TEMPERATURE CONDITIONS DURING THE SPRING MIGRATION

Mackerel of the southern contingent appear first at the place where the earliest rise in temperature of the water takes place.[22] This is consistent with older views such as that of Goode, Collins, Earle, and Clark who state (1883: 97) "their presence [in the open ocean] is nearly synchronous with the time when the water temperatures of the harbor [Woods Hole] have reached a weekly average of 45° (7.2° C.)." But a general correspondence of rise in temperature and appearance of mackerel proves no relation between the two for both are seasonal events and other elements of seasonal changes may be responsible. On the other hand, if there is a direct relation between the two, then the first appearance of mackerel should be early or late depending on whether vernal warming is early or late.

This appears to be true, since the first catches of the seasons of 1926, 1927, 1931, and 1933 varied as much as 10 days from each other (April 9–18), but varied only 2 days from the time that the temperature reached 45° F. (7.2° C.) at the Chesapeake Lightship in these respective years. The events in the other six seasons of the present investigation, with one notable exception, are not pertinent, because in these seasons the water at the Chesapeake Lightship had already attained 45° F. before the fleet arrived on the fishing grounds, and in all save the exceptional year, the first catches were made within several days of the arrival of the fleet, weather permitting. In 1932, however, during an exceedingly mild winter, the water did not cool below 45° F. (7.2° C.) until March 11 and was again up to 45° F. by March 21. Although the fleet arrived in the fishing area about the first of April, no mackerel were caught until April 15 after the water at the Chesapeake Lightship had stood at 50° F. for a week. Giving due weight to this striking exception, it must be concluded that temperature has a limiting rather than a causal influence on the appearance of mackerel. They are prevented from appearing in coastal waters before these warm to 45° F. (at the Chesapeake Lightship) but do not necessarily appear immediately upon attainment of this temperature.

The relation of temperature to the advance of the southern contingent along the coast may best be examined in the season of 1932 when oceanographic cruises at frequent intervals provided temperature observations on the mackerel fishing grounds during May and June (fig. 16). When first approaching the coast in April [23] (fig. 16, A) the schools of mackerel advanced shoreward as far as possible without entering water much cooler than 9° C., and in the first half of May (fig. 16, B and C) they advanced about as fast as did the 9° C. isotherm. After this time they lagged noticeably behind the progress of warming. Large bodies of mackerel remained in the vicinity of New York, where they were in water of 12° C. temperature, although they could have continued 200 miles eastward before reaching water as cool as 9° C. At the same time other schools were in a more easterly vicinity. These could have immediately pursued their northeastward journey, remaining in warm water by detouring slightly southeastward around the cooler Nantucket Shoals,[24] or they could have gone through the inner passage 10 days later.[25] Instead they remained around the edge of Nantucket Shoals, moving gradually around the periphery of the shoals, not reaching Massachusetts Bay until the end of June, though temperatures in the Bay rose to 9° C. before the middle of May.

To be sure, the lack of mackerel catches by vessels in May and the first half of June does not mean that some did not enter Massachusetts Bay during that period. On the contrary some were there by May 8, for mackerel were taken in a trap near Gloucester on that date; others were taken by pound nets at various points around the Bay during the remainder of May and during June. In all likelihood, these early arrivals were mackerel of the northern contingent, for in other years size-frequency distributions of mackerel from Massachusetts Bay in May and early June have always born greater resemblance to the northern rather than the southern contingent. Furthermore, the numbers caught were few in May and early June indicating that the southern contingent had not yet reached there.

[22] Although the 9° C. isotherm of early April 1930 in fig. 14 corresponds to the inshore limit of first catches, this particular temperature cannot have any significance because the catches are from many different years when the water may have been quite different in temperature.

[23] Since no temperature records were available in April 1932, temperatures and catches of 1929 were substituted. Although 1929 was a colder spring, the relation between location of catches and temperature is still evident, for both relate to the same year in each case.

[24] Whether they would have encountered temperatures much below 9° C. on Nantucket Shoals after May 25 cannot be said. The isotherms on fig. 16 were drawn on the basis of temperatures at the periphery of the shoal region and the minimum temperatures over the shoals proper is not known.

[25] Vineyard and Nantucket Sounds then were warmed to at least 10° C. as judged from temperatures at Pollock Rip Lightship situated at the eastern end of Nantucket Sound.

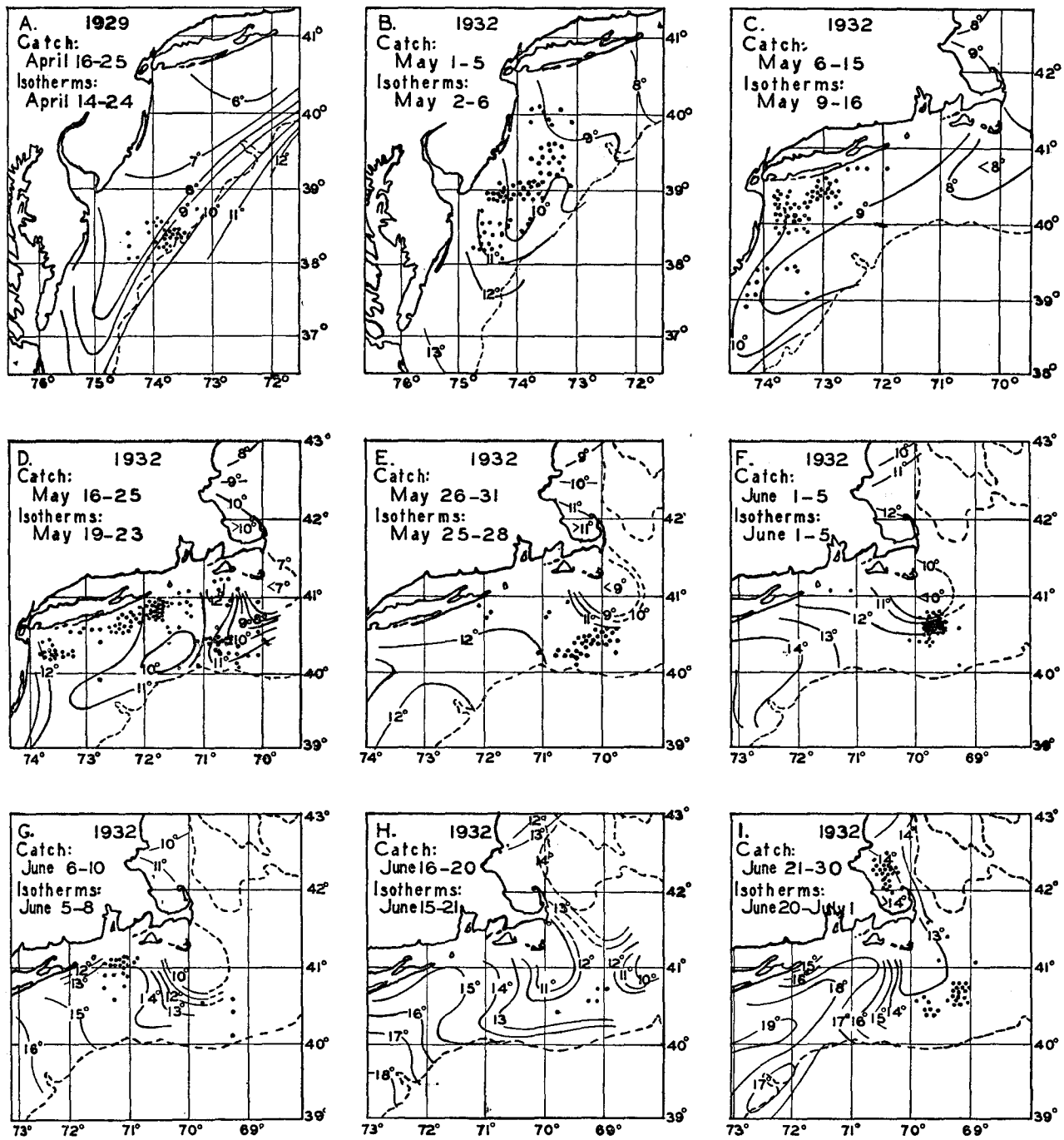

FIGURE 16.—Distribution of mackerel catches (shown by dots) during successive time intervals during the springtime in relation to surface temperatures (shown by isotherms for each degree centigrade).

It was not until June 10 that daily quantities as large as 1,000 pounds were taken in pound nets in any of the localities (representing more than 50 pound nets) of which records were available. Obviously, the southern contingent did not enter until late June when the vessel fishery shifted from the Nantucket Shoals region to Massachusetts Bay.

Beyond this point, geographically and chronologically, suitable temperature data are not available to pursue the relationship further, except to point

out that the surface waters of the entire Gulf of Maine usually become warm enough to be habitable to mackerel, from the temperature standpoint, by mid-June (Bigelow 1927, fig. 39, p. 574).

Comparison of surface isotherms and location of mackerel catches in other years are entirely consistent with the evidence of 1932 and it may be concluded that water colder than 7° or 8° C. forms a temperature barrier to northward advance of the mackerel, but the warming of the water to this point does not necessarily attract the fish along their northward migration.

RELATION OF FEEDING CONDITIONS TO SPRING ADVANCE

In American waters the mackerel is primarily a plankton feeder (Bigelow 1925: 202), consuming practically all members of the zooplankton except jellylike organisms such as medusae and ctenophores. From data given by Bigelow and Sears (1939), it appears that the waters along the spring migration route of the mackerel are well supplied with zooplankton from south of the offing of Delaware Bay in April to the offing of the south shore of New England in June. However, neither Bigelow and Sears (1939: 253–261, 268–270) in comparing distribution of mackerel catches with charts of nutritive plankton at richest level [26] in 1930, nor I in comparing the locality of mackerel catches with volumes of zooplankton in water stratum above the thermocline in several other years, could find a sufficient preponderance of instances wherein mackerel catches coincided with plankton concentrations to suggest that the mackerel tended to travel or tarry in waters richest in plankton content. However, if the feeding of mackerel reduces a zooplankton concentration rapidly and severely, one would expect an initially positive correlation between mackerel and zooplankton to become a negative one as feeding proceeds. Therefore this type of observation must remain indeterminate until much more is known about the dynamics of the situation. This need not prevent an examination of the relation of zooplankton and mackerel in more general terms.

During April, May, and at least a portion of June, in the area traversed by the mackerel, Bigelow and Sears (1939: 214–217) found evidence of a diurnal vertical mass migration of the zooplankton, causing the shoal water stratum from surface to about 20 meters to contain much more plankton in the nighttime than in daytime.[27] By July, however, this migration upward into the shoal stratum at night is suppressed, and plankton in this upper stratum is as poor in the nighttime as in daytime.

Having previously seen that the mackerel, while it is in continental-shelf waters, is a near-surface fish, probably confined to waters above the thermocline, it follows that feeding conditions become poor for the mackerel south of Cape Cod by July, for the plankton, even though persisting in this area, keeps to waters at or below the thermocline and, for the most part is inaccessible to the mackerel. Catches of mackerel are seldom made in this area after late June when the surface stratum becomes poor in plankton. While it is possible that some might stay, and that they might find subsistence by keeping to the deeper levels, in most years there is no evidence that any do.

There are, however, exceptional years when the main body of mackerel, as judged from the catch locations, does not depart on schedule. In 1928 and 1931 some mackerel catches continued to be made south of Cape Cod through July, and in 1936 the mackerel seiners continued to make catches there almost throughout the summer. Unfortunately, information is not available on plankton for this time of year in 1928 or 1936, but the surveys reported by Bigelow and Sears include 1931. Their summaries suggest that July of 1931 was particularly outstanding for plankton abundance at the north end of the area below Cape Cod. Their values for the whole column were 782 cubic centimeters [28] in that year as compared with 448 cubic centimeters and 285 cubic centimeters in 1930 and 1929, the only years available for comparison (loc. cit. p. 200).

