harbor over the greater part of this period affords means of further investigation of the relationship of water temperature to lobster catches.

Figure 14 shows monthly lobster catches in Maine plotted against the corresponding mean water temperature for the months of October through April for the years 1939 to 1949. A curvilinear relationship is evident which is fitted by the equation

$$\log y = -2.6089 + 0.0589X \qquad (1)$$

The correlation coefficient for log catch and temperature is 0.854 which, for 72 degrees of freedom, is highly significant.

In figure 15 the catches for the months of May through September are plotted against the corresponding mean monthly temperatures. The relationship is similar to that above, although it is quite obvious that the monthly catches in summer are occurring at a considerably lower level than would be predicted from the winter relationship. The correlation between log catch and temperature is 0.548 which is also highly significant.

These data are inadequate to show that lobsters are less available during the summer months when temperatures are highest, or that an optimum temperature condition is exceeded during the summer months. Lobsters begin moulting in the western part of the state in May, the process continuing more of less progressively eastward along the coast until late September. Males molt prior to females; marked changes in the proportion of the sexes are observed in the catch during the molting period; and the molting of females is attended by mating activities. During this period there is a decrease in availability. Subsequent to molting the lobsters are in a soft-shelled condition. Although abundance is usually high following molting, principally because of the recruitment of lobsters which had been below legal size prior to molting, this abundance, combined with the soft-shelled condition, usually results in a decline in market price. For these reasons, fishing effort and the resulting catches may not reflect true availability during the summer months.

A reasonable objection to the foregoing is that the high degree of correlation between lobster catch and water temperature is based on total catches by months and not on catch per unit effort. Although some effort data by months has been collected since 1939, its reliability has never been established through adequate analysis. Using the effort data, however, for the period 1939-1946, no correlation between catch per unit effort and temperature is apparent. For the years 1939 to 1942 a highly significant correlation between monthly catch per unit effort and temperature is obtained. These discrepancies appear to be the result of a rapid rise in the abundance of lobsters over the period 1943-1946, so that the catch per unit effort corresponding to a given temperature is changing each year. During the period 1939-1942, the annual catches did not vary a great deal, the monthly catches thus indicating availability rather than abundance. Although the annual catches since 1946 have attained a fair level of stability, monthly effort data are not available.

Whatever the reasons for the significance of the relationship between monthly catches and monthly temperatures, it is, of course, evident that equation (1) cannot be expected to hold at temperatures much higher than 50°F. A month with an average surface temperature of 65° would, for example, yield a catch about equal to the average annual Maine catch in recent years, according to equation (1). Disregarding the effect of molting on availability, it is apparent that temperature, if it is the significant factor, can increase availability up to but not beyond the actual abundance.

<u>Fluctuations in whiting (*Merluccius bilinearis*, Mitchill) landings</u>:

Statistics on landings of whiting prior to 1937 are scattered and the period since 1937 is hardly long enough to attempt to relate in detail fluctuations in catch to corresponding temperature changes. A comparison of landings in New England with those south of Cape Cod shows, however, a striking decrease in the latter areas and a corresponding increase in the former. The trends resemble those observed in lobster landings north and south of Cape Cod.

The increase in landings in Massachusetts and in Maine is undoubtedly due in part to improved market conditions and more facilities for freezing. Although the price of whiting increased sharply in 1943, the trend since 1944 has been downward. The decrease in landings in states south of Cape Cod cannot be explained in terms of changes in these factors and the scarcity of whiting since 1948 has apparently led to a sharp increase in price (Figure 16).

Whiting landings for New York and New Jersey are shown in Figure 16 together with the average price per pound for the years 1937 to 1950. A downward trend in landings is evident to 1947 with a precipitous drop in 1948. Although recent figures are not yet published, it is reported that whiting catches remained at a low level in 1951 and 1952. The decline in whiting catch has not been accompanied by any decline in fishing effort or demand but it has been accompanied by a price increase. A substantial part of the whiting catch is made by stationary pound nets. These nets catch a variety of species, so that their successful operation does not depend on the presence or absence of a particular species. The whiting catch of these nets has suffered a decline which corresponds in magnitude to that of the total catch by all gear. The pound net fishery in New Jersey, for example, averaged about 4.8 million pounds of whiting annually from 1942 to 1945. In 1948 and 1949 the catches were 168,100 and 354,600 pounds respectively. It is reported to us also that whiting vessels from Gloucester which formerly found it profitable to go to the New York-New Jersey area to fish during the summer months no longer do so because of the scarcity of this species in that area.

While a general increase in New England landings of whiting is found for the period 1937-1950, the catch has actually declined in Connecticut and Rhode Island, the increase in New England being due to increased landings in Maine and Massachusetts. Landings for Rhode Island and Connecticut, which have followed almost identical fluctuations, are shown in Figure 17. These landings rose suddenly between 1942 and 1943, perhaps because of the price increase in 1943, but have declined more or less consistently since to the earlier level. Landings in Maine and Massachusetts are shown in Figure 18, together with the Maine price. Although the price increased substantially in 1942 and 1943, there was no corresponding increase in landings. The Maine price has since declined from the high of 2.5 cents in 1943 to about 1.0 cent in 1952, the catch in Maine increasing over the same period from two to 22 million pounds.

An interesting fact is that while the total Massachusetts landings of whiting have increased since 1937 the pound net catch has decreased (Figure 19). The catch per pound net for the period 1937 to 1942 averaged 78,775 pounds. The catch per net since 1943 has averaged 22,783 pounds.

Bigelow and Welsh (1924) state that the silver hake (whiting) is strictly a summer fish in the Gulf of Maine, sometimes appearing in the Massachusetts Bay-Cape Ann region as early as the last week in March and regularly striking there by May and that this applies equally to Georges Bank where the first whiting were taken by otter trawlers from April 27 to 29 in 1913. They further state that the fish vanish from coastwise waters and from the offshore fishing banks sometime in late autumn and that it is probable that the fish do not winter in the deep basin of the Gulf of Maine but withdraw from it altogether at the approach of cold weather.

With reference to the abundance of whiting relative to other fishes on Georges Bank, Bigelow and Welsh refer to the otter-trawl investigations of 1931, stating that during the period April to September the average catch per trip was about 14,000 individuals of haddock to 1,800 individuals of whiting. The Gloucester fishermen today recall the former seasonal occurrence of whiting on Georges Bank and in the Gulf of Maine.

If the whiting was once strictly a summer fish in the Gulf of Maine, this situation most certainly is untrue today. Cursory examination of weigh-out sheets for the port of Gloucester January, February and March 1952 indicates that small whiting boats can make consistently good catches during these months in subareas XXII E, which lies off the coast of Massachusetts, and XXII D, which lies off the coast of western Maine. The weigh-out sheets also show that whiting appear in small amounts, but regularly, as an incidental catch for boats fishing in subareas XXII F and G. (See Rounsefell, 1948 for description of statistical areas).

A partial list of whiting landings at Gloucester is shown below for the months of January and February. These are trips in which whiting predominated in the catch, many of the trips consisting almost entirely of whiting.

Date	Length of trip (days)	Vessel	Size category*	Grounds fished	Pounds of whiting
1952					
Jan. 4	1	Captain Drum	OTS	XXII E	9,375
15	1	Captain Drum	OTS	XXII E	3,000
28	1	Captain Drum	OTS	XXII E	7,450
4	1	Holy Name	OTM	XXII E	1,000
10	1	Holy Name	OTM	XXII E	800
15	2	Holy Name	OTM	XXII E	6,750
21	1	Holy Name	OTM	XXII E	525
10	1	Immaculate Conception	OTM	XXII E	1,400
15	1	Immaculate Conception	OTM	XXII E	4,130
16	1	Immaculate Conception	OTM	XXII E	300
6	1	Rosie and Macie	OTM	XXII D	4,050
15	1	Rosie and Macie	OTM	XXII D	3,600
23	1	Rosie and Macie	OTM	XXII D	3,550
10	1	Rosemarie	OTM	XXII D	2,600
14	1	Rosemarie	OTM	XXII D	4,500
3	1	St. Mary	OTS	XXII E	900
5	1	St. Mary	OTS	XXII E	9,000
10	1	St. Mary	OTS	XXII E	1,740
14	1	St. Mary	OTS	XXII E	380
Feb. 2	1	Captain Drum	OTS	XXII E	7,350
8	1	Captain Drum	OTS	XXII E	2,500
11	1	Captain Drum	OTS	XXII D	16,400
17	1	Captain Drum	OTS	XXII D	7,675
3	2	Holy Name	OTM	XXII D	9,600
9	1	Holy Name	OTM	XXII D	12,450
17	1	Holy Name	OTM	XXII D	3,875
28	1	Immaculate Conception	OTM	XXII E	4,050
18	1	Carlo and Vience	OTM	XXII E	3,500
27	1	Chebeague	OTM	XXII D	2,285
27	1	California	OTM	XXII D	7,600

* OTS - Small otter trawler, 5-50 gross tons; OTM - Medium otter trawler, 50-150 gross tons.

The maximum depth of water in subarea XXII D is about 120 fathoms and in subarea XXII E is about 150 fathoms. The larger part of both subareas is under 80 fathoms. It is unlikely that these boats fished in the deeper waters, not only because no quantities of redfish appear in the catches but also because the deeper water lies more distantly from port, making it unlikely that it could be profitably fished in a one day trip.

To determine more exactly the depths in which whiting are caught during the winter months, interview sheets for the port of Provincetown were examined for the month of January, 1953. These sheets are prepared by a port interviewer and show, for each trip, the approximate position and the range of depths in which the vessel fished, as well as the weigh-out. Out of 41 trips in which whiting were landed by small otter trawlers, 25 percent of the fishing was in depths of 30 fathoms or less, 50 percent was in depths between 30 and 55 fathoms, and 25 percent was in depths between 55 and 70 fathoms. All of the trips were to subareas XXII E and XXII G. The Provincetown interviews also make it clear that the actual availability of whiting is not shown by the amounts landed. Haddock, cod, and flounders appear to be the species sought. Of several boats fishing in the same area on the same day, some will show whiting in the weigh-outs and others none.

Examination of monthly landing records in Maine shows that whiting may be landed in any month of the year. The landings during January, February and March are small compared with summer landings. These whiting probably do not come from the deeper water of the Gulf of Maine, for these depths are fished only by the redfish boats which rarely trouble to save whiting when they encounter them.

Recent data on the abundance of whiting relative to other species on Georges Bank is available from the otter trawl investigations conducted there during the summers of 1948-1951 by the Fish and Wildlife Service. These investigations showed whiting to be the most abundant fish in the catches, outnumbering haddock by 164 to 100. The predominance of whiting was not due merely to unusual abundance in areas or depths where haddock are not found. In subarea XXII J in depths between 30 and 60 fathoms, a favored fishing area for the commercial haddock fleet, haddock outnumbered whiting only by about 1.5 to 1.

Even allowing some latitude for the incompleteness of earlier observations the evidence indicates major changes in the distribution and habits of whiting since Bigelow and Welsh described the distribution of the species. If one advances the hypothesis that there has been a general warming of coastal waters, the pattern of observed changes may be explained but one must look to the collection of data in the future to substantiate such an hypothesis. According to this hypothesis, coastal waters south of Cape Cod have become too warm for whiting to be present in abundance, or possibly, too warm for the successful incubation of the eggs. (Bigelow and Welsh, 1924, p. 394 state that experiments in the hatchery at Woods Hole point to 65° to 70° as the upper limit to successful incubation.) Since the warming may be expected to be more pronounced close inshore where the pound nets are located, the decline in these catches in Massachusetts is explained by the presence of waters in these areas somewhat warmer than the whiting prefers. The presence of whiting in the Gulf of Maine during winter months is due to a general amelioration of winter conditions as indicated by January temperatures at Boothbay Harbor and St. Andrews, N.B.

This hypothesis hangs, of course, on a very slender thread of evidence. It will be objected that whiting tolerate a wide range of temperatures and that the relatively slight changes indicated by the available data are not sufficient to explain the observed change. We are not certain that this is a valid objection. The possibility that whiting may be able to tolerate the complete range of temperatures in the areas under consideration does not necessarily indicate that there are not optimum conditions which they prefer and will seek.

Even given optimum temperature conditions, whiting will require food and the presence or absence of food will, or course, affect the distribution. Aside from the consideration that any fish may have become adjusted to certain "optimum" environmental conditions because these conditions are related to its food supply, the hypothesis of a temperature factor in distribution may be removed only one step from a direct relationship.

Fluctuations in menhaden (Brevoortia tyrannus, Latrobe) catches:

Although occasional small menhaden catches have been reported for Massachusetts since this fish reappeared in abundance in 1922, after an almost complete absence north of Cape Cod since about 1900, this fish remained unreported in Maine waters until 1945 when small numbers were caught and used for lobster bait. In 1951, seven million pounds of menhaden were reported landed at Gloucester and in 1952 landings at the same port amount to 26 million pounds (Anon., 1952).

The catch of menhaden in Maine rose from 24,000 pounds in 1948 to five million pounds in 1949, the rise in 1949 being largely due to the presence of menhaden seiners from the southern fleet in that year. (Anon., 1949). The catch in the past several years probably does not reflect the actual abundance. Local vessels have not been equipped for menhaden seining and New England conservation regulations have made difficult the operation of out-of-state vessels within the three-mile limit where menhaden schools are most abundant. (Anon., 1951). The trend in the Maine and Massachusetts landings is indicated below:

Year	Massachusetts	Maine
1942	10,200	--
1943	68,700	--
1944	22,700	--
1945	85,000	8,400
1946	81,200	--
1947	89,700	14,000
1948	1,047,300	24,109
1949	7,473,500	5,027,345
1950	8,762,000	409,000
1951	7,000,000*	1,514,334
1952	26,000,000*	604,558

* Gloucester landings only.

It is impossible to state to what extent the warming of inshore waters, as indicated by surface temperature records at Woods Hole, Boothbay Harbor, and St. Andrews, has affected the reappearance of the menhaden north of Cape Cod. According to Bigelow and Welsh, 50° is the coldest water temperature this fish will tolerate. Menhaden were reported abundant at Eastport about 1845 (Goode, 1877) but they were not present in that area during the 1870's when the menhaden fishery in the Boothbay Harbor region was at its height. In 1876, records of surface water temperatures at Eastport (Goode, 1877) show average July and August temperatures of 47.2° and 50.2° respectively, sufficiently low to indicate unfavorable conditions for menhaden. In the same year, surface temperatures at Portland, Maine, about thirty miles west of Boothbay Harbor show July and August temperatures of 66.7 and 63.9 respectively, so that the presence of menhaden would not be surprising. It must be pointed out, on the other hand, that surface water temperature records at Boothbay Harbor over the period 1906-1949 show that temperatures in that area have probably been sufficiently high for the presence of menhaden every year (See Appendix I).

With a migratory species such as menhaden, its presence or absence north of Cape Cod during the summer months is not necessarily determined by the inshore conditions where it is commonly caught but may be determined by other conditions along its migratory route. Unfavorable conditions along the way may act as barriers.

Northward extension of miscellaneous southern forms:

King mackerel, *Scomberomorus regalis*

This southern fish is described by Jordan and Evermann (1896) as "not very common on our Atlantic coast." Although appearing sporadically in the statistics of landings for the Middle Atlantic states since 1877, it seems to have appeared in the landings with increasing frequency in recent years. It is reported in Middle Atlantic landings for the years 1931, 1933, 1937, 1946 and 1948-1950. The species is not reported for any of the New England states from 1919 to 1931 for any of the years in which annual surveys were made of fish landings. It is reported for Massachusetts in 1931 and 1946 and for Connecticut in 1935 and 1946.

Frigate mackerel, *Auxis thazard*

The frigate mackerel was reported in great numbers in the vicinity of Point Judith, Rhode Island, in August 1949 (Arnold, 1951). Landings are reported for Massachusetts and Rhode Island for the years 1945-1950 and for the Middle Atlantic states for 1948-1950.

Filefish

A filefish was reported caught in a lobster trap at East Harpswell, Maine, in the fall of 1950 (Anon., 1950a). Although not identified as to species, the occurrence of any filefish north of Cape Cod is extremely rare and has not been reported for many years.

Butterfly ray, Gymnura altavela L.

Recorded at Point Judith, Rhode Island, 1949 (Arnold, 1951).

Little tuna, Euthynnus alletteratus (Rafinesque)

Twenty-eight little tuna were captured in a fish trap in Cape Cod Bay in September 1949, a new record for this fish north of Cape Cod (Schuck, 1951).

Lizard fish, Synodus foetens L.

Reported as "relatively abundant in southern New England in the summer of 1949" (Arnold, 1951)

Dolphin, Coryphaena hippurus L.

The dolphin was reported in numbers in Block Island Sound in mid-summer, 1949 (Arnold, 1951). A new record north of Cape Cod in 1949 was reported by Schuck (1951). This fish was reported as being in the Cape Cod Canal in August, 1951 (Clark, personal communication).

Harvest fish, Peprilus alepidotus L.

One specimen of the harvest fish was reported for the tip of Cape Cod in October, 1949 (Arnold, 1951).

Spanish mackerel, Scomberomorus maculatus, Mitchell

A specimen of the Spanish mackerel was reported from North Bay, Cotuit, Massachusetts in October, 1949 (Arnold, 1951).

Sea Bass, Centropristes striatus, L.

A sea bass was caught in a lobster trap in the fall of 1950 at Corea, Maine, and was identified at the University of Maine. (Anon. 1950 b).

Pinnixa and Polyonyx

In 1911, Pinnixa chaetopterana was the common commensal living in the tubes of Chaetopterus pergamentaceus Cuvier (Sumner et al, 1911). At the present time this crab is rare in the Woods Hole region, having been replaced by the southern form Polyonix macrocheles (Rankin, J., personal communication.)

Xylophaga dorsalis

Previously unreported on the Maine Coast, this wood borer caused extensive damage to lobster traps in the Mt. Desert area in the winters of 1949 and 1950. It has since extended its range east and west (Dow, 1950; Anon., 1950a; Anon., 1951).

The green crab, Carcinides maenas, L.

The extension of the range of the green crab north and east from Cape Cod in 1874 to the Passamaquoddy Bay region in 1952 has been described by Scattergood (1953).

As Scattergood points out, there were ample opportunities for the transportation and transplantation of this crab northerly by lobster smacks and sardine carriers as early as Civil War times in the case of the former and from about 1900 in the case of the latter:

"The mere transportation of the crabs to other areas evidently did not assure their establishing populations there. Conditions for the survival and successful reproduction have to be present or new and permanent crab populations will not develop. Evidently such conditions were not always present in many Maine areas, for if the environment had been favorable, green crabs would have been established along the entire Maine coast before the early 1900's. If we knew what environmental changes have been necessary for the recent increased abundance and the greater dissemination of the green crab, we would probably understand why the crabs were not more common in Maine waters at an earlier time."

There is evidence that the green crab cannot establish itself in areas where the winters are severe (Anon, 1952). This fact alone seems sufficient to account for the extension of the range of the green crab northward. Examination of Boothbay Harbor surface water temperatures for the months of January and February (Appendix I) Shows, for example, that the average temperature for the period 1906-1930 was 32.3°F. for the months of January and February. For the period 1931-1949, the January-February temperatures averaged 34.2°F, an increase of nearly 2 degrees. For the period 1945-1949, the average is 35.1°, a most remarkable increase when one considers the effect on ice conditions along the shore tidal zone. Prior to 1930 monthly averages below 32°F., probably indicative of shore ice conditions, occur with considerable frequency in the months of January, February or March, so that it was probably impossible for the green crab to establish a permanent population. Since 1930, months with temperatures below 32°F. have been rather infrequent and the persistent spread of the green crab northward would seem to indicate that sufficient numbers have survived the more severe winters to assure a more or less permanent population in the northern part of its range.

- THE END -

C 1

MONTHLY MEAN WATER TEMPERATURES
Boothbay Harbor, Maine

APPENDIX I - 1

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1949	38.4	36.0	37.0	42.9	50.9	57.3	63.5						
1948	34.6	32.4	34.8	40.5	47.5	53.6	60.5	61.2	56.9	48.0	47.6	42.5	46.7
1947	36.5	35.6	36.5	41.1	46.7	54.0	63.2	63.4	60.5	55.9	48.6	40.0	48.5
1946	33.5	33.7	37.5	40.4	46.5	53.6	60.3	60.4	58.8	52.5	47.7	41.3	47.2
1945	36.5	33.6	35.8	43.5	47.6	53.5	59.8	61.7	58.3	51.0	45.7	37.1	47.0
1944	34.1	34.0	34.0	38.6	48.2	52.9	60.8	60.5	58.7	51.0	45.8	39.2	46.5
1943	32.8	32.9	33.6	37.0	46.1	53.0	55.5	59.9	54.7	51.7	46.7	40.1	45.3
1942	34.6	32.0	33.9	39.8	49.8	56.3	60.1	60.0	57.3	52.8	45.0	37.4	46.6
1941	36.2	33.2	35.5	41.7	48.3	53.2	60.6	57.0	52.1	50.4	44.8	39.5	46.0
1940	31.4	29.1	30.0	36.2	47.9	51.9	59.5	58.9	56.3	49.2	45.0	39.7	44.6
1939	34.1	32.0	32.0	34.6	44.4	49.8	57.1	60.0	54.7	48.0	40.9	33.7	43.4
1938	34.4	31.7	32.3	37.5	43.8	56.0	59.6	60.2	54.3	49.8	43.8	37.3	45.1
1937	36.0	36.0	37.5	41.3	48.7	56.6	61.5	64.2	57.9	51.1	45.0	41.7	48.1
1936	33.7	31.3	37.4	40.7	46.0	53.1	60.5	61.6	57.3	48.0	39.3	36.0	45.4
1935	32.0	32.0	34.8	41.1	47.0	56.5	62.4	62.3	57.4	50.9	45.2	37.9	46.6
1934	31.8	30.0	31.9	41.1	50.2	56.6	61.5	60.0	59.1	46.9	41.3	36.2	45.6
1933	38.0	38.0	38.2	41.6	50.3	57.1	61.6	62.1	55.8	48.3	42.8	35.5	47.4
1932	36.2	36.0	35.9	40.2	45.7	54.1	58.7	62.5	56.9	50.5	46.5	38.9	46.8
1931	38.0	36.5	38.7	43.5	48.1	59.6	64.2	60.4	58.0	50.1	45.2	38.3	48.4
1930	32.3	31.2	33.1	39.5	47.2	57.7	62.6	60.9	57.2	53.7	45.5	37.8	46.6

APPENDIX I - 2

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1929	34.5	33.1	33.7	37.7	46.1	58.8	57.9	58.7	55.5	49.0	42.6	32.7	45.0
1928	36.0	33.0	34.9	39.1	46.6	55.0	63.1	64.6	57.4	51.7	43.8	38.0	46.9
1927	33.4	32.5	34.5	38.6	47.1	55.7	60.9	60.4	56.8	51.1	44.6	38.7	46.2
1926	32.7	29.8	32.2	36.1	45.0	54.0	61.2	61.4	56.3	50.3	43.5	35.6	44.8
1925	29.6	31.5	35.5	40.6	48.0	55.5	61.4	61.2	56.1	46.8	41.5	36.8	45.4
1924	34.3	30.9	34.5	39.2	46.9	54.6	61.5	61.1	56.9	50.4	43.8	35.8	45.8
1923	30.1	29.8	30.5	38.5	49.0	55.4	59.6	58.5	57.8	50.0	44.3	40.4	45.3
1922	31.8	31.0	34.9	41.6	49.4	58.1	63.9	62.4	59.0	49.4	41.6	33.4	46.4
1921	35.4	33.2	36.7	43.1	50.7	57.1	63.4	60.7	59.3	51.4	42.7	37.2	47.6
1920	29.9	29.4	35.6	39.7	49.7	55.5	61.6	64.1	57.0	53.5	43.8	39.8	46.6
1919	34.5	34.5	36.8	41.6	48.5	58.3	62.8	60.5	57.3	50.4	44.1	36.8	47.2
1918	28.1	29.5	33.0	38.8	49.0	54.0	62.3	62.0	56.6	49.8	44.3	37.5	45.4
1917	33.0	29.9	31.9	36.6	40.6	51.3	59.8	62.6	53.9	48.0	40.3	31.9	43.3
1916	33.0	31.3	30.8	38.3	45.0	52.9	59.4	59.4	54.6	47.3	41.3	35.4	44.1
1915	31.4	30.7	33.1	39.9	45.3	54.4	60.1	58.8	57.2	47.7	41.8	36.3	44.7
1914	34.1	29.9	31.9	37.1	46.0	53.0	58.4	59.8	56.4	50.4	42.1	34.6	43.6
1913	36.6	33.4	35.7	40.7	46.3	54.0	61.7	61.3	56.9	53.4	47.5	41.8	47.4
1912	31.7	30.4	33.2	38.9	47.1	54.1	61.6	62.0	57.3	50.7	44.8	38.9	45.9
1911	34.9	31.5	34.3	40.0	49.1	55.8	64.8	61.2	56.4	50.1	44.0	39.5	46.8
1910	34.6	33.5	37.2	45.3	50.0	57.3	64.0	63.1	59.4	50.9	46.7	36.4	48.2

APPENDIX I - 3

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1909	33.7	32.3	35.5	40.7	47.8	58.1	61.2	62.6	59.0	53.4	45.3	38.5	47.3
1908	36.2	32.4	34.8	40.1	50.0	56.3	62.4	62.9	58.9	53.1	44.1	37.2	47.4
1907	32.2	29.0	32.2	37.4	42.9	51.5	57.7	59.7	57.3	48.4	43.1	39.0	44.2
1906	34.9	31.4	31.3	37.7	44.9	51.7	58.5	62.1	55.7	49.0	42.3	35.5	44.6
1905			32.7	38.0	44.2	52.7	59.4	60.1	54.3	47.9	41.4	35.8	
44 Year averages by months (1905 thru 1948)	33.9	32.30	34.40	39.74	47.25	54.92	60.94	61.2	57.0	50.4	44.4	37.5	45.0

Source.

Daily reeords of surface temperatures (8 a.m., 12:00 a.m., and 4 p.m.) taken at Boothbay Harbor by Branch of Fish Culture, Fish and Wildlife Service, Boothbay Harbor, Maine.