Furthermore, there seemed to be a lesser tendency for the plankton to be confined to the deeper layers in that year. Whereas in July 1929 the ratio of

[26] All zooplankton except jellylike organisms such as ctenophores, medusae, or salps, was taken as the nutritive portion, and at stations where hauls were taken at several depth levels, the volume of the haul with largest catch was selected.

[27] In this connection it is interesting to note that purse seine fishing for mackerel at this season of the year is done at night whereas in later months it is done in the daytime.

[28] The quantities of plankton reported by Bigelow and Sears (1939) are given in terms of cubic centimeters of plankton per 20-minute towing with a 1-meter net. The speed of towing was judged to average 1.2 knots. Tows were horizontal at several different levels at each station in 1929 and oblique through several different strata in subsequent years. The "whole column" quantity is the mean of the catches at the several different levels or strata. While Bigelow and Sears do not claim the accuracy attending the straining of a measured amount of water, registration of flow past a current meter in the mouth of the net for 130 of these tows made under my supervision in 1932 indicated that the net strained an average of 456 cubic meters of water per 20 minutes of towing. Thus the statistics of Bigelow and Sears may be translated to the basis of cubic centimeters of plankton per cubic meter by multiplying them by a factor of 0.00219.

deep [29] to surface volumes for both day and night hauls was approximately 8 to 1, in July 1931 it was only approximately 5 to 1. The hauls were not strictly comparable for the 2 years, having been made horizontally in 1929 and obliquely in 1931, and so do not conclusively prove that plankton was more abundant in the strata accessible to the mackerel in 1931. The direction of change on both bases of comparison—total volume and relative proportion in the surface layers—suggests that the plankton may have afforded richer feeding in 1931, when mackerel stayed in the area through July, than in other years of record such as 1929 and 1930.

Although there are exceptional years, such as the ones just discussed, the fact remains that the main bodies of mackerel usually appear in the southwest portion of the Gulf of Maine between May 20 and June 20 and so have departed from the area south of Cape Cod well before its surface waters have been impoverished. They arrive in the Gulf of Maine at a time when zooplankton feed is rich there, where, according to Bigelow (1928: 45), copepods "reach their high-water mark early in June and other forms follow somewhat later."

Having reached the Gulf of Maine the southern contingent of mackerel has completed its spring migration. Although this is not true of the northern contingent, the lack of plankton records along Nova Scotia at times and places suitable for examining feeding conditions along the route of this contingent's migration prevents further pursuit of the subject.

On the whole, we have seen that plankton is relatively abundant along the route of the mackerel's spring migration at the time it takes place. It will be recalled from the section on food that during the months of the migration the fat content of the mackerel is increasing (table 2) thus proving that these relatively high abundance levels of zooplankton furnish good feeding. While there is no evidence that local mackerel and zooplankton concentrations tended to coincide with each other, the agreement of plankton abundance and the presence of mackerel in general suggests that evolutionary processes have brought about a habit pattern in which this species reaches various areas along its route of spring migration at a time when, on the average, feeding conditions are favorable.

[29] For the deep stratum in 1929 the hauls centered at the 10- to 30-meter level and in 1931 they centered at 20–30 meters.

RELATION OF SPAWNING TO THE SPRING MIGRATION

It has long been known that mackerel, when they approach the coast in the spring, are ripe or nearly ripe for spawning. But until the present investigation, simultaneous records of egg concentrations and mackerel catches were not available, and it was difficult to deduce the relationship between migration and spawning. Bigelow and Welsh (1925: 207) were of the opinion that mackerel "do not resort to any particular and circumscribed breeding ground, but shed their eggs wherever their wandering habits have chanced to lead them when the sexual products ripen." As we shall see, the evidence now available indicates that the process is not haphazard, the southern contingent resorting to certain grounds and the northern to others, and, although some eggs are shed elsewhere than on these grounds, such spawning is trifling compared to the concentrations on the respective major spawning grounds.

Some few members of the southern contingent spawn immediately upon entering continental-shelf waters, for we have taken eggs from surface waters at the edge of the continental shelf off the Virginia Capes in mid-April (lat. 36°46′ N., long. 74°37′ W., April 18, 1929). Greater numbers spawn farther inshore when the population reaches the offing of Cape May, but the maximum spawning concentration for the southern contingent is in mid-May in the triangular bight between the New Jersey and Long Island coasts (Sette 1939: 158). The main body moves to this area fairly rapidly and after the peak of its spawning there (after mid-May), continues its journey in the direction of Nantucket Shoals in a much more leisurely fashion, especially when nearing the Shoals.

Members of the northern contingent reach the area off southern New England presumably from offshore at about the same time or a little earlier than the main body of the southern contingent. They leave this region much sooner, and they seem not to spawn here, such spawning as does take place in southern New England being no more than can be accounted for by late-spawning individuals of the southern contingent as it moves eastward to occupy this area. Furthermore, such few samples of mackerel (of sizes appropriate to be of the northern contingent) as were examined from this area when the northern contingent predominated, were not ripe. Upon leaving this area, a small

portion of the northern contingent goes around Cape Cod into Massachusetts Bay (p. 290) where they spawn in May and June. The major portion of the northern contingent crosses the Gulf of Maine to the coast of Nova Scotia, and, joined perhaps by others from offshore, quickly make their way along the coast toward the Gulf of St. Lawrence (p. 290). Despite the large population moving along this coast in June [30] practically no spawning takes place here.[31] Following the tremendous June run along the Nova Scotia coast is the peak of spawning in the Gulf of St. Lawrence, indicating that this is the principal spawning ground of the northern contingent.

Thus, it appears that the spring advance of mackerel toward and along the coast is a series of three spawning runs: First, an advance toward the coast in the offing of the Maryland-Virginia peninsula and northward to occupy the inner half of the continental shelf up to southern New England in April and May; second, a small run into Massachusetts Bay in May and June; third, a larger run impinging first on the south coast of New England but destined to follow along Nova Scotia and into the Gulf of St. Lawrence, reaching there during June, and spawning through July and to a lesser extent into August. In all instances, especially the third mentioned, the movement is rapid until the spawning ground is reached. Once spawning has been accomplished the further movements of the shoals are more leisurely, more random in nature, and seldom seem to involve the whole units of the population.

To regard the spring movements as something other than spawning migrations would not account for (1) the definite concentrations of eggs in the Delaware Bay-Long Island sector, in Massachusetts Bay, and in the Gulf of St. Lawrence, (2) the consistently poorer egg concentrations off southern New England despite the dense population of adults that pass this sector in the spawning season, (3) the very scanty spawning along Nova Scotia despite the abundance of mature mackerel in June, (4) the rapid passage of the various contingents along the coast until they spawn, and their more leisurely progress afterward. All this, however, is consistent with the theory that the spring migration is a series of spawning runs.[32]

Of course, to say that these are spawning runs implies that the mackerel are impelled by the spawning urge without explaining the mechanism by which the movements are directed. In fact, the directive influence guiding the migrations of fishes is unknown for most fishes, many of which perform extended spawning migrations and have been much studied.

On the other hand, it has become known in recent years that bird migrations are connected with the development of reproductive organs, and this appears to be associated with lengthening of the day, either directly or through its influence on the amount of activity.

If the lengthening of the day somehow causes gonad development in the mackerel, and this in turn sets up a process causing the mackerel to move northward (whereby the lengthening of the day is augmented by the earth's inclination), several peculiarities of the migration would be explained. In the first place, migration begins shortly after the spring equinox when days become longer than nights. In the second place, the movement is as nearly northward as topography permits. In the third place, the only notable pause by a migrating group is the one which occurs when the northern contingent approaches the coast of southern New England where it is completely blocked in the northerly direction by the west to east trend of the coast line, and also for a time is partially blocked in the easterly direction by the cold water overlying Nautucket Shoals; rather than turn southerly to detour this cold water area, the contingent seems to wait until further warming erases this barrier. Finally, their taking a westerly (if not southwesterly) trend into Massachusetts Bay when the tip of Cape Cod is reached and into the Gulf of St. Lawrence when the north coast of Cape Breton Island is reached in June nearly coincides with the summer solstice when the lengthening of the day ceases and shortening begins. If this means a weakening of the impulse to move northerly they would be free to go in any direction. Actually, they turn westward where the water is, on the average, warmer.

Against this hypothesis is the fact that in Europe

[30] June catches comprise more than half of the annual take of counties along the coast of Nova Scotia (Sette and Needler 1934: 33).

[31] The data on spawning in Canadian waters are drawn largely from Dannevig 1919, and Sparks 1929, and have been discussed in detail by Sette 1943.

[32] To be sure, there is some scattered spawning wherever mackerel are found in the spawning season and, before the major concentrations of spawning in Massachusetts Bay and in the oceanic bight between the New Jersey and Long Island coasts were made known by this investigation, it was natural to suppose that the spawning was more or less at random.

a portion of the mackerel are known to winter in the deeper waters at the edge of the Norwegian Channel in the North Sea, and if these are of the same population that are caught in spring or summer around the British Isles or along the coasts of Sweden and Denmark, their movements in spring could not very well be northerly in direction. More must be known about the physiological responses of mackerel to various stimuli before this version of the migratory impulse can be anything but a hypothesis.

SUMMER SOJOURN

After the spring migration is over, the mackerel of the northern contingent have passed beyond the present-day range of the United States fishing fleet and the data of this investigation therefore pertain only to the southern contingent's summer habitat.

The region lying south and west of Cape Cod appears to be spawning ground rather than a summering place. Although every year a few mackerel, mainly young ones, remain scattered along the shores from Long Island east to Nantucket Shoals and are caught in pound nets in small, irregular quantities in every month of the summer, the main body after spawning moves in leisurely fashion eastward and around Nantucket Shoals into the Gulf of Maine. Usually they have passed the Shoals by July 1, but some years they linger later. In 1928 and 1931 some were there until July 31 and in 1936 the seiners continued to make catches in this region almost continuously through the summer.

The decline in abundance of plankton that takes place in the surface waters south of Cape Cod during the late spring months may be responsible for the departure of the main body of mackerel from this area at the end of June. In harmony with this idea is the previously noted (p. 294) instance of 1931 when plankton abundance was unusually high south of Cape Cod during July, and mackerel stayed there through the month, instead of proceeding to the Gulf of Maine.