APPENDIX II

MONTHLY MEAN WATER TEMPERATURES
Woods Hole, Massachusetts

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1952	36.1	35.0	36.4	45.2	54.0	65.0							
1951	37.1	34.9	38.4	46.7	56.0	65.0	70.6	71.7	70.2	61.4	50.4	41.3	53.6
1950	39.6	36.2	34.0	42.3	50.1	62.0	69.7	71.3	66.2	59.5	52.9	42.9	52.2
1949	37.7	36.7			55.4	65.5	71.6	72.5	67.9	61.4	52.0	41.9	
1948	30.0	30.5	35.2	44.6	52.2	60.6	69.1	71.3	68.0	58.3	50.4	43.8	51.2
1947	35.8	34.0	36.2	43.5	57.9	58.8	71.7	72.4	69.6	60.9	49.4	38.4	52.4
1946	32.9	31.9	39.0	45.3	53.0	61.9	68.4	68.6	66.3	61.1	53.6	42.9	52.1
1945	32.4	30.6	38.0	48.0	54.5	63.1	70.7	70.6	68.6	59.1	50.5	37.8	52.0
1944				42.1	59.2	63.1	70.0	71.8	68.2	59.2	48.0	38.1	
1943													
1942	33.3												
1941	33.6	30.6	32.3	41.9	52.5	61.1	68.1	69.4	67.0	60.3	51.2	41.8	50.8
1940	29.7	30.0	33.4	40.3	51.1	59.1	65.7	67.9	66.4	57.0	47.9	39.2	49.0
1939	33.3	31.4	34.1	40.6	48.9	59.8	66.1	70.6	65.2	57.4	44.8	36.8	48.2
1938	35.8	36.2	37.7	45.0	51.9	60.4	66.9	70.1	64.4	57.2	50.8	39.6	51.3
1937	39.9	37.4	37.7	43.5	52.9	62.5	68.2	72.2	66.5	56.6	49.2	44.6	52.6
1936	31.2	29.5	37.6	45.2	55.1	63.0	68.2	70.7	67.2	60.2	49.4	39.7	51.4
1935	30.8	28.6	33.6	39.9	49.9	59.6	67.4	68.3	63.5	56.3	50.1	36.5	47.0

APPENDIX II - 2

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1934	32.7	29.8	32.5	42.9	52.8	62.4	69.9	69.9	67.8	58.3	47.9	39.0	50.5
1933	39.3	35.7	35.9	43.2	53.8	62.4	67.5	70.2	67.7	60.8	47.3	38.0	51.8
1932	41.1	35.9		43.6	53.1	62.1	69.6	72.2	67.5	60.9	50.5	41.0	
1931													
1914	33.9	31.1	32.0	42.0	51.8	62.4	66.4	68.7	67.2	60.5	49.1	39.1	50.4
1913	39.2	34.1	38.1	45.5	52.9	62.0	69.6	71.7	66.8	60.2	51.2	42.7	52.8
1912	31.6	30.1	34.0	42.3	51.8	65.0	69.4	69.5	66.9	60.1	51.5	41.5	51.1
1911	34.7	31.3	33.7	41.3	52.9	62.5	71.0	71.1	66.3	57.8	49.1	41.5	51.1
1910	31.5	32.0	37.8	46.9	55.3	62.6	70.4	71.0	66.9	60.4	48.0	36.7	51.6
1909													
1908	35.7	30.4	35.9	41.3	52.4	61.9	71.0	69.3	62.7	57.2	46.6	40.2	50.4
1907													
1906	33.0	34.4	35.0	42.2	53.2	62.8	68.9	70.9	68.1	60.0	48.4	36.2	51.1
1905	30.7	29.0	32.6	42.4	52.0	61.5	70.3	69.9	66.3	59.4	48.1	39.8	50.2
1904	29.3	29.0	33.1	40.9	53.3	62.2	69.4	65.8	67.0	57.7	46.5	34.4	49.1
1903	32.7	32.0	39.1	45.7	54.5	61.0	67.6	68.0	66.6	57.3	47.8	36.5	50.7
1902	31.5	29.1	36.2	45.7	54.0	62.0	66.3	69.1	67.3	60.7	52.0	38.8	51.1
1901	33.2	29.6	33.4	41.2	51.2	61.2	69.6	69.9	68.7	62.2	47.8	36.8	50.4
1900	34.6	31.2	33.8	40.9	52.7	61.7	68.6	70.9	68.8	60.1	50.7	39.8	51.1

APPENDIX II - 3

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	MEAN
1899	33.4	30.8	34.5	41.6	51.9	63.2	69.6	69.4	66.0	57.8	49.4	41.8	50.8
1898	36.1	34.0	39.0	43.7	49.7	60.5	68.2	70.8	68.2	59.6	49.9	37.1	51.4
1897	32.0	31.6	35.4	43.0	49.7	60.0	69.6	70.3	67.6	59.4	49.9	41.9	50.9
1896	32.9	31.7	32.4	40.7	53.3	63.4	65.7	70.9	66.7	58.2	53.1	41.2	50.8
1895	34.0	29.6		42.0	53.4	63.4		69.9	67.6	59.5	49.5	39.7	
1894	35.0	32.7	37.6	42.7	53.6	62.0	70.4	69.4	67.2	59.6	48.1	39.2	51.5
1893	29.6	29.8	30.7	40.9	51.0	61.2	69.6	73.3	67.4	60.4	52.4	40.8	50.6
1892	36.8	31.9	33.3	42.5	51.1	62.1	69.9	71.8	67.1	58.8	50.6	37.3	51.1
1891	33.1	34.8	35.7	44.3	52.3	61.1	66.9	68.6	69.1	57.6	47.4	42.0	51.1
1890	40.2	36.4	36.4		53.3	62.0	69.4	71.1	68.0	59.0	48.0	36.7	
1889	36.6	32.2	34.7	42.7	55.7	65.4	68.7	70.7	67.2	57.0	49.8	44.4	52.1
1888	31.1	30.4	33.1	41.0	50.2	62.7	66.6	68.9	64.3	54.3	48.6	39.1	49.2
1887	32.6	33.2	34.7	40.0	52.6	62.0	70.6	72.0	66.5	58.9	48.2	40.3	51.0
1886	32.2	30.9	32.2	42.6	55.7	62.5	68.7	69.1	68.1	60.3	51.0	38.0	51.0
1885	34.6	29.8	31.8	40.3	50.1	61.3	71.4	71.8	65.9	55.6	51.4	39.7	50.6
1884	32.4	34.5	35.3	42.8	55.1							41.5	
1883		31.2	32.3	41.4	52.5	64.9	71.3	69.9	65.1	55.9	47.7	37.1	
1882	34.5	33.1	37.5	43.3	49.8	61.6					48.0		
1881		30.9		41.0	53.8					59.0	50.5		
	34.10	32.15	35.07	42.83	52.88	62.15	69.01	70.33	67.01	58.97	45.92	39.69	

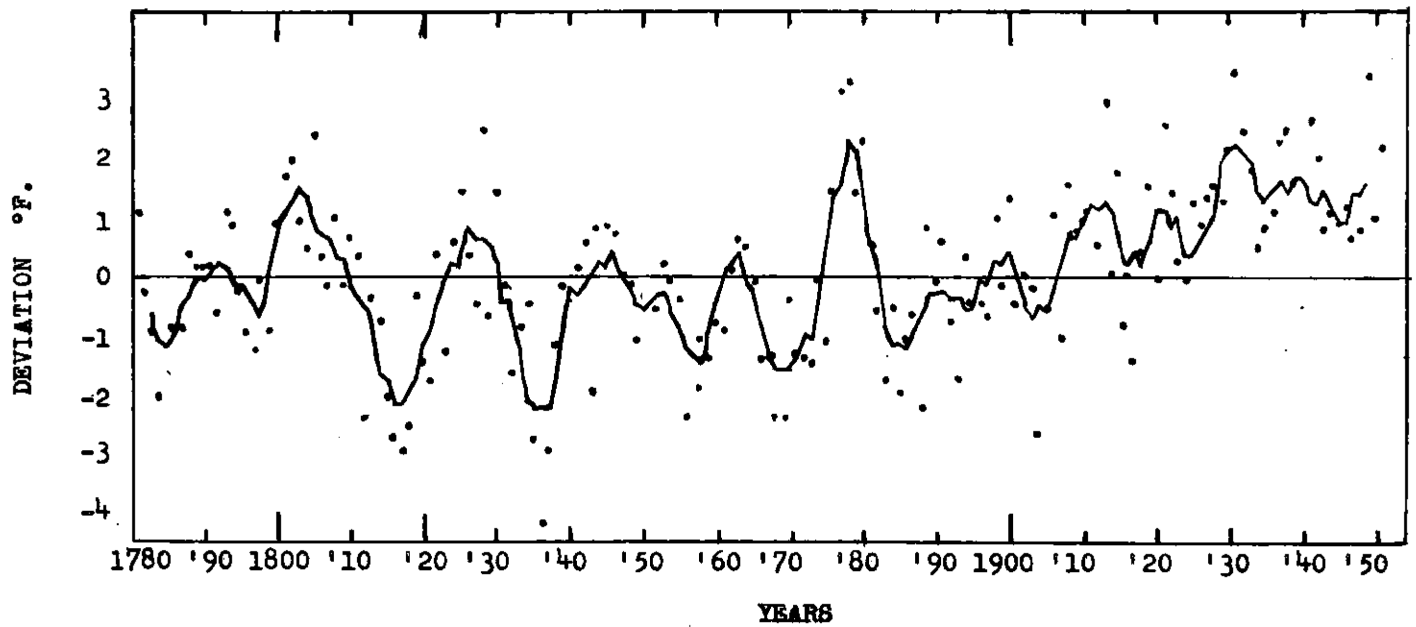

Figure 1. **Annual deviation from the mean temperature, 1780-1951, at New Haven, Connecticut. The solid line is a five-year moving average.**

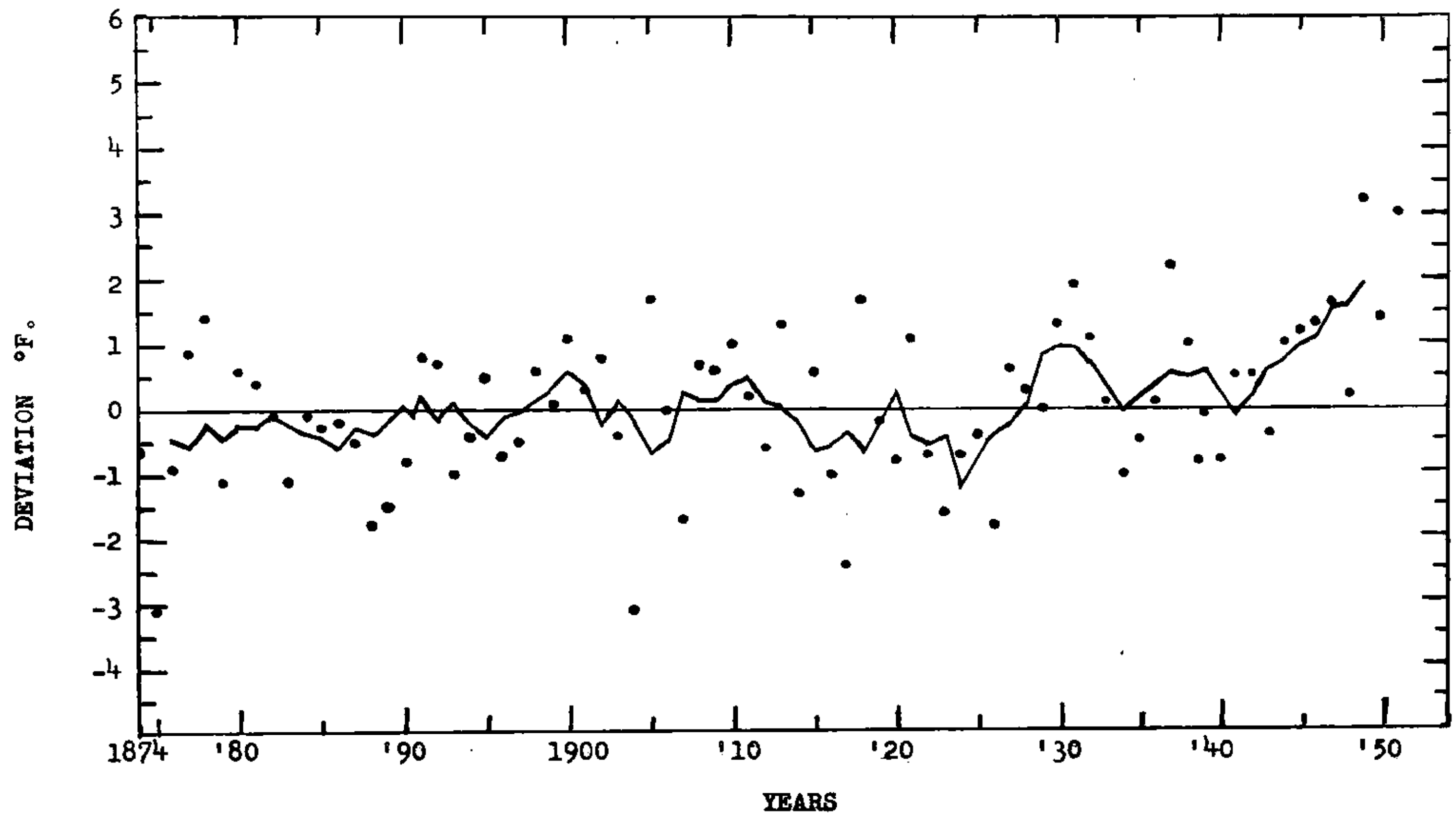

Figure 2. Annual deviations from the mean temperature, 1874-1951, at Eastport, Maine. The solid line is a five-year moving average.