During summer in all the years of this investigation, the catches of mackerel have come from the coastal zone and contiguous banks of the western half of the Gulf of Maine (fig. 17). A line drawn due south from Mount Desert Island to about 40 miles offshore and then paralleling the general trend of the coast line to Cape Cod, then eastward again to the sixty-eighth meridian and then south across Georges Bank would include on its western side all

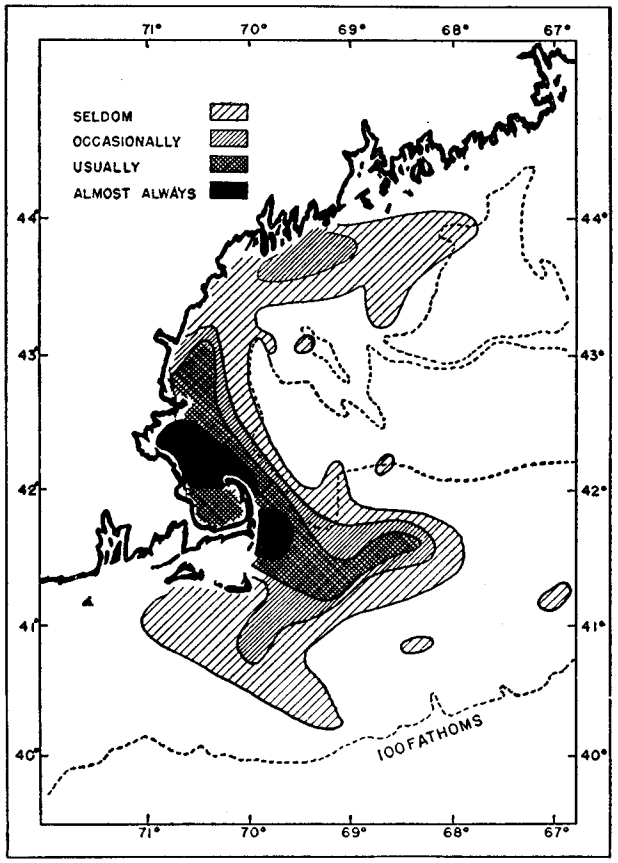

FIGURE 17.—Prevalent distribution of mackerel in the Gulf of Maine during July, August, and September, during the 10 years of investigation, as indicated by the number of seasons that catches were recorded from each 10-minute rectangle on the scale: "seldom," 1–2 seasons; "occasionally," 3–5 seasons; "usually," 6–8 seasons; and "almost always," 9–10 seasons during the period 1926 to 1935, inclusive.

but three catches of the many thousands whose location had been recorded during the course of the present investigation. This appears to be at variance with the opinion of Bigelow and Welsh (1925: 190), who reviewed records of sightings of mackerel schools and of catches from earlier years to conclude that "at one time or another the mackerel is practically universal in the Gulf of Maine, for not only does it appear in great abundance on the offshore grounds—that is, Nantucket Shoals, Georges and Browns Bank—and all over the central deeps, but also throughout the coastal belt; . . ." They mention in particular that in 1882 "vast schools were found over the offshore deeps of the Gulf between Georges Bank, Browns Bank, and Cashes Ledge and thence northward to within 40 miles or

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so of the Maine coast . . ." However, occurrence in the middle portions of the Gulf must have been exceptional rather than usual even in these earlier years.

In reading through the many accounts of mackerel fishing and of the mackerel fishery published during the first several decades after establishment of the United States Fish Commission, one is impressed with the frequency in which fishing along the coast is mentioned, with the emphasis on the coastal nature of the fishery in the Gulf of Maine in summertime, and with the rarity of any really offshore records. In the season of 1885, when month by month accounts of the progress of the mackerel fishery were published (Wilcox 1885, 1887), the locations of fishing within the Gulf of Maine were so much like those recorded during the present investigation, that it is impossible to select any instance of significant difference.

Beginning with 1893, statistics, classified by fishing ground, were published on the landings at New England ports by the fishing fleet. The mackerel landings reported in this series were tabulated by Sette and Needler (1934: 27) for each year during the period 1893 to 1930. Out of a total of 260,662,000 pounds reported from the Gulf of Maine localities from 1893 to 1925, the only catches that could be classified as coming from the middle portion of the Gulf of Maine were those from Cashes Bank, which aggregated only 103,000 pounds or 0.04 percent of these 33 years of landings. During the next 5 years the percentage relationship is about the same; of a total of 160,135,000 pounds 37,000 or 0.02 percent came from Cashes Bank. Similarly for the first 33 years 18.7 percent were reported from Georges Bank and during the next 5 years 24.4 came from there. From the records of the present investigation we know that the catches during the 5 later years were practically all from the westerly end of Georges Bank and there is no reason to believe that those of the preceding 33 years did not come from the westerly end of the Bank also. In the earlier period also 6,886,000 pounds or 2.6 percent were reported from the Bay of Fundy. All of the remainder in both periods came from grounds classified as "New England Shore."

The 33-year period was prior to the present investigation and the 5-year period coincides with the first half of the investigation. In comparing the two periods, there is little to suggest that mackerel have occupied different portions of the Gulf formerly than they do now, excepting the Bay of Fundy catches. The latter were all landed in the years 1901 to 1906, suggesting that for a short time, only, a fishery was found profitable there. A similarly impermanent fishery was carried on in the Bay of Fundy some 30 years earlier, but was abandoned, apparently for lack of mackerel there after 1876.

In general, then, it appears that the 10 years considered here are not atypical, either of the mackerel's habits or of the mackerel fishermen's habits in most years, at least since purse-seine fishing became customary. While our series does not include such an exceptional year as 1882, or any series of seasons affording catches from the Bay of Fundy, and so cannot throw light on these unusual occurrences, they should serve well to represent the most usual pattern of the fishery's distribution during the summertime.

There is reason to believe that when the adult mackerel population consists mostly of the younger ages, the schools tend to stay relatively close to shore during summertime; when it is comprised mostly of the older and larger adults, the schools tend to range farther offshore. During the three summers beginning with 1926, the 1923 class dominated in the population of the Gulf of Maine. Hence, the average age and size of individuals composing the population increased steadily during this period, the modal lengths as of July being 38.2, 39.4, and 40.1 centimeters in 1926, 1927, and 1928, respectively. During these three seasons there were successively higher proportions of catches at offshore locations.

In 1926, all catches were made within 45 miles of shore; in the following year, 82½ percent of the catches were made within 45 miles of the shoreline and 17½ percent were made farther than 45 miles from shore; and by 1928, 33 percent of the catches were made farther than 45 miles from shore (table 17).

In 1929, the trend seemed to set back toward the shore line, only 26 percent of the catches being made more than 45 miles from shore. However, in this season the population consisted of two well-marked size groups. There were the large mackerel of the 1923 and older classes now grown to a modal length of 40.8 centimeters, and the yearling mackerel of the 1928 class having a modal length of only 27 centimeters (in July); and there were very few fish of intermediate sizes from the 1924 to 1927 classes. When the samples from purse-seine catches of 1929 in the Gulf of Maine are segregated according to the two size groups, more than 57 percent of the large-fish

samples proved to have been caught from beyond 45 miles from shore, whereas, less than 1 percent of the small-fish samples were from beyond the 45-mile zone. Thus the trend toward "offshoreness" of large fish continued through 1929.

TABLE 17.—*Distance from shore of purse-seine catches of mackerel during July to October, inclusive, 1926 to 1929*

Year	Percentage of mackerel taken at each 10-mile (nautical) interval of distance from shore							
	10	20	30	40	50	60	70	80
1926	66.0	29.1	4.1	0.7				
1927	37.8	19.4	14.5	10.8	8.0	6.3	2.6	0.6
1928	37.8	9.2	9.8	10.2	8.2	18.4	5.1	1.3
1929	54.0	9.5	3.8	6.8	13.3	10.3	2.2	.2

It should be noted, however, that these offshore catches were confined almost entirely to the northwest portion of Georges Bank (area XXII H), none being made over the central deeps of the Gulf of Maine.

In the years since 1929 there has been a goodly supply of 1-, 2-, and 3-year-old mackerel in the population, and these afforded good catches in the inner coastal zone, so that it was not necessary for the fleet to go farther offshore to locate the larger sizes even though a greater market preference for the latter tended to counteract this inclination. Such of the larger sizes of mackerel as were present in the coastal zone near the western side usually were there only early in the summer immediately following the spawning season, thereafter, they disappeared from the catch, presumably going farther offshore than the fishing fleet cared to follow as long as the fishing on the smaller sizes alongshore proved successful.

In addition to the size-connected difference between inshore and offshore mackerel in the summertime, there is evidence also that the population is not homogeneous from north to south. Unfortunately, space does not permit inclusion of detailed frequency graphs of samples in small-area and short-time groups for the summer months. But the early fall period is an extension of the summer period during which the mackerel population apparently remains distributed more or less according to the summer pattern. Fortunately, examples of the lack of homogeneity now to be considered are evident in the graphs for early fall in the three seasons included in figure 11. In fact, they are so obvious that the reader may have questioned the implication in the section on the existence of contingents that each contingent is a unit population rather than an aggregate of several more or less discrete populations inhabiting different subareas. To a limited degree the latter is true as we shall see.

The differences in the early fall (September) length-frequency distributions of table 23 and figure 11, suggestive of nonhomogeneity between subareas can be grouped into two categories (1) slight differences in the position of the modes and (2) differences, usually slight, in the relative strength of the right-hand tail of the various distributions.

The first category is illustrated in the September 1926 distributions as a difference between subareas D and E on the one hand and G on the other. Since D is represented only by 40 fish out of the 2,900 measured during this month, it has been left out of consideration and the distributions simply of subareas E and G compared in pairs as given in table 18.

TABLE 18.—*Comparison of length-frequency distributions for September 1926 by the chi-square method with corresponding probability values*

Comparison	Chi-square	P
Area E with area G:		
Sept. 1–10	39.3	<0.001
Sept. 11–20	60.8	<.001
Sept. 21–30	38.3	<.001
Sept. 1–10 with Sept. 11–20:		
Area E	19.3	.05
Area G	21.0	.03
Sept. 11–20 with Sept. 21–30:		
Area E	19.77	.05
Area G	25.4	.008

It is seen that where the distributions from the same subarea in successive periods are compared, the chi-square value tends to be around 20 to 25 which, for the 11 degrees of freedom afforded by the 12 size-classes remaining after pooling the tails below 35.5 and above 40.0 centimeters, corresponds to probabilities between about 0.01 and 0.05. These results conventionally would be considered of significance or of border-line significance. But when account is taken of the theory underlying the chi-square distribution from which the probability value is derived in conjunction with the conditions under which these samples of mackerel were drawn, a conventional interpretation is questionable.

Although each of the frequency distributions here under consideration contains in the order of 500 individuals (240 to 600), this is not the equivalent of a set of 500 independent random drawings from a universe. Our individuals were drawn in subsets

of 20 individuals, 1 such subset from each cargo of mackerel. The cargo of mackerel in turn is usually made up of the catch of 1 school or sometimes 2 or 3 schools, but never as many as 20 schools. If, as there is reason to believe, the mackerel tends to assort into schools according to size of individual (p. 264), we no longer can regard a set of 500 fish made up of 25 subsets as 500 fully independent drawings and we should expect the tabular values of P to be fictitiously low.

However, if the number of individuals per sample, the tendency of assortment by sizes in the schools, and the variance of the general population which is assorted into schools all remain approximately the same as between sets of data to be compared and if the data are partitioned into size classes affording identical number of degrees of freedom for each set, then the relative values of chi-square or of its corresponding probability may be of significance. In all probability these conditions are either exactly or approximately met in the several frequency distributions listed in table 18. Furthermore, it probably is consistent with all known facts to regard a chi-square value of 20 to 25 between these particular pairs as indicating no real difference in the populations sampled.

Turning now to comparison of distributions for different subareas during the same time period, the chi-square values are 38 or higher and corresponding probabilities are less than 0.001. Whatever the limitations of the chi-square method as applied to these data, there can be no doubt that the samples of subarea E differed more from those of subarea G than did the samples taken during successive time intervals within each subarea. Adding to this evidence the fact that the displacement of the mode in E as compared with G is consistently in the same direction, the evidence is substantial that the distribution of mackerel by sizes was not homogeneous as between subareas.

For summers and early fall of other years such small but doubtless significant differences between the frequencies of sizes of mackerel from well-separated areas of fishing are sometimes detectable from inspection of the frequency graphs and sometimes not. The suggestion therefrom is strong that during the summer period the mackerel population may become segregated between several fishing grounds and remain so for several weeks to a month or more at a time.