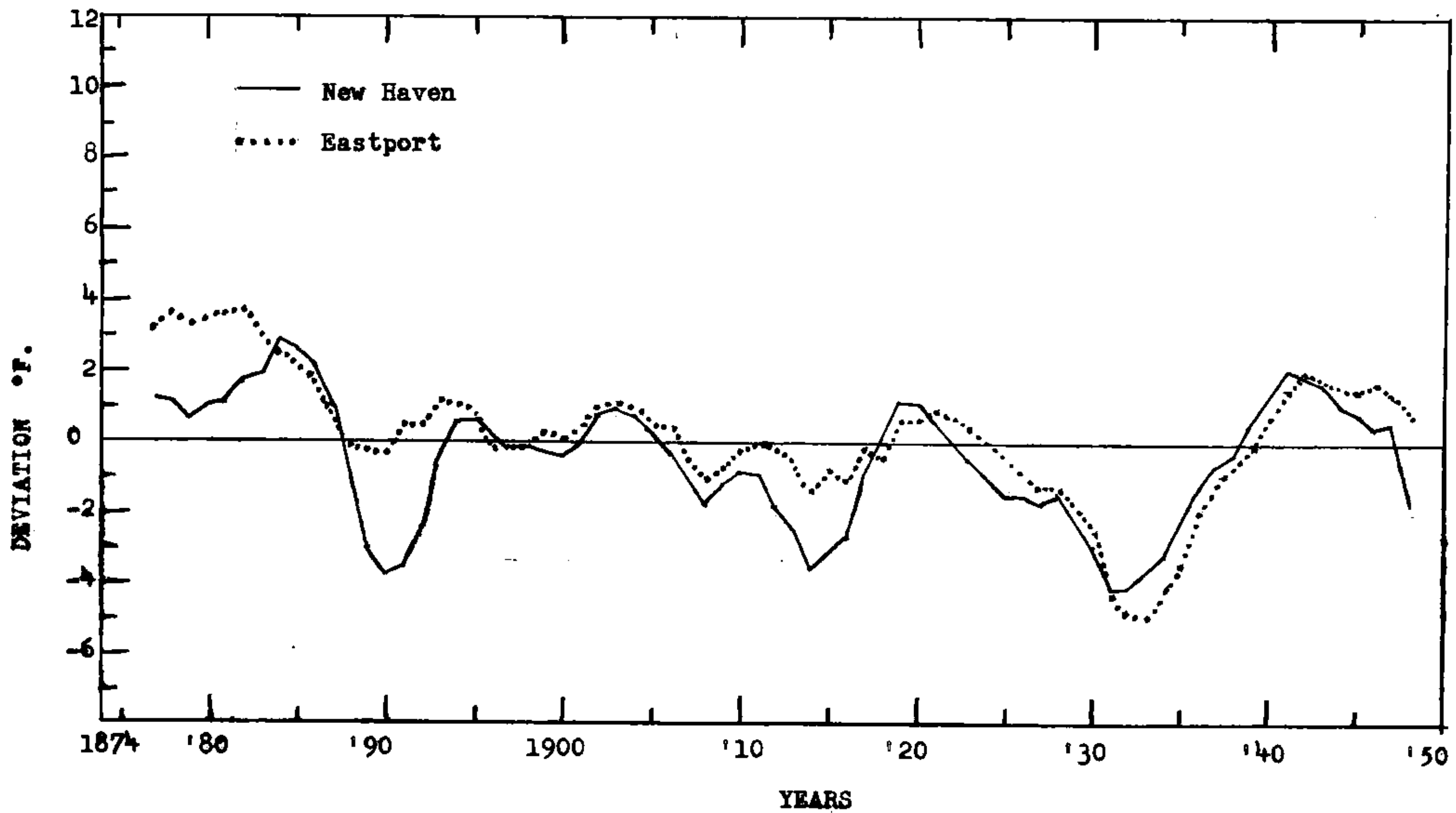

Figure 3. January-July differences in temperature as deviations from the mean difference, 1874-1951, at New Haven, Connecticut, and Eastport, Maine. The curves are five-year moving averages of the actual deviations.

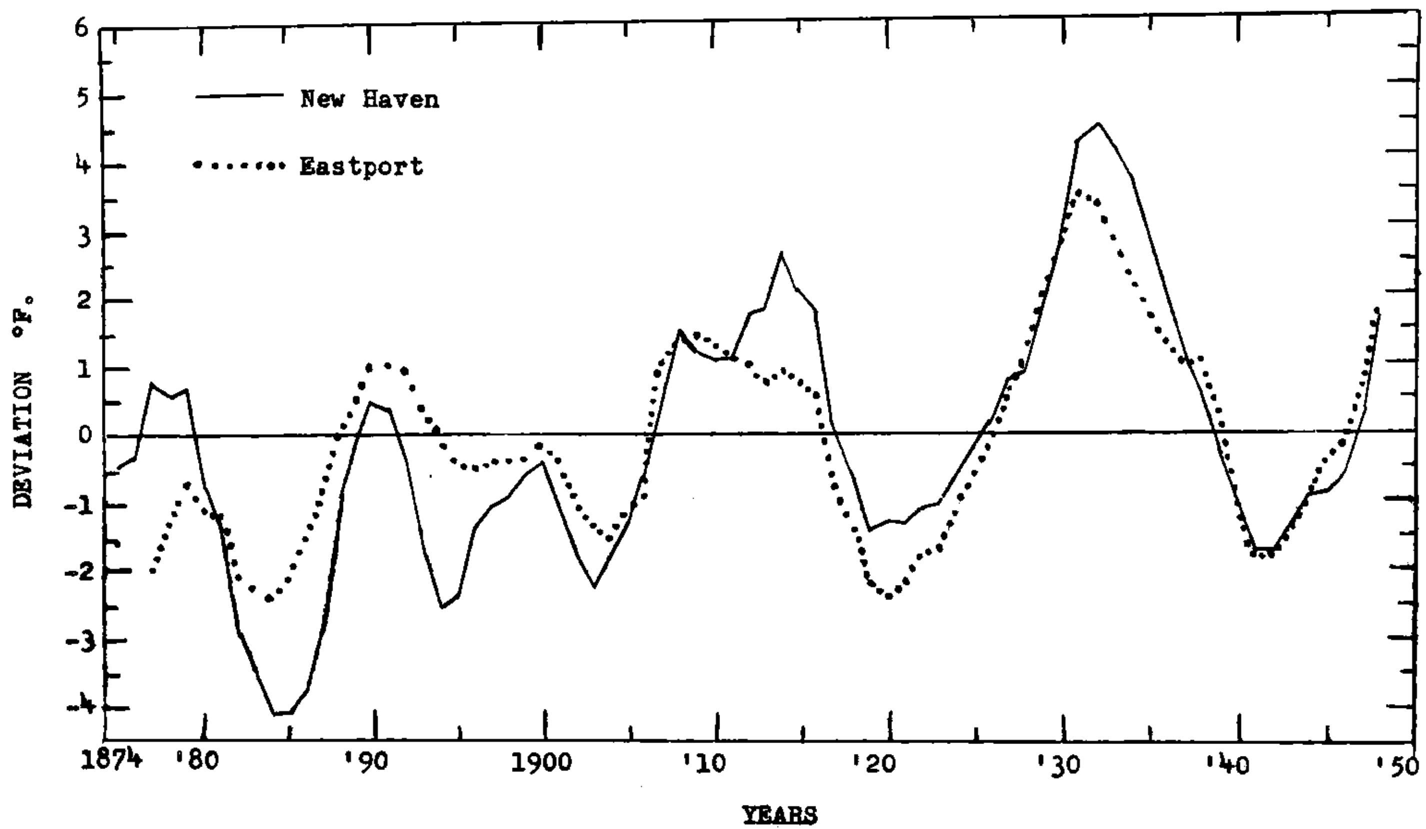

Figure 4. January temperatures as deviations from the mean, 1874-1951, at New Haven, Connecticut, and Eastport, Maine.

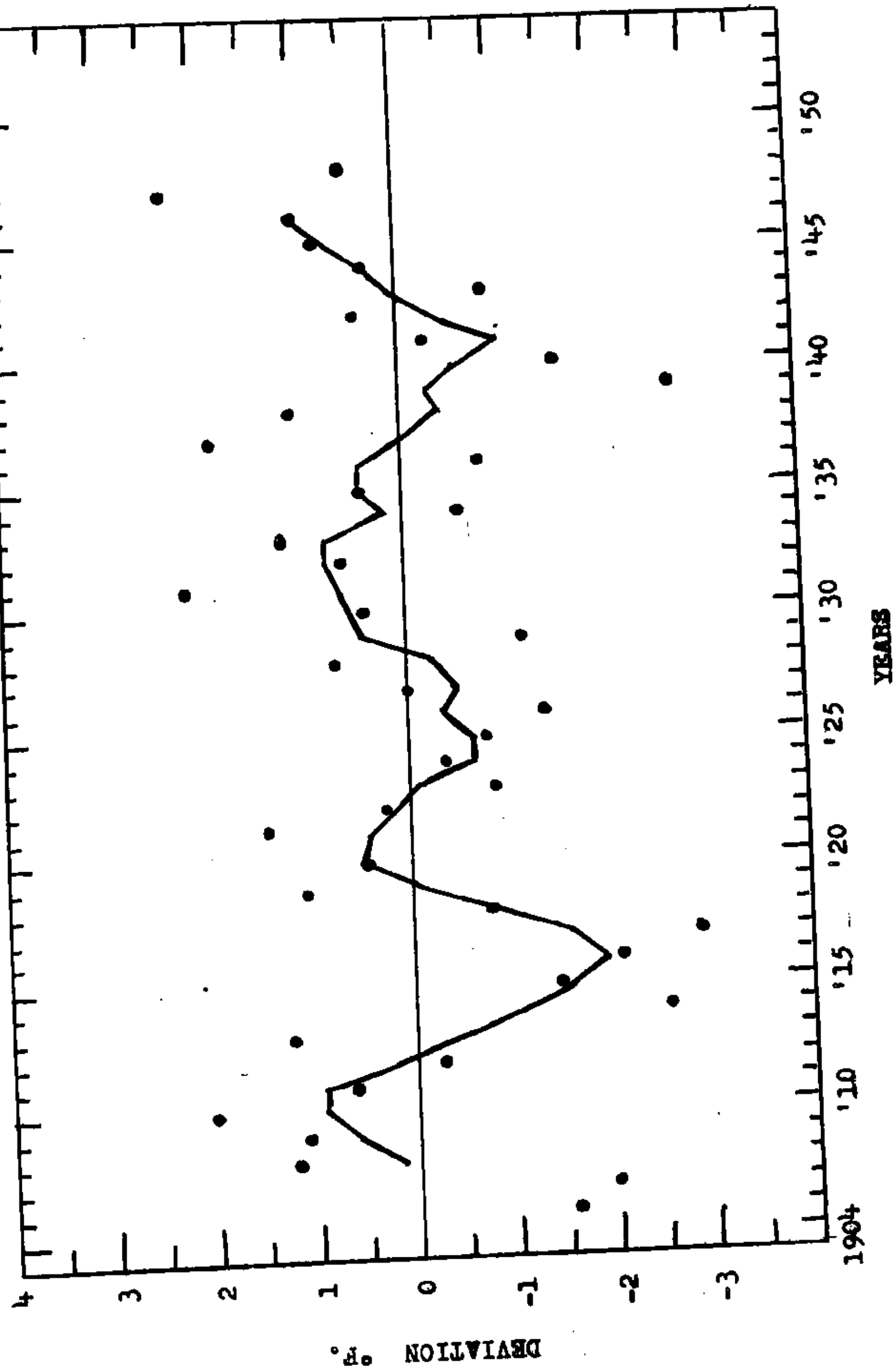

Figure 5. Annual deviations from the mean surface water temperature, 1906-1948, at Boothbay Harbor, Maine. The solid line is a five-year moving average.

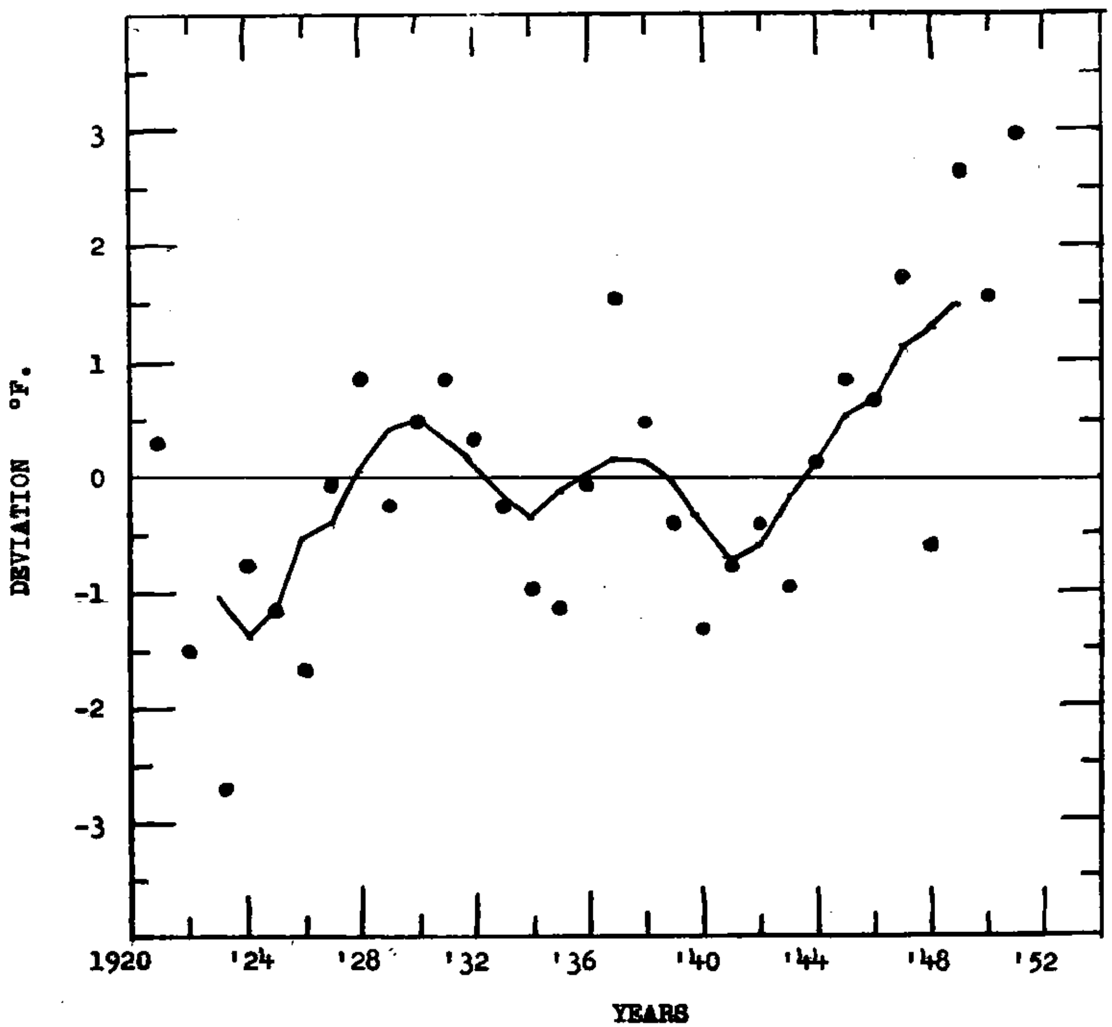

Figure 6. Annual deviations from the mean surface water temperature, 1921-1951, at St. Andrews, New Brunswick. The solid line is a five-year moving average.