I have noted no instance where such segregation has persisted during the entire summer and early fall. In 1926, for instance, though the segregation was plain during September, there was little evidence of it during the preceding August. In 1927, on the other hand, it was well marked as between subareas F and G during a part of August, but at that time there were only a few catches from subarea F and later they ceased completely. The segment of the population in subarea F may have been a small one that later joined with the probably larger populations in E or G in which their relatively small numbers would be undetected.

On the whole, these segregational events seem irregular and temporary, indicating certainly a lack of complete mixing of the main population at all times during summer but not indicating the existence of stable independent units.

The second category of nonhomogeneity is illustrated by the frequency graphs for September of 1927 in figure 11. The frequencies from subarea E have a long "tail" extending to the right which is much more pronounced than the tail extending to the right in the frequencies from subareas G, H, O, and P. Taking the sum of the individuals whose lengths exceed 41.25 centimeters as the tail of the distributions, and pooling all September data, it is found that the distributions from subarea E have 48 out of 320 or 15 percent of the individuals in the tail, whereas those from G, H, O, and P have only 123 out of 2,210 or 5.6 percent in the tail. Treating the four counts given in the preceding sentence as a 2 by 2 contingency table, the chi-square value is 43.5 which corresponds to a probability of far less than one in a thousand that such a divergence in the tail portions could occur by chance. Part of this difference may be attributed to the nonrandomness of the several samples comprising each set of data, as was above discussed at length. But the very high chi-square value suggests that the difference is real. Even a greater weight of evidence is provided by the fact that the mackerel-lengths comprising the tails of the distributions from subarea E cover approximately the range of lengths that are present in the entire distributions of what has been recognized as northern contingent, as exemplified in the December frequencies of the same year.

In fact, it is possible to examine the question: Is the distribution of individuals among the size classes in the tail on the distribution from area E consistent with the hypothesis that the tail consists of an admixture of northern contingent mackerel

such as were caught in December with southern contingent mackerel such as were caught in subareas G, H, O, and P in September? We have given as our empirical distribution, 320 fish from area E in September, of which only the frequencies in the right-hand tail above 41.25 centimeters are of interest. These comprise 48 fish. Our hypothesis is that these 48 fish are distributed as if they were combinations of 2 populations: (1) Southern contingent mackerel for which the model distribution is the set of samples containing 2,210 fish from areas G, H, O, and P for the month of September, and (2) Northern contingent mackerel for which the model is one set of samples containing 800 fish from drift-gill-net catches from area E during December 11 to 20. These will be called populations I and II, respectively. Population I has 123 fish and population II has 667 fish above 41.25 centimeters. The proportion of population I to population II in the combination is not included in the hypothesis and must be determined empirically.

If we let x_1 be the numbers of fish to which population I should be weighted and x_2 be the numbers of fish to which population II should be weighted, then

$$x_1+x_2=320$$

will satisfy the requirement that the theoretical population will have the same number as the observed population, and

$$\frac{123}{2{,}210}x_1+\frac{667}{800}x_2=48$$

will satisfy the requirement that the theoretical population will have the same number of fish as the observed population in the segment of the tail lying above 41.25 centimeters. Solving the two simultaneous equations we find that the frequencies of population I should be weighted to total 281.2 fish and those of population II to total 38.8. Combining these two populations so weighted we may examine the tail portion above 41.25 centimeters to see whether the distribution of fish among the several class intervals is sufficiently similar in both the theoretical and the observed population to be consistent with the hypothesis that this tail of the latter distribution could be composed of an admixture of northern with southern contingent fish.

In applying the chi-square test, it is necessary to combine several of the half-centimeter class intervals to contain a minimum of five individuals per new class-interval (in the theoretical distribution). After this is done there are seven class-intervals with a total chi-square of 9.0; entering the table with 6 degrees of freedom, the probability is 0.17 that the difference between the two curves could have arisen by chance. Thus, within the limitations of sensitivity of the test, which, with only 48 fish, distributed in seven size classes, is not very great, the hypothesis that the area E samples contained northern contingent fish in the tail is consistent with the data.

Indications, similar to the above, of admixture of some northern contingent mackerel with the predominently southern contingent mackerel in the northwesterly portions of the Gulf of Maine are evident, not only in the 1927 material, but occur practically throughout the summer mackerel frequencies of all 10 years of the series. Frequencies from subareas C, D, E, and F, all north of Cape Cod, contain, in the size classes appropriate for northern contingent mackerel, an excess of individuals over the relative number found in these size classes among the mackerel taken contemporaneously in subareas G, H, O, and P, all east and south of Cape Cod. More rarely, there are groups of samples taken, usually in the northwestern part of the Gulf of Maine, which have size compositions nearly identical with that of the northern contingent mackerel as it is found in the spring off Nova Scotia or in the late fall off Massachusetts.

It appears to me, therefore, that there must be a small segment of northern contingent mackerel that stays in the Gulf of Maine throughout the summer, that this segment is small relative to the southern contingent present in the summer, and that this small segment generally keeps well north of Cape Cod.

In some seasons there has been a tendency for the distribution of mackerel catches as a whole to be more northerly than in others. The years 1926, 1927, and 1933 to 1935 were examples of southerly distribution wherein practically all of the catches were made in Massachusetts Bay or southward (fig. 18). During the years 1929 to 1933 a much larger proportion of the catches were made north of Cape Ann (fig. 19). It may be significant that the southerly distribution was most marked during the years when the 1923, 1930, 1931, and 1933 classes were dominant; whereas the northerly distribution was confined to the years when the 1927, 1928, and 1929 classes were dominant. The first-named group of year classes were predominantly members of the southern contingent even in their later years, while the last-named group appeared to have joined the

northern contingent after attaining appropriate ages. It is possible, therefore, that year classes destined eventually to be northern contingent members, may presage this event by exhibiting a tendency toward northerly summer distribution some years before they actually join the extensive northerly spring migration of the northern contingent.

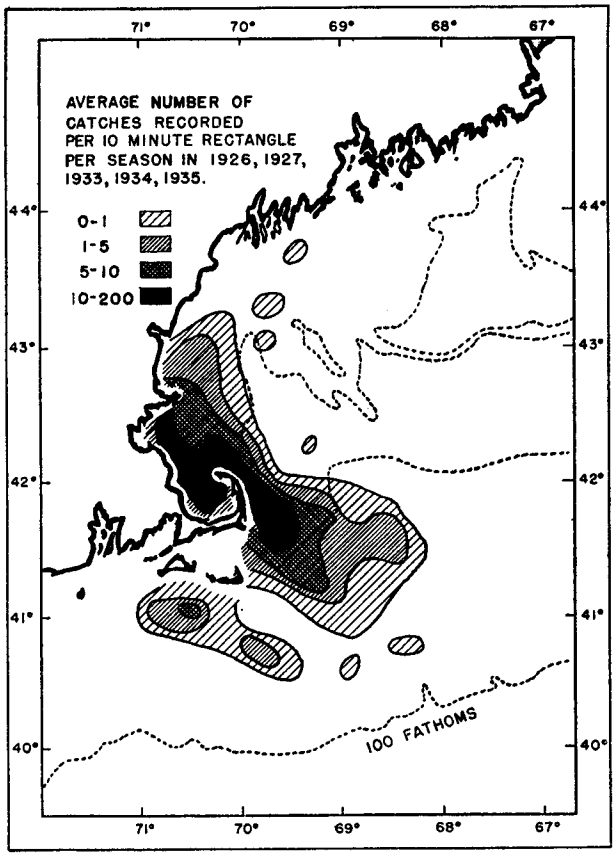

FIGURE 18.—Relative concentration of mackerel schools in 1926, 1927, and 1933–35 during the months of July to October, inclusive, as indicated by the average number of catches made per 10-minute rectangle per season by purse-seine vessels.

INFLUENCE OF FEEDING CONDITIONS ON MOVEMENTS OF THE MACKEREL IN SUMMERTIME

Regarding the feeding conditions encountered by mackerel and the effects of distribution of planktonic feed on the distribution of mackerel during their summer sojourn in the Gulf of Maine, there is a regrettable paucity of information on plankton that is suitable for drawing conclusions. Bigelow's (1926) data are for years not covered by my records of mackerel distribution. They demonstrate that the plankton is richer in the Gulf of Maine generally

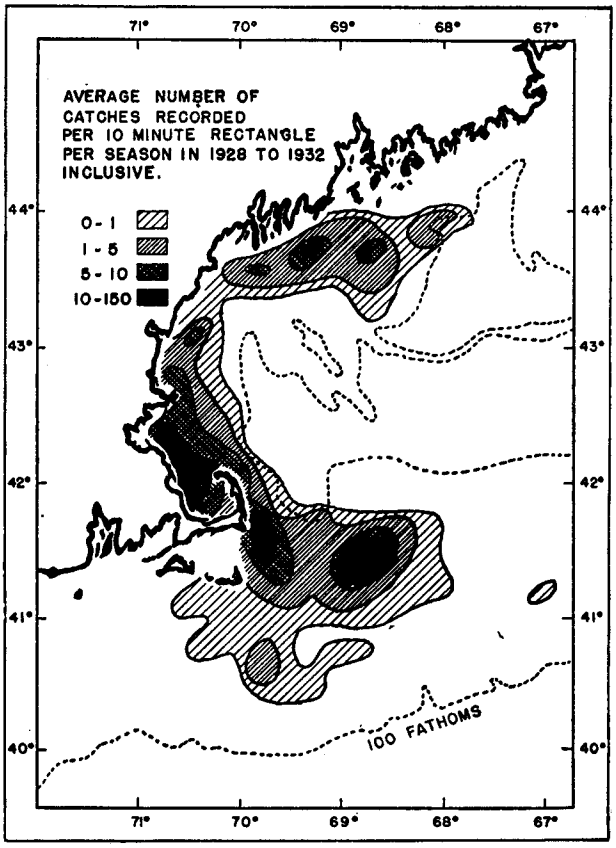

FIGURE 19.—Relative concentration of mackerel schools during July to October, inclusive, during the years 1928 to 1932, inclusive, as indicated by the average number of catches made per 10-minute rectangle per season by purse-seine vessels.

during the summer period when the mackerel catches are also taken mainly in the Gulf of Maine, but do not indicate whether it is richer in the parts usually frequented by the mackerel than in other parts. In fact, his quantitative hauls for the summer period (Bigelow 1926: 86) show the richest band extending from southwest to northwest directly across the Gulf of Maine with only its southwesterly extremity coinciding with the area customarily yielding mackerel catches. Also the alongshore area north of Cape Ann where mackerel are caught in abundance in some years gave the lowest plankton volumes. This apparent lack of correspondence between richness of plankton and mackerel catching grounds may however be entirely without significance because Bigelow's quantitative hauls were drawn vertically from near bottom to surface and portray the aggregate plankton population rather than the concentration in the surface layers inhabited by the mackerel.

Similarly Redfield's (1941) quantitative study of plankton in the Gulf of Maine was based on vertical hauls through the entire water column and was not particularly suited for the solution of the problem here considered. After examining my charts of mackerel catches in relation to his plankton volumes, Redfield was able to conclude that "It seems sufficiently clear that in early summer mackerel are available chiefly along the southern shores of the Gulf, that by late summer their abundance has shifted to the northern shores, including the Bay of Fundy. This is the distribution of the maximum of zooplankton population as well." Beyond this generalization that the sequence from south in early summer to north in late summer in both plankton and mackerel distribution, it is not possible to see any striking correspondence between the two on the basis of the Redfield data.