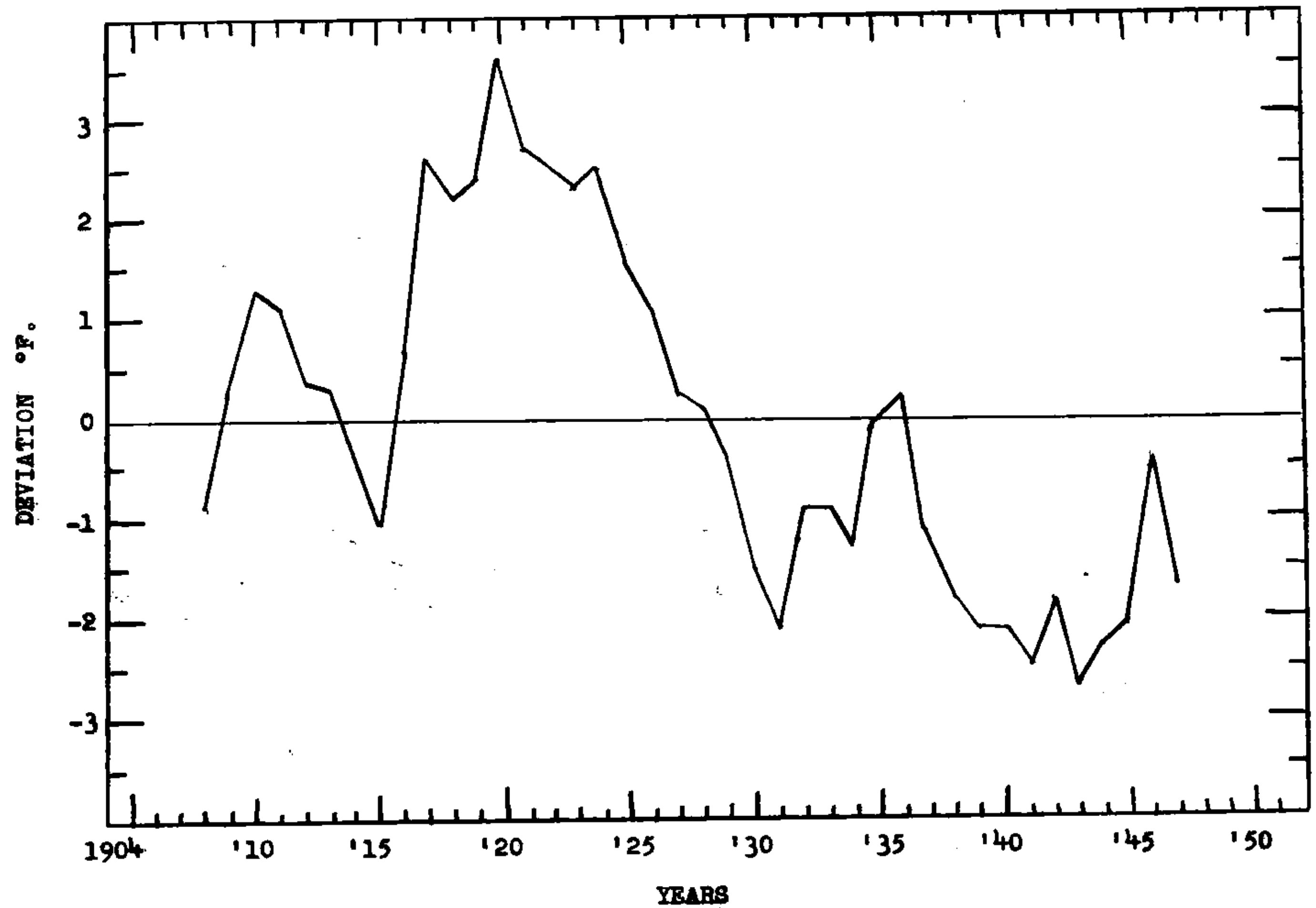

Figure 7. Five-year moving average of January-July differences in surface water temperatures as deviations from the mean difference, 1906-1949, at Boothbay Harbor, Maine.

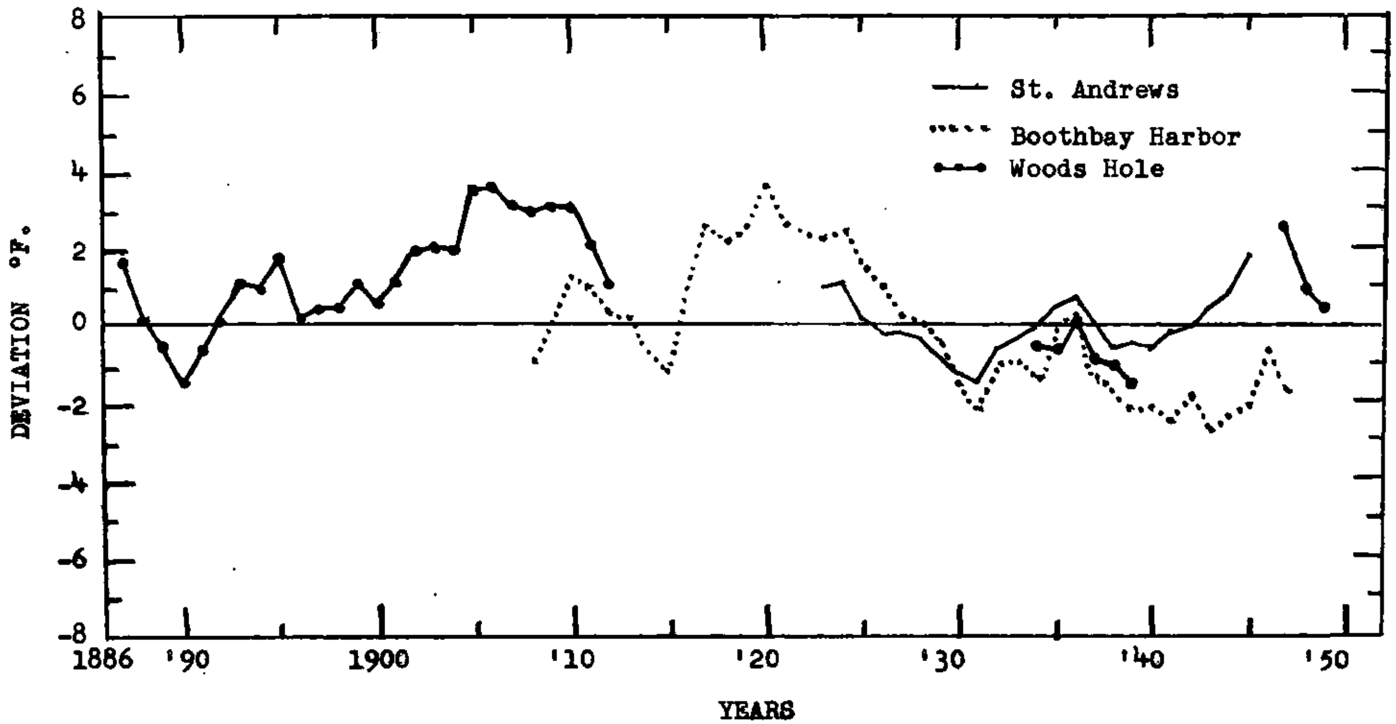

Figure 8. Five-year moving averages of January-July differences in water temperature as deviations from the mean difference at St. Andrews, New Brunswick, Boothbay Harbor, Maine, and Woods Hole, Massachusetts.

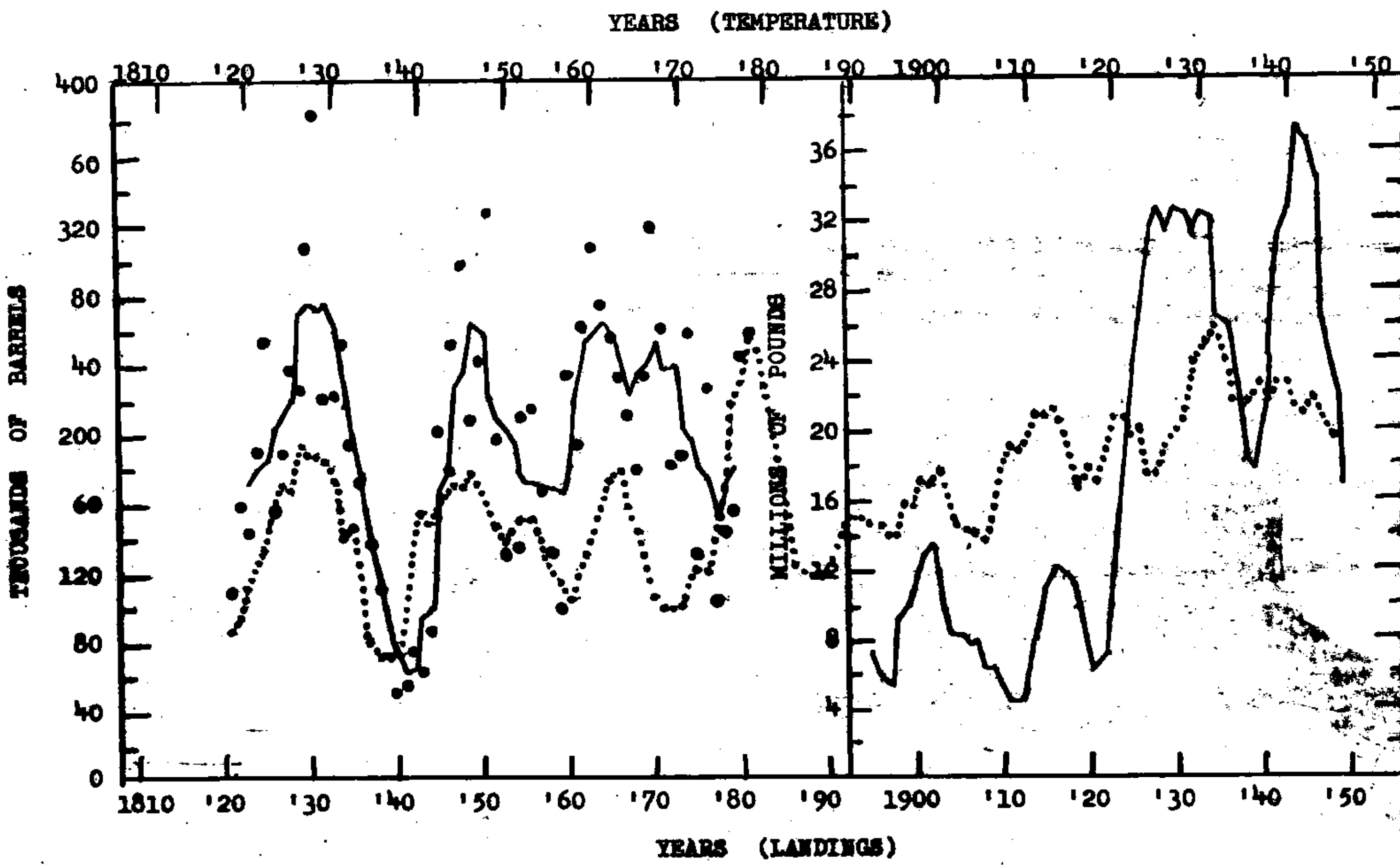

Figure 9. Fluctuations in mackerel landings (solid line) and fluctuations in annual mean temperatures at New Haven (dotted line).

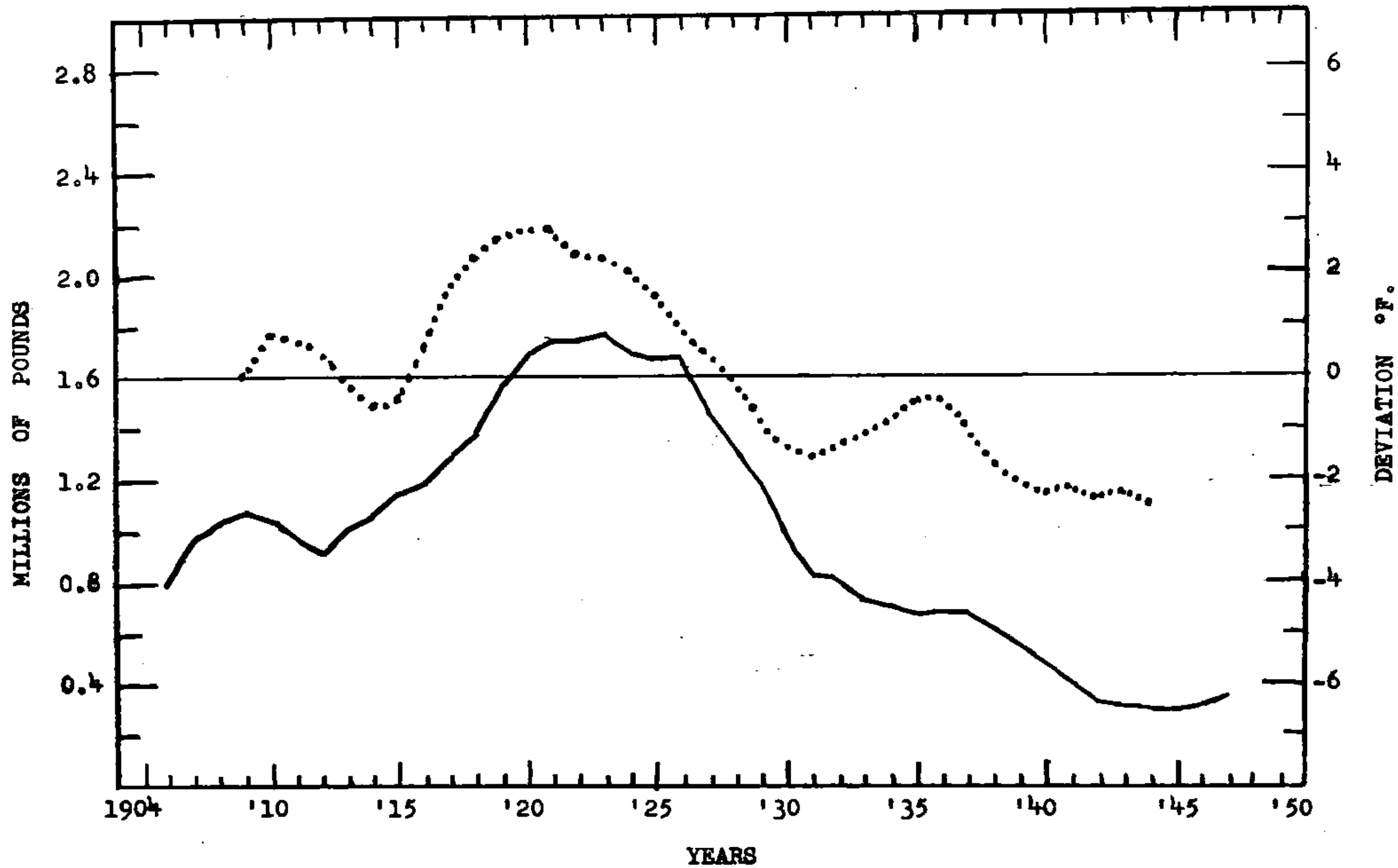

Figure 10. Landings of lobsters in Rhode Island as five-year moving average (solid line), 1904-1949, and surface water January-July differences at Boothbay Harbor, Maine, as deviations from the mean difference (dotted line).

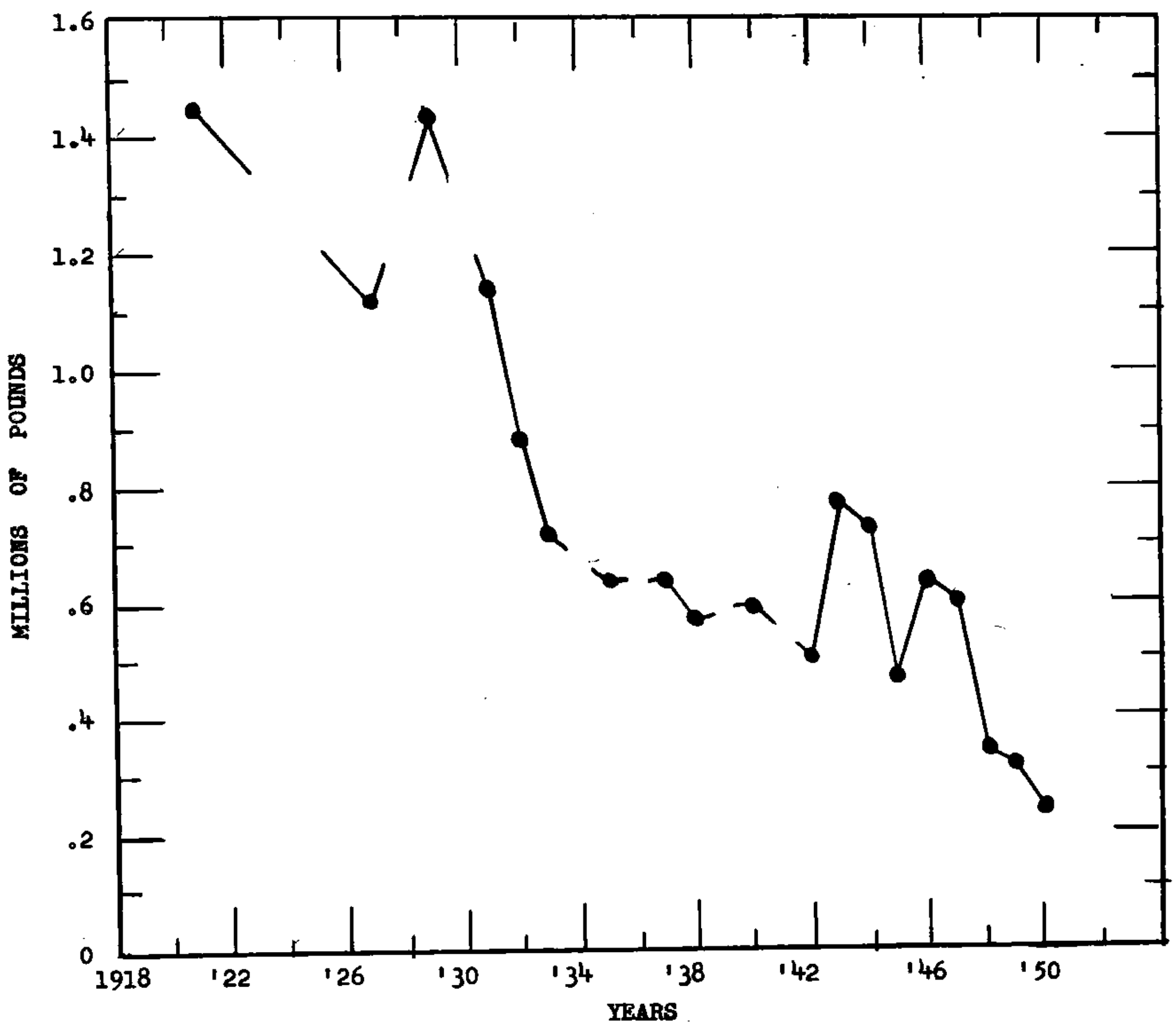

Figure 11. Millions of pounds of lobsters landed in the Middle Atlantic states, 1921-1950.

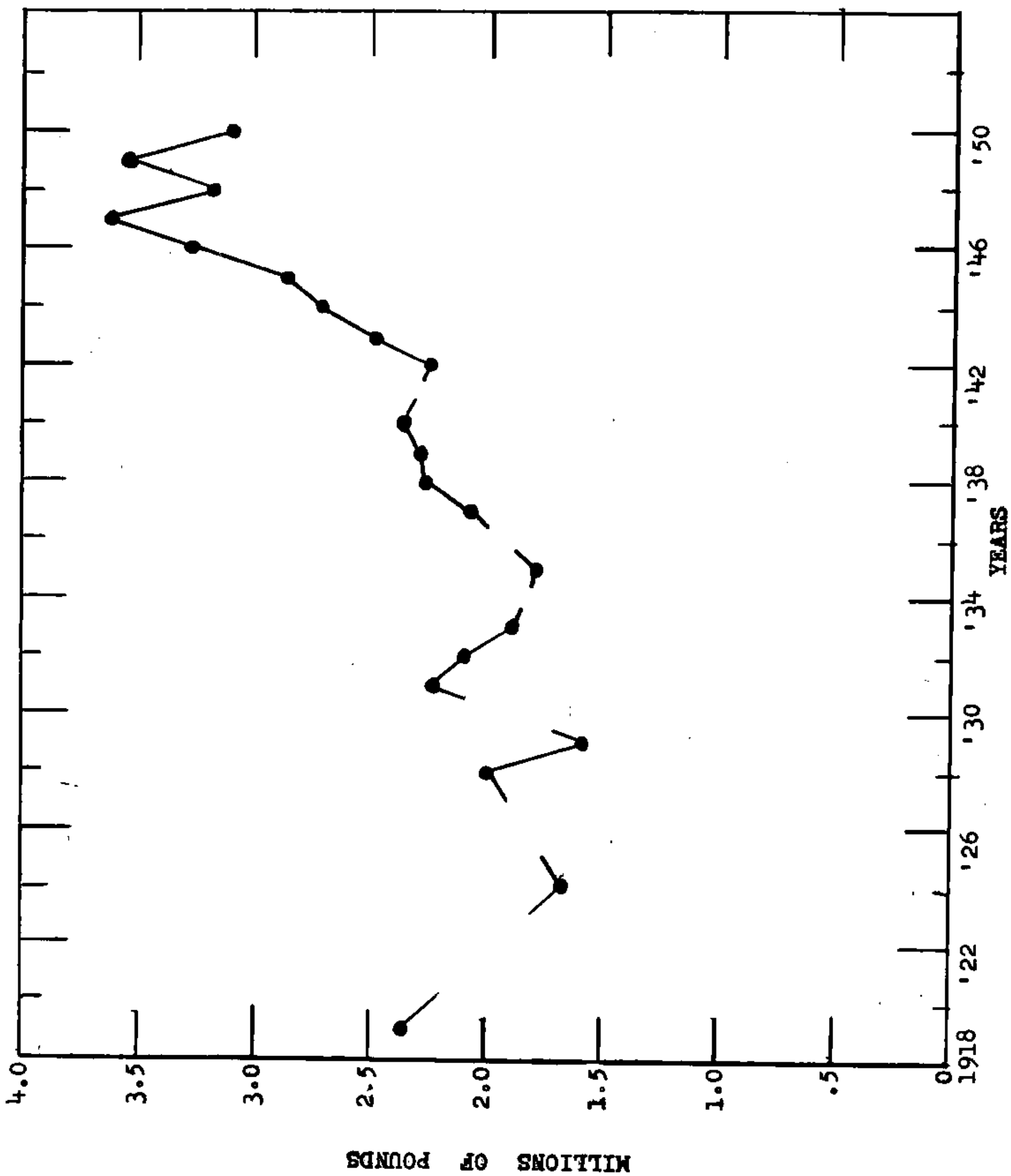

Figure 12. Millions of pounds of lobsters landed in Massachusetts, 1919-1950.

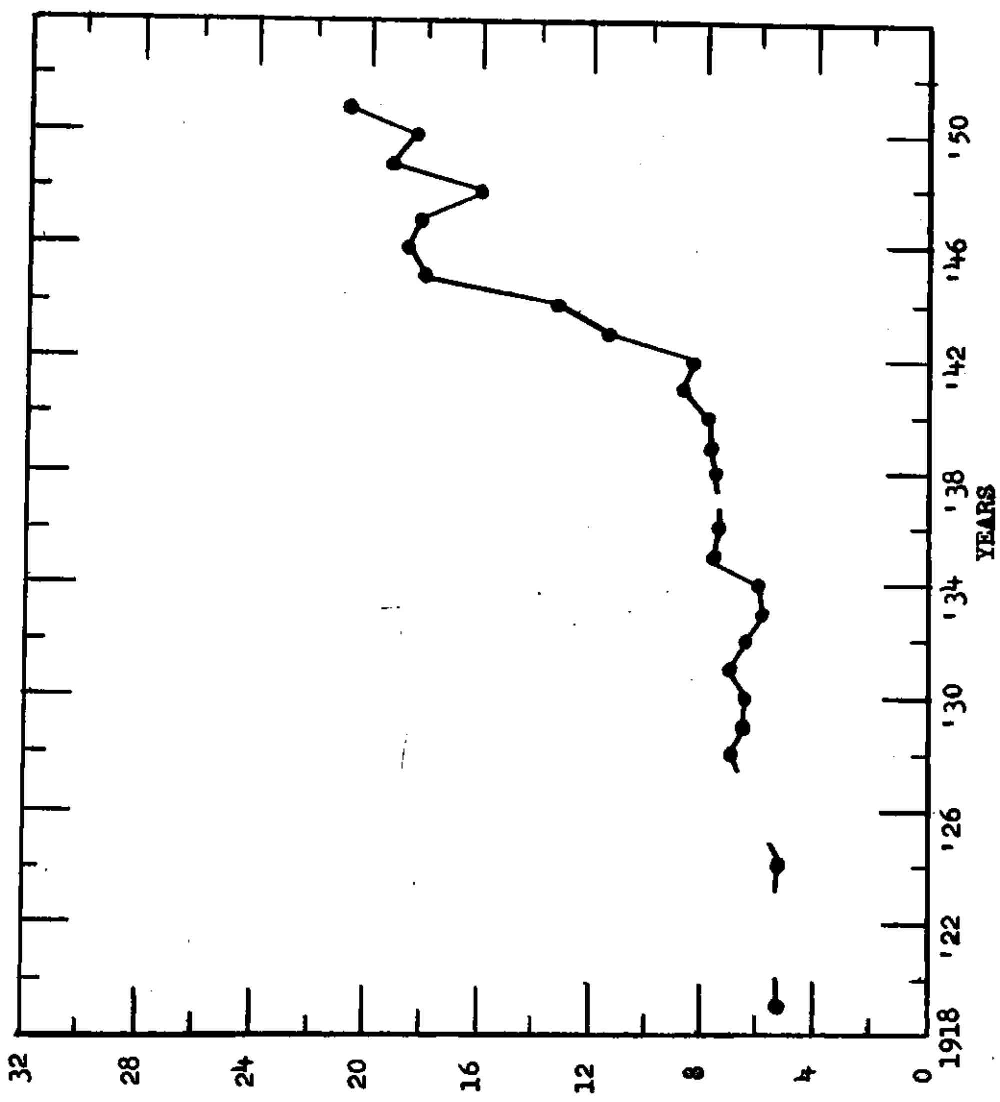

Figure 13. Millions of pounds of lobsters landed in Maine, 1919-1951.