The charts of plankton distribution given by Redfield cover periods either rather early or rather late in the summer period. In the period of May 21 to June 3, 1934, the plankton-rich zone, as shown by the area included within the 50 cubic centimeters (per square meter of sea surface) contours, extended from abreast the Massachusetts Bay-Cape Cod-Nantucket Shoals sector in an easterly direction across the Gulf of Maine. Mackerel catches at that time were mostly (65 percent) west of Nantucket Shoals and so not within Redfield's survey area. The remainder were from statistical area XII–O, at the very southwesterly corner of the survey area, and it is not clear whether any were within the plankton-rich zone. From an extrapolation of the isometric lines representing plankton distribution, it appears likely that only a part of these mackerel catches could have been within the plankton-rich zone.

In the period September 2 to 14, 1933, the plankton-rich zone, as judged from the 50 cubic centimeters contour, covered the westerly portion of the Gulf of Maine, its westerly boundary lying well offshore, averaging perhaps 40 miles from the coast. A plankton-poor area with less than 25 cubic centimeters seemed to border the entire western shore line. All the mackerel catches for the month of September 1933 were made in Massachusetts Bay and close in to Cape Ann; thus the mackerel were well inshore of the main zone of plentiful plankton and in water that was very poor in plankton, unless there was a local plankton concentration within Massachusetts Bay. Redfield's survey included no stations within the Bay, though there was one at the tip of Cape Cod which should have reflected any richness of the Bay because the circulation pattern is such that water usually flows out of the Bay past this station. Since only 3 cubic centimeters were taken at this station, it hardly seems that the Bay could have been very rich in plankton at this time.

In the period of September 17 to 27, 1934, the plankton-rich zone lay obliquely across the Gulf of Maine, extending roughly from southwest to northeast and mostly over the central deeps. Mackerel apparently were confined to the westerly borders of the Gulf. Of 225 mackerel catches during September 2 to 29, 1934, inclusive, 204 were in Massachusetts Bay, which was not sampled for plankton in the Redfield survey of September 1934. Of the remaining 21 catches only three were in the zone of plankton yielding more than 100 cubic centimeters drained volume of plankton per square meter of sea surface, 7 were in the 50–100 cubic centimeter zone and 12 in water yielding less than 50 cubic centimeters per square meter.

This apparent lack of agreement is perhaps what would be expected from the nature of the organisms concerned and from the type of data upon their occurrence. It has been pointed out that mackerel probably keep to the waters above the thermocline and the latter is often only 20 meters below the surface and seldom more than 50 meters below. Furthermore, the evidence on the distribution of mackerel is the location of fishermen's catches which are made only at or near the surface. Zooplankton, on the other hand, occurs at all levels from surface to bottom and the evidence on its relative abundance was from vertical hauls which represent the total quantity from surface to sea bottom rather than the concentrations in the upper levels. According to Bigelow (1926: 28) there is a decided cleavage in the plankton community between the upper and lower levels with the 100- to 150-meter level roughly delimiting the two. Accordingly, the vertical hauls in deeper portions of the Gulf of Maine draw on plankton populations in addition to those that either remain in near-surface levels or migrate into and out of them diurnally as does the important calanoid community (Bigelow 1926, p. 24; Clark 1934a, p. 430, 1934b, pp. 436–444). The inclusion of the deeper plankton in the vertical hauls would make the plankton appear to be relatively rich over the central deeps of the Gulf of Maine, when in fact the

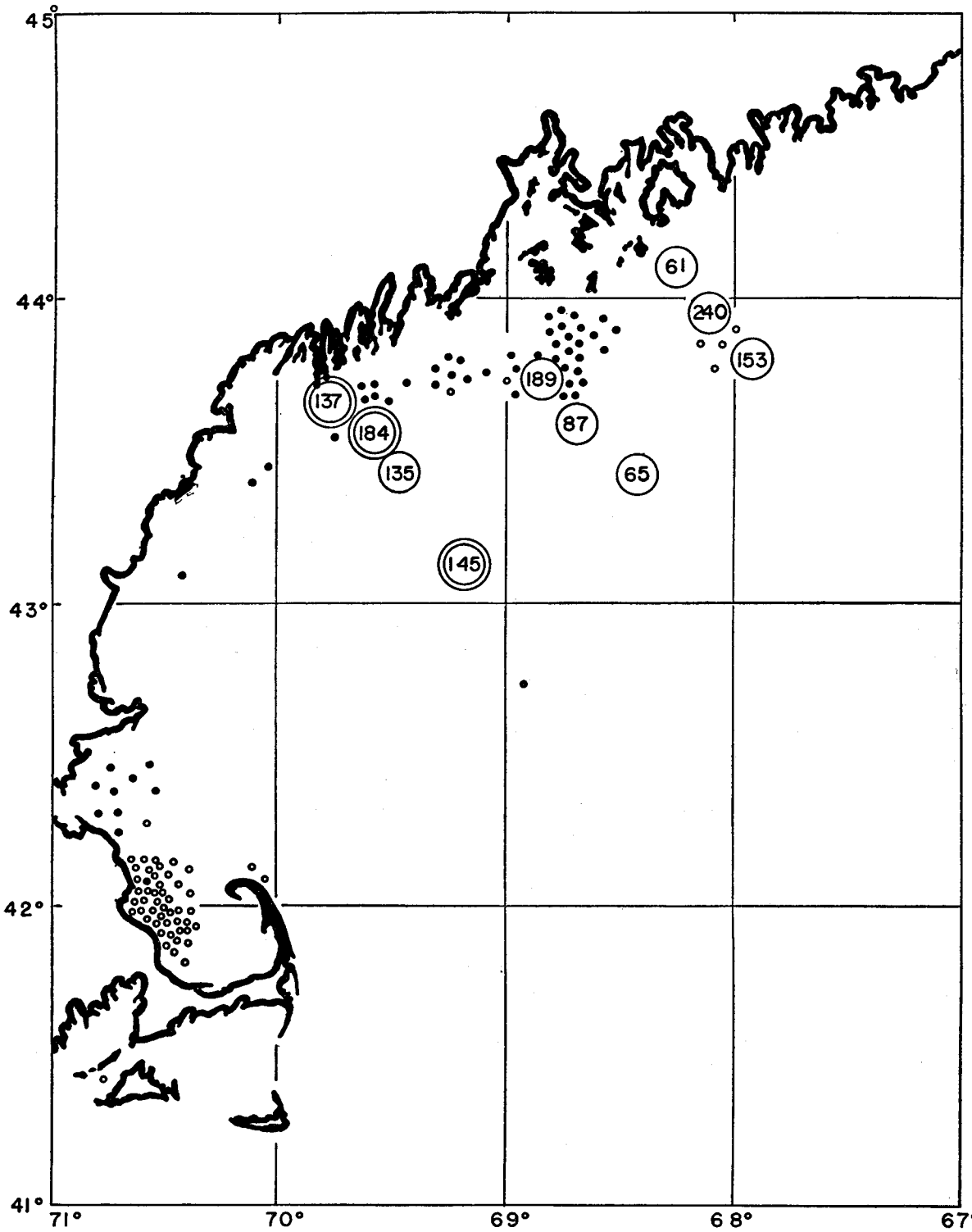

FIGURE 20.—Distribution of mackerel catches and of zooplankton in the upper 50-meter stratum of the waters of the Gulf of Maine in late August 1932. Solid dots indicate catches of large, and small, open circles catches of small, mackerel during August 6 to 20, 1932. Large circles indicate the position of the plankton hauls, and the numbers in them give the quantity caught, in centimeters (by displacement), per 20-minute oblique tow with a meter net from 50 meters to the surface. Double circles indicate that more than 30 percent of the plankton, by number, consisted of euphausids.

plankton in upper layers inhabited by the mackerel might really be much poorer over the central portions of the Gulf than along its borders.

To properly investigate the relation between feeding conditions and the mackerel's distribution in the summertime would require a quantitative sampling of that portion of the plankton which is available to the mackerel. This would likely include all of the forms living continuously in the layer above the thermocline and also those forms which may be found below the thermocline in the daytime but migrate upward nightly to or through the thermocline as Calanus (Clark 1934a, 1934b) sometimes does. The results of such sampling should moreover be available for the same period of time as is covered by the information on mackerel distribution.

Despite the fact that the Gulf of Maine probably is the most-studied portion of the sea adjacent to North America, I have been unable to find data that meet this specification. Most nearly approaching it are data on a group of hauls reported by Fish and Johnson (1937). For present purposes, as published, they have the fault of including plankton bathymetrically unavailable to mackerel, for the catches of hauls traversing the layer from 50 meters to the surface were combined with the catches of hauls traversing the layer from bottom to the 50-meter level. However, Dr. Charles J. Fish kindly furnished me his measurements of volume in terms of cubic centimeters of plankton, drained measure, caught in 20-minute oblique hauls drawn from 50 meters to the surface. They were taken mostly in the daytime and may not fully represent the calanoid community. The values have been plotted in figure 20, to which have been added the locations of mackerel catches during nearly the same period of days as was covered by the plankton survey.

Unfortunately, the area covered by the plankton survey does not extend far enough in a southwesterly direction to include the entire fishing area. The sector along the coast of Maine was sampled by Fish and Johnson, and also afforded mackerel catches. In this sector the plankton tended to be most concentrated in a zone paralleling the coast and lying about 15 to 25 miles offshore. The mackerel catches are concentrated along approximately the same zone. Giving due consideration to the fact that the time periods for mackerel and plankton catches are not identical and that the plankton catches may variously underrepresent or overrepresent the calanoid community, depending on where its vertical migration brought it in relation to the 50-meter level at the particular time each haul was made, the agreement is very good.

This suggests that mackerel may, during their summer sojourn, keep to areas that provide the richest feeding. Alternatively, it suggests that they are most accessible to the fishermen in such areas. In either case, some of the great differences in the distribution of the mackerel catches within the Gulf of Maine during some seasons as compared with other seasons might prove to be due to unusual variations in the plankton production cycle and in the distribution of the plankton community. Surveys designed expressly to test this possibility might have fruitful results, not only in elucidating the ecological complex of which the mackerel population is a part, but also in the discovery of causes of apparently anomalous fluctuations in the success of the mackerel fishery.

All of the above discussion is based on the premise the zooplankton is the basic feed of the mackerel in the summertime. There is the possibility, also, that small fish and other relative active forms may be important in the ration of the mackerel (p. 268). This possibility needs investigation. If found to be true, there would be a further interesting possibility. Small fish used as feed by the mackerel, in turn feed upon the plankton. If such small fish are tolerant of a wider range of temperature than the mackerel and so free to feed below the thermocline as well as above it, they could, in effect, constitute a food link between the deeper plankton community and the near-surface mackerel.

FALL DEPARTURE

Little can be added to the information already extant concerning the autumn movements of that portion of the mackerel population inhabiting Canadian waters in the summertime, except to point out that although some mackerel remain there until late in the fall (to the end of November), statistics on the monthly catch in the various portions of Canada (Sette and Needler 1934: 34) indicate that the fall run of mackerel is heaviest along the shores of Prince Edward Island in September and along the southeastern shore of the Gulf of St. Lawrence and the coasts of Cape Breton and Nova Scotia in October. Presumably this peak in the catches marks the passage of the main body of northern contingent mackerel along these coasts on its departure from waters north of the Gulf of Maine to go to its winter habitat south of the Gulf of Maine. The small

portion of the northern contingent that winters along the edge of the continental shelf off Nova Scotia apparently lags behind the main body in leaving Canadian shores. This is suggested by the small catches made off Nova Scotia after October.

South of Canadian waters there is more detailed evidence available on the time of fall departure. Typical of this evidence are the frequency graphs included in figure 11. In 1926, the population in the Gulf of Maine continued to have typically southern-contingent characteristics, its frequency distribution being unimodal with modal length at 38 centimeters, until October 15. Thereafter, it changed sharply to a modal length of 40.5 centimeters among the mackerel caught by seiners, and subsequently shifted upward to 41 or 41.5 among the mackerel caught by fishermen operating drift gill nets (known locally as "netters"). These sizes, obviously characteristic of northern-contingent mackerel, undoubtedly indicated the incursion of the latter group into the Gulf of Maine, where they replaced the southern contingent as it withdrew from the Gulf of Maine in the middle of October.

The change is not always abrupt. In the following year, 1927, purely southern-contingent mackerel with a modal length of 39 centimeters were in samples from the Gulf of Maine until October 8. But these were joined by northern-contingent mackerel in the latter half of the month causing multimodal size composition with one mode indicated at 39.5 and another well-pronounced at 41.5 centimeters. By the end of October, however, the southern contingent had gone, leaving practically no fish at the former modal length of 39 or 39.5 centimeters. On the other hand, the northern-contingent mackerel with their modal length at 41.5 or 42 centimeters made up the entire catch after November 1st and continued to furnish fishing to the netters until the middle of December.

In some years the late summer and fall samples show traces of that minor portion of the northern contingent which is presumed to stay in the Gulf of Maine instead of migrating to Canadian waters as the major portion is supposed to do. Late in August of 1928, while a population with modal length of 40.5 centimeters, obviously of the southern contingent, was found in the offing of Cape Cod (areas XXII–G and H, August 22 to 29), another population with modal length at 42.5, obviously northern contingent mackerel, was in the northern part of the Gulf of Maine (area XXII–C, August 23 and 24). Early in September these northern-contingent mackerel had moved down to Massachusetts Bay, judging by the size composition of 60 mackerel from area XXII–E, September 6 to 10. Some of them had filtered past Cape Cod to join the southern contingent still present in areas XXII–G and H, causing a pronounced skewing toward the right of the length-frequency curves for middle and late September. During the ensuing days of September, this hump persisted, indicating that northern- and southern-contingent mackerel were mixed in the offing of Cape Cod. Early in October the fishery shifted from the offing of Cape Cod to the offing of No Man's Land, i. e., southwestward past Nantucket Shoals. Here the population contained fewer mackerel in the 42–47 centimeter range and it is possible that the northern-contingent mackerel which were in the offing of Cape Cod early in September did not follow to the main body to the vicinity of No Man's Land. Unfortunately, the number of samples is hardly adequate to demonstrate this beyond doubt.

After an interval of time, large numbers of mackerel appeared in the offing of Cape Ann, where they became the object of the drift-gill-net fishery during the last few days of October, all of November, and the first half of December. Judging from the sizes of fish and their abundance, these must have been the main body of the northern contingent that had reached the western part of the Gulf of Maine on its return from waters off Canada.

Further examples might be drawn from other years, but the three given are sufficient to show the course of events, and when considered together with the monthly catch statistics, give a fairly complete report of the autumn withdrawal. According to this evidence, the southern contingent departs from the Gulf of Maine during October, at the same time as the northern contingent is leaving Canadian waters. At least a portion of the northern contingent, on leaving Canadian waters, passes through the Gulf of Maine, and it is this population in transit past Cape Ann that furnishes material for the drift-gill-net fishery in late October, all of November and early December. In passing through the Gulf of Maine, the earliest of the northern-contingent mackerel sometimes mix with the latest of the southern contingent, which have not left the Gulf of Maine by the time the northern contingent arrives there.

On leaving the Gulf of Maine, the southern contingent goes out by way of the offing of Cape Cod

and, in some years at least, passes westward to the offing of No Man's Land before disappearing. Thus it retraces a portion, but not all of its spring migration. The northern contingent on leaving the Gulf of Maine probably also goes by way of the offing of Cape Cod, for sometimes the latest catches are made in that locality; but more often the mackerel of this contingent disappear at the outer part of Massachusetts Bay.

The disappearance of mackerel in autumn at points north of their appearance in the springtime may be associated with a change in their vertical distribution connected with the break-down of the thermocline with autumn cooling. As has been discussed in an earlier section (p. 265), it is probable that mackerel are kept fairly near the surface of the sea in the summertime by a sharp thermocline which exists within 20 fathoms of the surface. With the cooling of the water in the autumn, surface chilling brings the temperature in the upper strata nearer to that at the thermocline, allowing greater mixture and a deepening of the upper stratum. No doubt, this is accentuated by autumn storms. Since the mackerel fishery depends on the presence of fish near the surface, this deepening of the stratum above the thermocline permits the mackerel to disappear to an ever greater extent from the range of perception of the fishermen; therefore, it is likely that in leaving the shores of their summer habitat the movement is one of descent as well as of migration southward and offshore. (See also p. 261).

EVIDENCE ON MIGRATIONS—FROM TAGGING EXPERIMENTS

The foregoing account of seasonal migrations has been based on a study of sizes of fish in the mackerel population. Tagging experiments should provide more direct evidence. Under the auspices of the North American Council on Fishery Investigations, such experiments were initiated in 1925 and were continued several years in both Canadian and United States waters. Unfortunately, they yielded disappointingly few significant returns. The bulk of recaptures was made in the same locality shortly after release and the returns from more distant localities at appreciable periods of time after releases were so few, and the evidence seemingly so conflicting, that no reasonable conclusions seemed possible.

It was particularly puzzling to find that there were a considerable number of recaptures in the United States fishery of mackerel that had been tagged in Canada, but there was only one recapture in the Canadian fishery of the mackerel that were tagged in the United States. The discrepancy was far too large to be accounted for by relative numbers of fish tagged, relative intensities of fishing or differential tagging mortality. Neither did it seem plausible that mackerel should always be going from Canada to United States waters and practically never in the contrary direction.

However, with the present knowledge gained from variations in size composition of the mackerel caught in the various localities at various times of the season the puzzling features of the tagged mackerel returns are no longer baffling and, in fact, confirm to a remarkable degree the conclusions resulting from the analysis of sizes. In examining the tagging data, their significance will be considered in relation to each of the subjects under which the migrations have already been discussed. The details of tagging methods and the records of releases and returns are given in appendix B.

Distinction Between Southern and Northern Contingents

If there are two groups, northern and southern, this should be evident from all tagging experiments, but would be revealed most strikingly by tagging during the spring mixing period off southern New England. Of the mixed population, those individuals whose sizes indicate them to be members of the northern population should provide returns showing a rapid migration northward and eastward, a minor portion reaching the western side of the Gulf of Maine and the major portion reaching Canadian waters. To be a valid test, the tagging should be done in the offing of Block Island and No Man's Land at a time when samples of the population indicate an alteration of the size composition of the sort demonstrated in the preceding pages—usually in the latter part of May. None of the tagging experiments meets this specification, but the releases of June 8 to 19 at Woods Hole (Mass.) approach it.

Although sampling was not regularly carried out in 1925, it is known from a study of the fish tagged in this experiment and from samples collected in August, September, and October of that year that the 1923-class was dominant and the 1921-class subdominant, and it is known further from the size composition in subsequent years that the 1923-

class was characteristically a southern-contingent class while the 1921-class and still older mackerel were mainly members of the northern contingent. The mackerel tagged in the experiment under consideration contained both elements roughly separable by a line drawn at 15⅝ inches, those below this length theoretically, belonging to the southern contingent, those above to the northern contingent. Thus this experiment meets the requirements of dealing with a mixed population. But it does not meet the requirement that it take place offshore along the main route of migration. Instead, the tagging was done far inshore in the bays and sounds. Hence, it might be suspected that these individuals had already split off from the main body and consist of a selected portion already committed to their area of summer sojourn. If this is true, those under 15⅝ inches belonging to the southern contingent should show a tendency to linger south of Cape Cod, indeed, might form that minor portion of the southern contingent remaining south of Cape Cod all summer. Those above 15⅝ inches, on the other hand, should pass quickly out of the southern New England area and into Massachusetts Bay either around Cape Cod or by way of the offing of southern Nova Scotia.

This expectation was confirmed by the returns from this tagging experiment (table 25). Those under 15⅝ inches were taken along various portions of the southern New England coast and even as far west as Long Island during the early months; and it was not until August that any were recaptured north or east of Cape Cod. Those above 15⅝ inches must have passed out of the southern New England area almost immediately. Aside from a few local recaptures during the first few days after release, all were recaptured east and north of Cape Cod both soon after release and during the subsequent months of the season. Hence, it is clear that the population which according to theory was identifiable from sizes as "mixed," did contain individuals which later separated according to their size into two groups corresponding in their movements as well as in their sizes to northern and southern contingents.

The returns during subsequent seasons were too few to be of much weight. Such as they are, they are confirmatory rather than otherwise, especially the one recapture in Nova Scotia in 1927. This was the only tagging experiment that was performed in United States waters that could, according to theory, provide returns from Canadian waters, and it was the only one that did provide such a return.

Migration of the Southern Contingent

According to hypothesis, mackerel tagged at any time or place in United States waters except in the area of mixing in the spring and fall, should be recaptured in United States waters.[33] This is true of all of the tagging experiments. None except the one of June 8–19, 1925, at Woods Hole, previously discussed, dealt with mixed populations and none other than this one produced Canadian returns.

Those tagged early in the spring before the time and south of the place of mixing should provide returns as far north as the Gulf of Maine. The only experiment in this category was the release May 24 to 27 of 400 mackerel in the offing of Delaware Bay. Of the two returns from this release, one was caught locally the following day, the other was taken off Cape Cod the following August. The returns, though sparse, are in accord with theory.

Those tagged during the summer in the United States waters should show random movements during the remainder of the summer and early autumn. This they did (table 26), but the random movements were perhaps fairly limited in scope, most of the individuals (254) being caught near the point of release and only a few (6) being recaptured in other areas. All recaptures were within the area forming the summer habitat of the southern contingent according to our hypothesis.

One would expect that recaptures during the late autumn of fish tagged in the Gulf of Maine would be made in the offing of Cape Cod and even west along the southern New England coast as far as Block Island. Unfortunately, only one of the mackerel tagged in the summer of 1925 was recaptured in the late autumn. This had traveled from the coast of Maine to the offing of Block Island, where it was caught October 19.

Thus, as far as they go, the tagging returns pertinent to the southern contingent are in accord with the evidence derived from size composition.

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[33] Still another exception should be made when technique of tagging marks the mackerel permanently enough to provide returns several seasons after release. Then, yearling mackerel spending the summer in the Gulf of Maine but destined to join the northern contingent as they grow older (p. 286) might be tagged in summer in the Gulf of Maine and be recaptured in Canadian waters in subsequent years. Since the tagging experiments were with impermanent tags (appendix B) this exception need not be considered.

Migration of the Northern Contingent

To be of significance in testing our theory that the northern contingent passes the southern New England coast in migrating to Canadian waters, tagging should take place in southern New England along the supposed route of migration during the period of so-called mixing in spring. From such taggings, one would expect a small portion to be recaptured in the western parts of the Gulf of Maine, but the major part should be recaptured during the ensuing summer in Canadian waters, perhaps as far north as the Gulf of St. Lawrence. Unfortunately, none of the tagging experiments took place at the time and area above specified. The experiment of June 8–19, 1925, was performed at the right time but too far inshore to be included with the representatives of the northern contingent. It apparently included mainly that segment of the northern contingent destined to spend the following summer in the Gulf of Maine (p. 301).