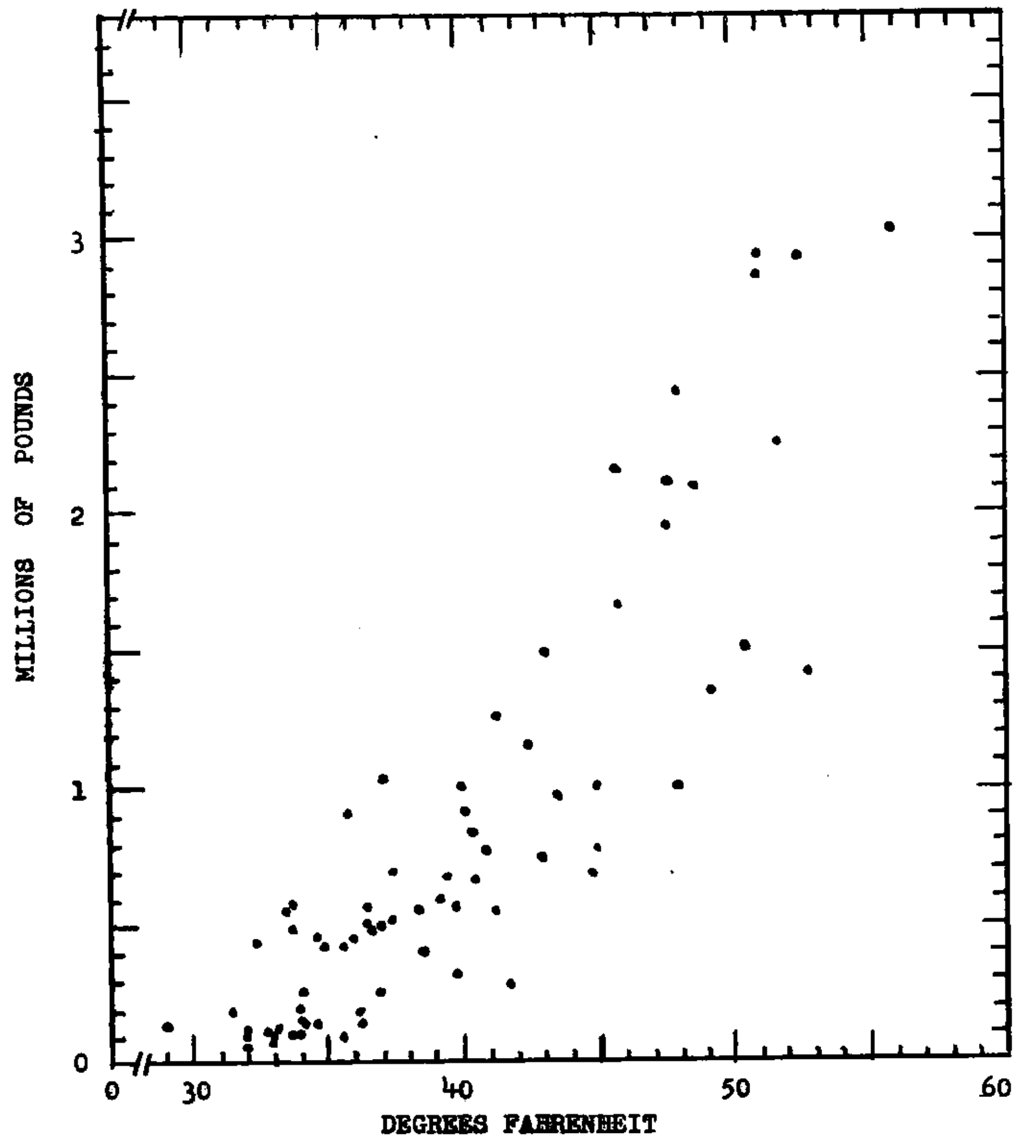

Figure 14. Monthly lobster catches in Maine plotted against corresponding mean surface water temperature at Boothbay Harbor for the months October through April, 1939-1949.

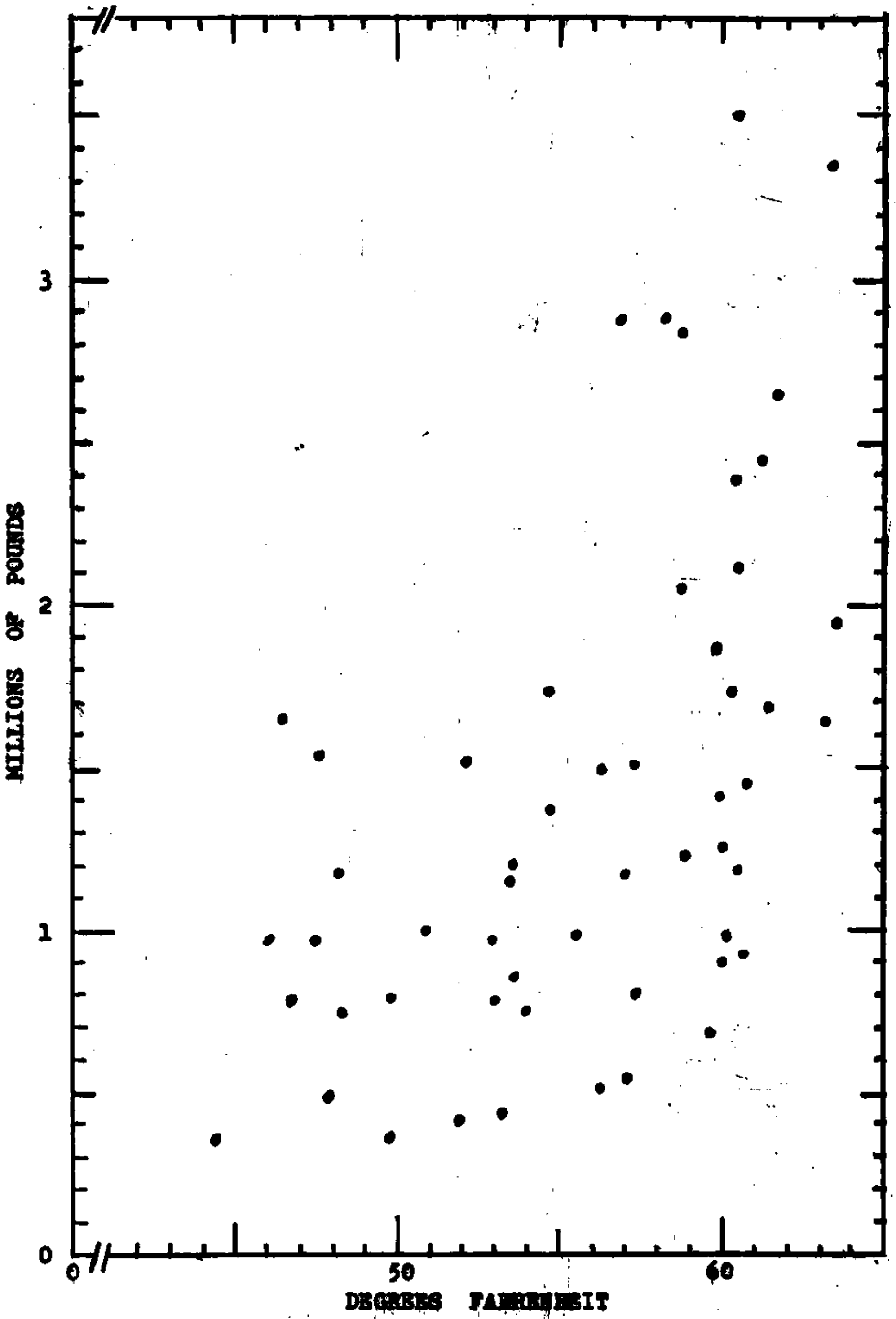

Figure 15. Monthly lobster catches in Maine plotted against corresponding mean surface temperature at Boothbay Harbor for the months May through September, 1939-1948.

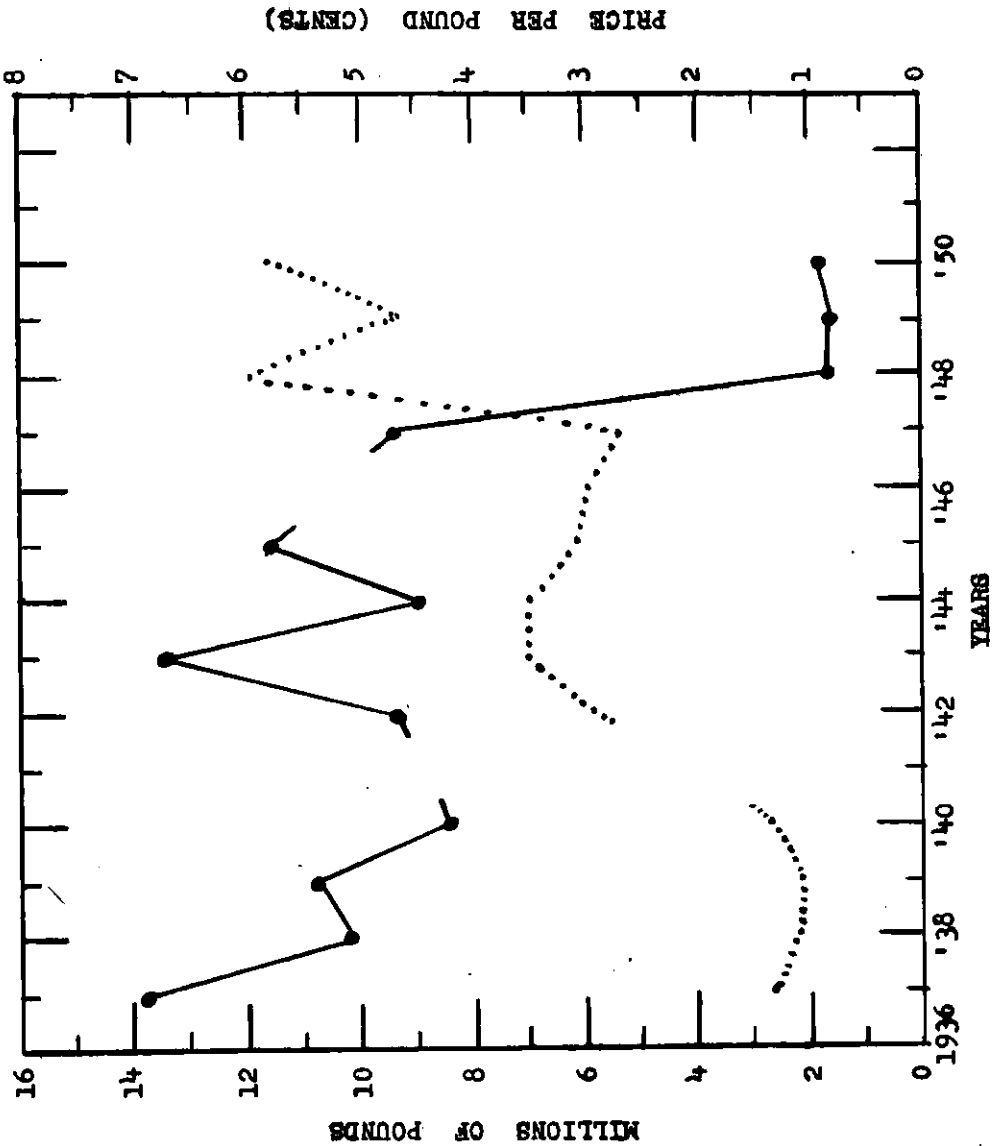

Figure 16. The New York-New Jersey whiting catch (solid line) and price (broken line), 1937-1950.