Failing adequate tagging experiments to test that portion of the theory involving passage of the northern contingent through United States waters on their way to Canadian waters in the spring, the next most important portion of the theory to examine is that involving their passage through United States waters on the way south in the fall. For this purpose, the reports on the releases of 7,746 mackerel in Canadian waters should be instructive. Although full results of these marking experiments have not yet been published, a preliminary account appeared in the Proceedings of the North American Council on Fishery Investigations, 1921–30 (p. 26). Also, the Biological Board of Canada (predecessor to the Fisheries Research Board of Canada) kindly furnished records on the United States recaptures of the mackerel tagged in Canadian waters. These are listed in table 19.

According to theory, all mackerel found in Canadian waters are members of the northern contingent and should pass through United States waters in spring and fall when migrating from their supposed winter habitat to their summer habitat and back again. There are two minor exceptions to this: (1) A small portion of the northern contingent, according to theory, stays in the Gulf of Maine which it enters either around Cape Cod or across Georges Bank and past Cape Sable at the southern tip of Nova Scotia; (2) another small portion, according to theory, may spend the winter at the edge of the shelf off Nova Scotia and pass directly to the coast waters in the spring and back again in the fall, without passing through United States waters.

The first of these exceptions would need to be taken into account only if the tagging took place near the southern tip of Nova Scotia in the spring, in which case, part might go westward into the Gulf of Maine and be captured there in the summertime, and part pass northeastward along the coast of Nova Scotia and would not be recaptured in waters off United States until they return in fall. The second exception would hardly be expected to influence returns to a perceptible degree, for it would tend only to reduce moderately the percentage destined to pass through United States waters. Unfortunately, the first of these exceptions affects the majority of the Canadian-tagged mackerel, for 6,812 out of the 7,746 or 88 percent were released near Yarmouth in June, at just the proper time and place to provide a high liklihood of including a considerable number of that small part of the northern contingent which is expected to enter the Gulf of Maine, passing the vicinity of Yarmouth on the way.

Looking first at the returns from the Yarmouth taggings of May and June, among the fish recaptured in the United States fishery the same season they were released, one was taken in June, one in July and three in August, all from along the coast of Maine. Hence, it appears that the Yarmouth fish did include some of that minor portion of the northern contingent that was expected to circle back into the northern part of the Gulf of Maine. Nonetheless, the major portion of Yarmouth fish must have gone eastward, as would be expected of northern contingent fish, for among the Canadian returns "over two-thirds of the fish recaptured had migrated eastward during the same summer" (North American Council on Fishery Investigations, 1932, p. 26). The context of the report from which the quotation was taken indicates that this fraction was computed on the whole first-season returns, including the fall season, and hence the fall recaptures in waters off the United States (eight in number) must have served to lower the apparent proportion of eastward migrants. Although the number of first-season returns is not given, it may be deduced. To the westward, that is, in waters off the United States, 5 were recaptured in summer and 8 in the fall—or 13 altogether. This probably

TABLE 19.—*List of mackerel tagged in Canadian waters and recaptured in waters off the United States* [1] *arranged according to month of recapture*

Tag No.	Data on release		Length in centimeters	Data on recapture	
	Date	Locality		Date	Locality
Recaptured during same season as released:					
June:					
5596	June 16, 1927	Yarmouth,[2] Nova Scotia	43	June 24, 1927	6 miles east ½ south of Halfway Rock, near Portland, Maine.
July:					
1124	June 28, 1928	do	47	July 18, 1928	Halfway Rock, near Portland, Maine.
August:					
3435	June 21, 1926	do	43	Aug. 16, 1926	Wood Island, Maine.
2832	June 9, 1928	do	48	Aug. 21, 1928	Bantam Rock, near Boothbay Harbor, Maine.
551	June 26, 1928	do	48	Aug. 22, 1928	35 miles southeast of Monhegan Island, Maine.
September:					
2142	May 30, 1928	do	47	Sept. 5, 1928	Near Scituate, Mass.
1211	June 28, 1928	do	45	do	80 miles southeast of Highland Light, Cape Cod, Mass.
7885	June 16, 1927	do	44	Sept. 6, 1927	25 miles southeast of Chatham, Mass.
1588	June 29, 1928	do	45	Sept. 9, 1928	Near Scituate, Mass.
5941	June 18, 1927	do	42	Sept. 22, 1927	4 to 5 miles southeast of Thatcher Island, Mass.
162	June 20, 1928	do	46	Sept. 24, 1928	85 miles southeast of Highland Light, Cape Cod, Mass.
October:					
1063	June 28, 1928	do	44	Oct. 10, 1928	2 miles off Cape Ann, Mass.
1282	do	do	43	do	Do.
1031	do	do	43	do	8 miles east of Thatcher Island, Mass.
1055	do	do	46	do	Do.
5731	June 17, 1927	do	40	Oct. 17, 1927	10 miles southeast of Thatcher Island, Mass.
802	June 27, 1928	do	45	Oct. 21, 1928	5 miles southeast of Rockport Harbor, Mass.
6486	Sept. 3, 1927	Flint Island, Cape Breton Island.	43	Oct. 22, 1927	10 miles southeast of Thatcher Island, Mass.
November:					
3910	June 20, 1928	Yarmouth, Nova Scotia	51	Nov. 5, 1928	15 miles northwest of Race Point, Cape Cod, Mass.
3761	June 18, 1928	do	44	Nov. 13, 1928	10 miles southeast of Thatcher Island, Mass.
December:					
6687	June 30, 1927	Dover Bay,[3] Nova Scotia	42	Dec. 23, 1927	28 miles east of Eastern Point, Gloucester, Mass.
Recaptured during season following release:					
May:					
115	June 20, 1928	Yarmouth, Nova Scotia	42	May 20, 1929	60 miles south-southeast of Atlantic City, N. J.
June:					
6075	June 30, 1927	Dover Bay, Nova Scotia	45	June 4, 1928	Lavalette, N. J.
5526	June 16, 1927	Yarmouth, Nova Scotia	42	June 17, 1928	30 miles south-southeast of No Mans Land, Mass.
507	June 26, 1928	do	47	June 18, 1929	5 miles northeast of Race Point, Cape Cod, Mass.
252	June 25, 1928	do	45	June 26, 1929	60 miles southeast of Highland Light, Cape Cod, Mass.
5643	June 16, 1927	do	44	June 28, 1928	1 mile southeast of Block Island, R. I.
July:					
6450	June 30, 1927	Dover Bay, Nova Scotia	46	July 5, 1928	Menemsha Bight, Vineyard Sound, Mass.
6353	do	do	44	July 29, 1928	8 miles southeast of Chatham, Mass.
August:					
3006	Aug. 17, 1925	Magdalen Island	40	Aug. 4, 1926	25 miles east-southeast of Graves Light, Boston, Mass.
6677	June 30, 1927	Dover Bay, Nova Scotia	46	do	50 miles south-southeast of Highland Light, Cape Cod, Mass.
6926	do	do	42	Aug. 7, 1928	Off Block Island, R. I.
October.					
732	June 27, 1928	Yarmouth, Nova Scotia	42	Oct. 11, 1929	South Channel near northern edge of Georges Bank.
372	June 25, 1928	do	45	do	South Channel.
6909	June 30, 1927	Dover Bay, Nova Scotia	42	Oct. 31, 1928	Provincetown Harbor, Mass.

[1] Available through the courtesy of the Biological Board of Canada.
[2] At Cranberry Head.
[3] At White Point.

constituted all of the westward returns and hence should be one-third of the aggregate first-season recaptures which accordingly would be 39 in number. Our interpretation is that 5 migrated westward in spring, the remainder (34) eastward, from whence they did not return until fall. Of the total, then, about one-eighth turned west after release at Yarmouth in the spring; about seven-eighths, or by far the major portion of Yarmouth spring mackerel went on their way to more easterly and northerly waters. It was the fall return of this major portion from waters off Canada that must have caused the United States recaptures of Yarmouth-tagged mackerel to rise to six each in September and October, with an additional two in November and December. Had the mackerel of this tagging experiment remained in the Gulf of Maine all summer, there should not have been such a rise in tag returns during the autumn months.

Of Canadian taggings in places other than Yarmouth, there were only two experiments, one of 108 mackerel at Magdalen Islands, and another of 826 near Canso, Nova Scotia. The returns in the summer of the season of tagging, from both these experiments, were all from Canadian waters as would be expected from theory. Those released near Canso showed "migrations to Cape Breton Island and around it into the Gulf of St. Lawrence as far as the north shore of Prince Edward Island during the same summer" (North American Council on Fishery

Investigations, 1932, p. 26). There were two fall returns in United States waters, one in October, the other in December, and both from near Cape Ann, where, according to the size-composition study, the drift-gill-net fishery exploits the schools of northern contingent mackerel on their way south through the Gulf of Maine in the fall.

A return from Sable Island Bank in January of a mackerel that had been released near Cape Canso the preceding summer confirms the possibility entertained in our hypothesis, that some of the mackerel of the northern contingent may move directly offshore and spend the winter along the edge of the continental shelf as far eastward as the Sable Island Banks. Nonetheless a return from this ground is surprising, inasmuch as there is no winter fishery for mackerel there (or elsewhere) and the chances of a tagged fish being caught incidental to other fishing seem very poor.

Returns during the seasons following that of tagging should also be instructive. Fish tagged in Canadian waters should be recaptured in waters off the United States the second and subsequent years, mainly in the spring and fall, very few in the summer. The 14 second-season recaptures took place as follows: One in May, five in June, two in July, three in August, and three in October. Thus the spring (June) returns had the expected superiority in numbers, but the summer returns were higher, and the fall returns lower, than expected from evidence on migrations of the northern contingent gained from the size-composition studies. This might be taken as evidence that mackerel which are members of the northern contingent in 1 year may forsake that contingent in others but there is another explanation for these tagging results which appears preferable.

This alternative explanation involves consideration of the effect of the tagging on the mackerel itself. Several tagged fish of the second-year returns came into our hands for inspection, and the condition of others where only the tag was returned was ascertained by correspondence with the parties capturing the fish. In all instances in which pertinent information could be obtained, the caudal peduncle, around which the tag was carried, was chafed, sometimes rather severely, and about half of the fish were emaciated. Thus, at least a portion of the tagged fish must have been severely weakened by the second season and might have been expected to lag behind the more vigorous untagged population with which they were to migrate. Corresponding with this expectation, mackerel marked with tags Nos. 115, 6075, 6450, 6926 were taken from southerly localities well after the time the main populations of both southern contingents and northern contingents had passed by, and Nos. 6353, 3006, and 6926 were taken from localities well after the northern contingent had passed by, though the southern contingent had not done so. Thus it appears likely that such of the tagged fish of the northern contingent as "joined" the southern contingent a year following, did so by lagging behind their companions because they were weakened by the tags.

That this did not represent a general joining of the southern contingent by members of the northern contingent is suggested by the fact that only 7 of the 14 second-season recaptures in waters off the United States of Canadian-tagged mackerel need be classified as "laggards." The others were taken at times and places appropriate for the northern contingent to have been passing through waters off the United States. Presumably still others of the same tagging lots passed through these waters without being recaptured and reached Canadian waters where, if caught, they would constitute second-season Canadian recaptures of which I do not have the records. It is possible that the so-called laggards may constitute a relatively small proportion of the tagged groups and their lagging in any case may not represent an event commonly encountered in normal uninjured mackerel.

Summary of Tagging Evidence

Tagging experiments, though not designed properly for the purpose, and therefore inadequate in many respects, substantially corroborate the evidence obtained from the size composition as to (1) existence of the two contingents, northern and southern, (2) the migration of the southern contingent from the offing of Virginia to the Gulf of Maine but not farther, (3) their departure from the Gulf of Maine around Cape Cod in the fall, (4) the migration of a portion of the northern contingent from southern New England into the Gulf of Maine, (5) the migration of this contingent northwesterly from southern Nova Scotia into the Gulf of St. Lawrence, (6) their return through the Gulf of Maine in the fall, and (7) the repetition in part of this migration in the year following tagging. The weakest link in the tagging evidence is its failure to demonstrate the migration of one portion of the mixed population

directly to Canadian waters while the other part remains in United States waters. This is due to lack of tagging in offshore waters of southern New England at the time the two contingents mix. Tagging experiments designed to examine this point are to be desired. In performing such experiments the experimental information of suitability of different styles of tags (appendix B, p. 356) should be useful.

MIGRATION OF YOUNG MACKEREL

JUVENILE MACKEREL

During the first month or two after hatching, mackerel drift in the upper layers of the sea as more or less helpless members of the plankton community. Toward the end of July in American waters, they attain a length of 50 millimeters (2 inches), are active swimmers, and aggregate in schools (Sette 1943: 177–178). Young mackerel as small as 5 to 10 centimeters (2 to 4 inches) long were collected only in inshore locations. Small schools of such mackerel wander into pound nets along shore where the water is only several fathoms deep, and on a few occasions when it was possible to visit the pound nets before they were hauled, series of such mackerel were collected with a dip net. The main spawning grounds are well offshore, and earlier plankton catches of mackerel larvae have always been offshore, also. So these young mackerel taken alongshore in late July and early August must have migrated some tens of miles toward shore and probably some distance alongshore as well. Whether the entire population of young mackerel at these sizes is involved in such an inshore migration is not known. No fishing gear is operated for the purpose of catching these sizes either inshore or offshore, and the presence of vast numbers in either zone might easily remain undetected.

By September, these mackerel become large enough to be retained, along with other fishes, in the commercial pound nets when they are hauled. They are about 8 inches long, known as tacks and spikes, and considerable quantities are caught during the fall months of the year, mainly along the coast of southern New England and along the shores of the Gulf of Maine as far north as Casco Bay.

Although practically all of the catches are by shore gear such as pound nets, traps, and weirs, it is not necessarily true that the entire population has migrated to the shore line, because occasionally a few tack- or spike-sized mackerel are found hanging in the meshes by their teeth when gill nets are hauled in offshore waters. Also, late in fall, the spike-sized mackerel sometimes plug the meshes of offshore purse seines. They have been known to fill the meshes so extensively that the purse seine cannot be handled safely and instances of loss of such plugged seines have occurred. For this reason purse-seiners exercise extreme caution not to set the seine around schools of mackerel of this size. Thus, although offshore catch records are rare, it is quite possible that a large part of the population may remain offshore in addition to the ones known, from the pound-net catches, to have migrated inshore.

From studies of size composition of samples of juvenile mackerel taken by the pound nets alongshore it appears that there are local subpopulations in many localities. That is, the samples from a given locality tend to be uniform through successive weeks, except for progression to larger sizes with growth, and tend also to differ markedly from the size composition of samples taken simultaneously in other localities.

Although the predominant tendency is toward uniformity within a locality and differences between localities, there are exceptions, when the size compositions appears to differ erratically in successive samples at a given locality. Such irregularity is more common where points of land jut out into the ocean, as at Montauk and Provincetown, than in large coastal indentations as Buzzards Bay and Vineyard Sound. It is also more common toward late fall in all localities.

This evidence in its entirety suggests that the juvenile mackerel tend to aggregate into relatively stable subpopulational units which remain more or less intact during summer and fall. Some of the units remain fairly localized, others roam more widely. But the mixing between units, if any, is too slight to bring about homogeneity in size composition along the American coast.

With the approach of winter the movements of the various aggregates apparently become more pronounced and probably successions of them pass through a given locality in making their fall departure from coastal waters. The latter may be at least as late as November in some years, for samples of the juvenile mackerel have been taken up to the end of November. Whether any remain until still later would not be known from our sources of

information because the pound nets usually are dismantled at this time in anticipation of the hazards of winter storms.

It is not known whether or not there is a broad division of the juvenile mackerel into northern and southern contingents, such as exists among the adults. Samples of juveniles were not taken from Canadian waters during this investigation, and I have not found published records concerning them. Presumably, the considerable spawnings in the Gulf of St. Lawrence give rise to juveniles which should be found around the shores of the Gulf and even along the outer Nova Scotian coast in the late fall. These, conceivably, might pass through coastal United States waters on their way to their wintering grounds. I can see no clear-cut evidence of this among our samples. Possibly the greater irregularities of size composition in the late fall are partly due to the passage of Canadian-reared juveniles through United States waters, but from the existing evidence it seems more probable that these are but expressions of the movements of the previously more localized aggregates within United States waters.

YEARLING MACKEREL

In their second year of life mackerel range from about 25 centimeters (10 inches) long in early summer to about 32 centimeters (13 inches) long by fall and are usually termed "blinks" or "tinkers" by fishermen and by the fish trade. They are in commercial demand, though usually commanding a lower price than adult mackerel. Samples are available from both pound-net and purse-seine catches. They seem not to be caught regularly by drift-gill-netters, no doubt, because the meshes of the nets are too large to gill them.

Though occasional samples of tinker mackerel have been found among the spring catches by both purse seines and pound nets, important quantities were never taken by purse seines until July or August during the 10 years of this investigation. Pound nets have yielded samples of tinkers somewhat earlier, in May of some years, but more often in June. This is in contrast with adult mackerel which were often caught by purse seiners in large quantities in the first half of April and always in the last half.

Assuming that the absence of catches of tinker mackerel is evidence of their absence from the fishing area, it would seem that the tinker mackerel were about a month later than the adults in arriving along the shore waters where the pound nets are located and several months later on the offshore purse-seining grounds. The assumption perhaps is justified for pound nets but not necessarily true for purse seines because with the latter method of fishing, the aggregation into schools and the vertical distribution of the schools in the water would determine whether or not they could be caught and, furthermore, with adult and tinker mackerel schools equally available the purse-seiner probably would seek the former rather than the latter on account of the price differential. Taking the various elements of evidence into account and recognizing their respective limitations, one may conclude only that the tinker mackerel normally do not migrate in company with the adult mackerel in the spring migration, and though their routes may be similar the tinkers are substantially later in arriving. It is probable that during late spring and early summer some of them at least tend to be close to shore, for they "run" into pound nets. Whether some are also offshore is in doubt. If present in offshore waters, they either are too far below surface or they are in schools too small to be economically attractive to purse seiners. The latter appears to me more probable for I have seen tinker mackerel in and near the western end of Vineyard Sound which were distributed in countless small schools each containing several scores to several hundreds of individuals. The fishermen call such aggregates "pods" and never try to net them.

As summer progresses, the tinker mackerel obviously aggregate into larger schools, for in July of some years and in August of others the purse seiners begin to catch them in large quantities and usually continue to do so until the end of October. Their summer catches of tinker mackerel have a range along the coast line identical to that of the adults, but average substantially closer to shore. Massachusetts Bay, Ipswich Bay, and the waters along the eastern face of Cape Cod perhaps furnish the bulk of tinker mackerel catches by purse seiners.

Like the juveniles, the yearlings tend to remain somewhat localized, once they have reached their summer habitat. This is evidenced by the great predominance of local as compared with distant returns from a few tagging experiments (see appendix B) and also from the comparatively uniform size composition among successive samples from the same area coupled with the differences in size composition of samples taken simultaneously from

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different areas. However, the localization, as far as it may be detected from size composition, is not so severe as among the juveniles. In general, there are fairly consistent differences in size composition as between the areas north of Cape Cod and those east and south. Within these two broad regions, the differences are much less pronounced and much less consistent.

Minute examination of this subject through size composition is complicated by the fairly rapid growth of yearling mackerel which changes the size composition sufficiently in successive short periods of time to preclude statistical tests based on simple assumptions and a full report on this subject must await future study of the growth of yearlings.

In all of the years of this investigation, purse seining either stopped or had negligible success after the end of October. With the end of purse seining, samples of young mackerel also cease to be available. It may be presumed from this that the yearling mackerel depart from United States waters along with adults of the southern contingent. Whether or not they are replaced by yearlings from Canadian waters which would be comparable to the northern contingent as recognized among adults cannot be known from our data because the only fishery taking place in waters off the United States at an appropriately late period of the year is by drift-gill-nets, the meshes of which are too large to sample the range of yearling sizes.

In summary, it has not been established that there are northern and southern contingents among the young mackerel. The migrations of the latter parallel those of the southern contingent as it is known among adults. This would be interpreted to mean that there are two contingents among the young and that only the southern one came within the observational scope of this investigation, or, alternatively, it could be interpreted to mean that all of the young behave as a single population with a migration pattern like that of the southern contingent, and that it is only in later adulthood that mackerel segregate into two contingents.

To discover which alternative is correct would require investigations on young mackerel in Canadian waters parallel with similar investigations in United States waters. The problem, I believe, would be solvable both by the tagging method, employing the internal type tag, and by the study of size composition. Its solution would have vital bearing on the fundamental question of whether or not the northern and southern contingents, as recognized among adults, are genetically discrete population entities. The conclusions reached would be critical in determining administrative policy in the development and maintenance of this mackerel resource. This field is perhaps the most important and promising for further advancement of knowledge regarding the mackerel population.

MORPHOMETRIC EVIDENCE

During the course of investigations, and before the existence of the two contingents was suspected, a brief survey was made of the possibilities of detecting subpopulations by differences in form and meristic characters. Various body proportions and counts of spines, rays, and finlets were recorded for a number of samples from several localities.

It was soon evident that a number of difficulties would be involved in such studies. The anterior spines of the first dorsal become covered with the integument in large individuals, the last ray of the second dorsal and of the anal is sometimes partially divided, and the body proportions change with size of the individual. To detect slight differences in any count or measurement, it is necessary for some characters to make time-consuming examination and for others to discount the influence of size of individual by rigorous statistical methods. Since the greatest interest would be attached to differences between the mackerel from waters off Canada and those from off the United States, and since the ranges in sizes available from these two regions did not overlap extensively in the season of survey of this subject, the discounting of size influence by comparing identical sizes or by studying the regression of a character on length was not then feasible. There were indications that some of the characters examined might be significantly different, but conclusive evidence obviously would require large scale activity. Therefore, the brief survey was terminated pending the opportunity of embarking on a comprehensive project in this field.

With the information now available from the study of size composition and from tagging, it would be possible to intelligently concentrate a morphometric study on certain time-place groups of samples that would be critical either for tests of the conclusions reached by other methods or for supplementing the present information in certain important respects. By so concentrating the effort, this method could be employed much more efficiently than would have

been possible at the time of the initial survey of its feasibility. Even so, the more important questions to be examined would require extensive material extending through a number of seasons.

Thus, to investigate the nature of the two contingents one would need to examine samples of a year class as it passed through a number of years of life. By assembling morphometric data on parallel series of samples from Canadian and from United States waters through the juvenile and yearling years, and for the successive later years of life, adding a third series consisting of samples from the northern contingent taken as it passes through United States waters on its northward journey in the spring and on its southward journey in the fall, one might expect facts to emerge that would be significant to the elucidation of the nature of the two contingents, and the contributions of each to the mackerel yield of both the United States and Canadian fisheries.