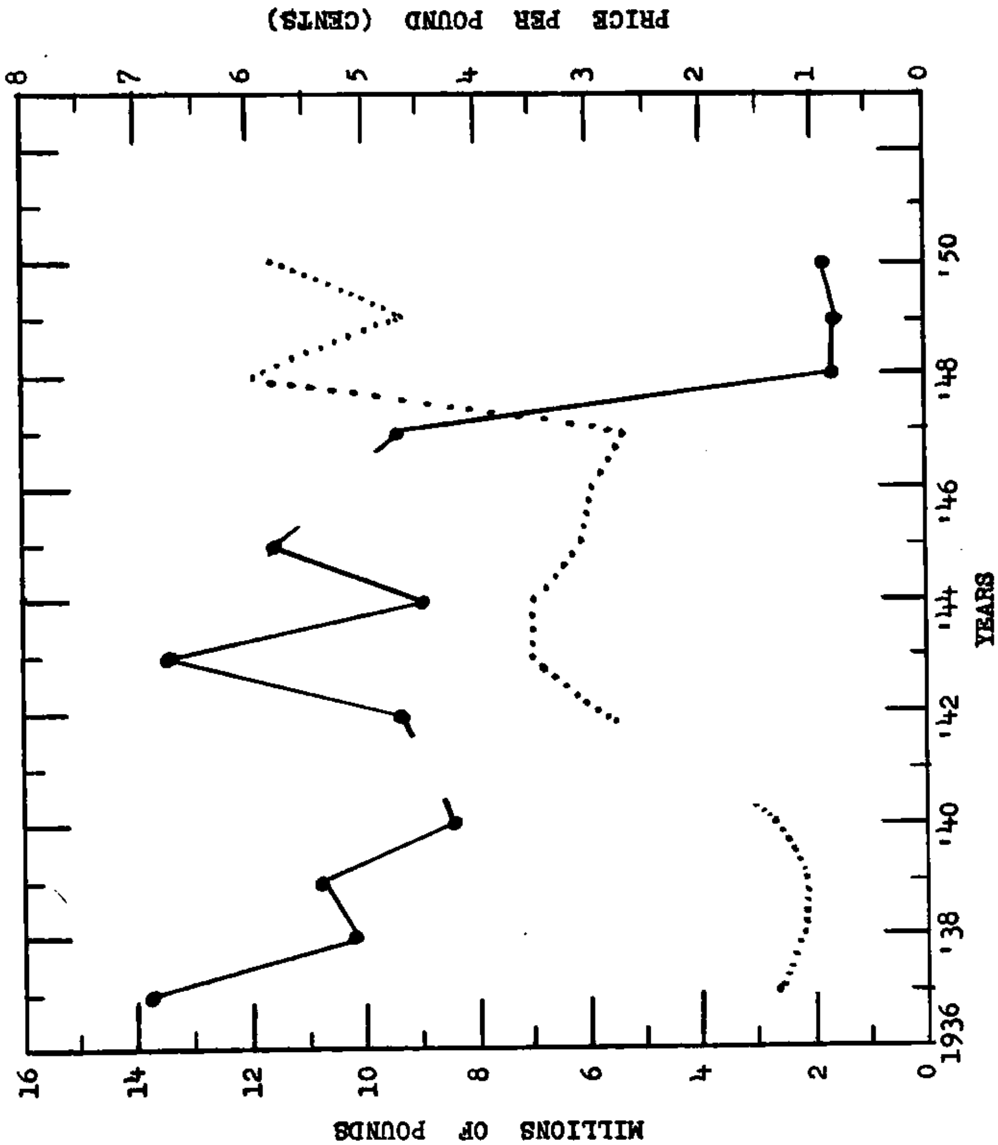

Figure 16. The New York-New Jersey whiting catch (solid line) and price (broken line), 1937-1950.

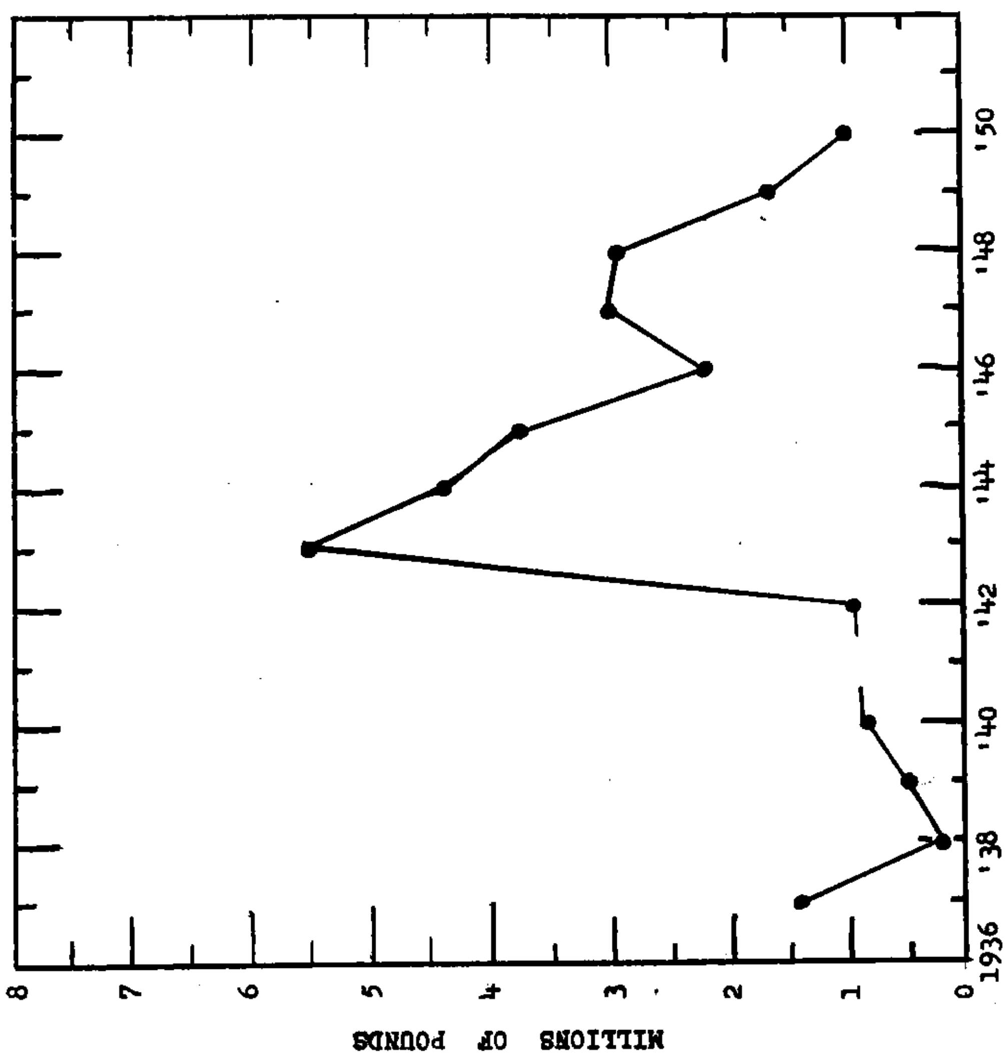

Figure 17. The Connecticut-Rhode Island whiting catch, 1937-1950.

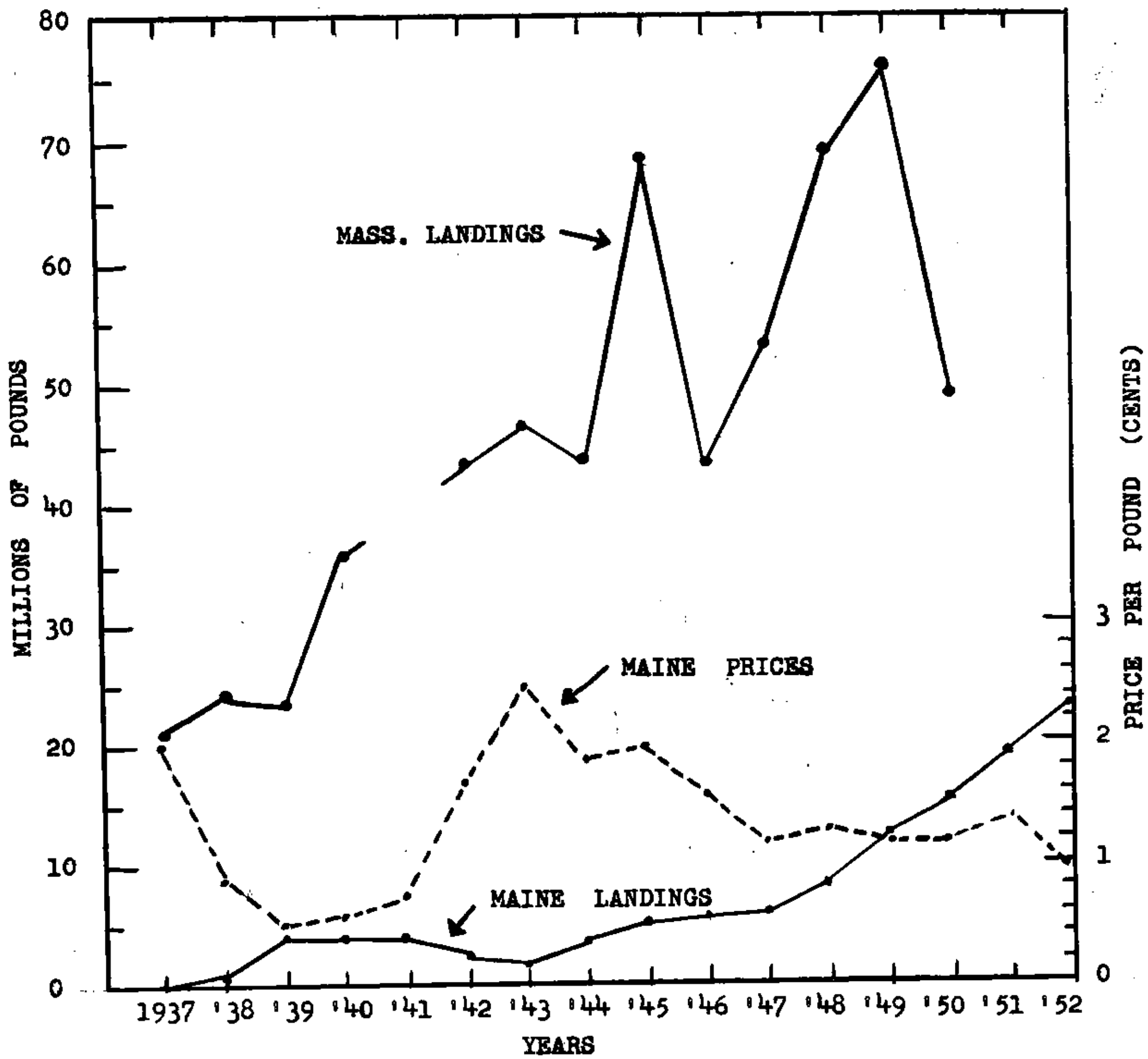

Figure 18. Landings of whiting in Maine and Massachusetts, 1937-1952, and the Maine price per pound.

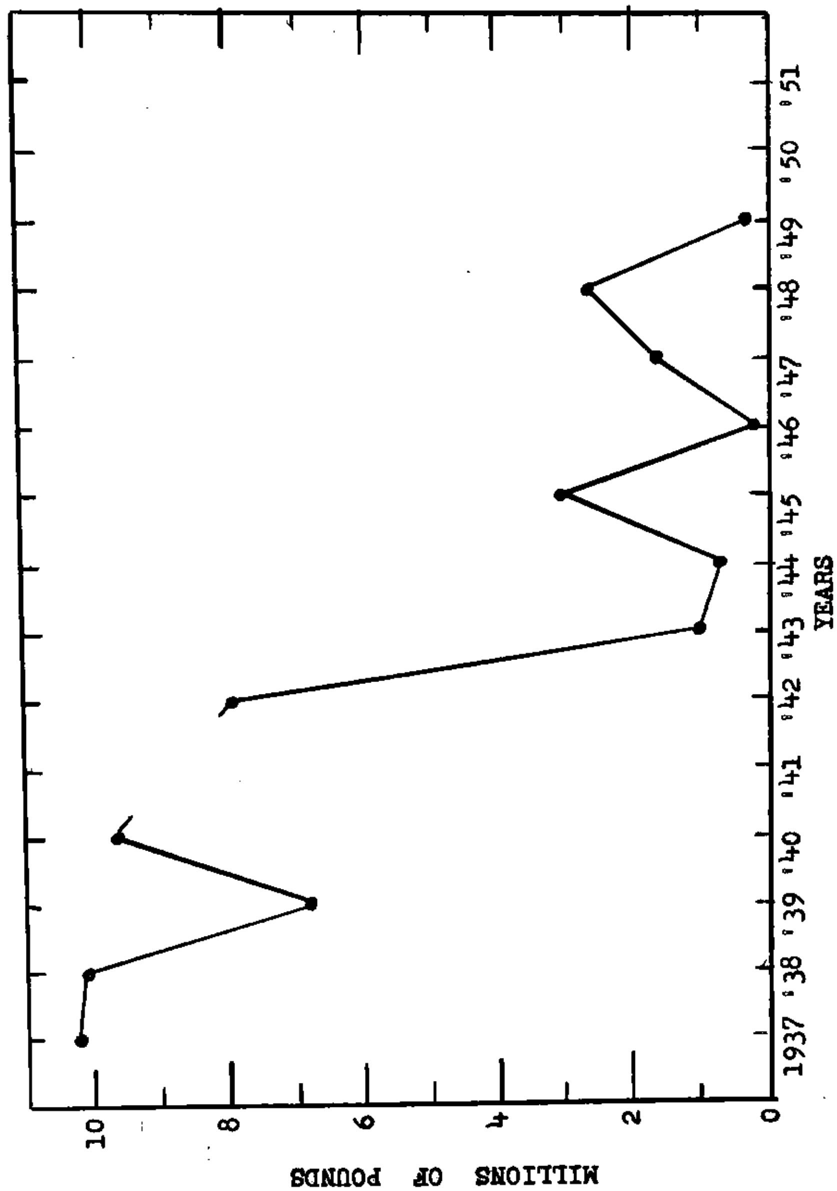

Figure 19. The catch of whiting by pound nets in Massachusetts, 1937-1949.

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