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BIOLOGY OF THE ATLANTIC MACKEREL (*SCOMBER SCOMBRUS*) OF NORTH AMERICA

PART II—MIGRATIONS AND HABITS

By Oscar Elton Sette

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BIOLOGY OF THE ATLANTIC MACKEREL (*SCOMBER SCOMBRUS*) OF NORTH AMERICA

PART II: MIGRATIONS AND HABITS

By Oscar Elton Sette, *Aquatic Biologist*

The commercial catch of mackerel, *Scomber scombrus* Linnaeus 1758, along the Atlantic coast of North America has fluctuated widely (Sette and Needler 1934) owing to similarly wide changes either in abundance or in availability of the fish to fishermen. Since such fluctuations vitally affect both the fishery and the trade in its products, and also because they confuse the conservation problem, the United States Bureau of Fisheries (now a part of the Fish and Wildlife Service) in 1925 undertook an investigation of the causes of these fluctuations. The work involved not only studies of the fluctuations, but also of the many phases of life history and habits which had to be understood to interpret the observations of the changes in catch.

This report is one of several resulting from the mackerel investigations. In it there have been collected the facts that pertain to habits and migrations, particularly those that are pertinent to the understanding of changes in abundance or availability. The first number of this series of reports (Sette 1939) was on the early life history with special reference to mortality; others will be on age and rate of growth and on fluctuations in abundance.

In considering the subjects included in this paper it is necessary to draw on results which are to be reported later. This is particularly true with respect to the ages of certain size categories of mackerel. To a limited extent the data have appeared in preliminary reports (Sette 1931, 1932, 1933, and 1934) but for the most part the technical details are to be included in reports now in preparation and as yet unpublished.

ACCOUNT OF INVESTIGATIONS

The major conclusions of this report rest on the size composition of the mackerel population as determined from measurements of individual fish in thousands of samples drawn from the commercial catch at the principal ports of landing. The collection of data began in 1925 after part of that fishing season had elapsed. Much of the work in that year was preliminary in nature and not strictly comparable with subsequent observations. During the ensuing 10 years, 1926 to 1935, the program was carried out consistently so that data are comparable and the present report is confined to this period, except for the inclusion of certain data from tagging initiated in 1925.

The interviewing of fishermen for catch-date and locality and the sampling was done by Magnus I. Gregorsen in 1925, R. A. Nesbit in 1926, E. W. Bailey in 1927 and 1928, and by F. E. Firth in subsequent years. In many of the seasons R. A. Goffin contributed many samples from minor ports, principally Woods Hole, Mass., and also assisted in tagging experiments at that place.

Tagging of mackerel was recommended by the North American Council on Fishery Investigations and initiated under the supervision of Wm. C. Schroeder early in the 1925 mackerel fishing season, and after I undertook an investigation of the mackerel in all its phases during midseason of that year the tagging program was transferred to me. After completing the 1925 tagging season and upon comparing the size composition of the tagged fish with that of the samples taken from catches landed by mackerel vessels at Boston, it was obvious that the population from which the fish were drawn for tagging differed strikingly from the population upon which the vessel fishery was based.

This was not particularly surprising inasmuch as the tagging utilized fish from alongshore traps and pound nets whereas the vessel catch came mostly from offshore schools. Since the vessel catch was by far the major element in the mackerel fishery as a whole (Sette and Needler 1934: 14) and presumably consisted of fish that were representative of the main population whereas the trap and pound-net catch presumably represented an inshore fringe of the main population, it was considered unlikely that tagging returns would be representative of the migrations of the population as a whole, or even of a very important segment of the whole population.

It also became apparent by the end of the first season's tagging that the tags were injuring the fish, with unknown effects on their survival and their migratory pattern.

For these reasons the emphasis on tagging was shifted from large-scale releases to small-scale experimental work directed toward improvement of tags and exploring the possibilities of tagging fish from the offshore population. The details of these experiments, in which I was ably assisted by R. A. Goffin in getting and caring for the fish in captivity and by R. A. Nesbit in developing ideas for devising and testing various tags, are given in appendix B.

The Biological Board of Canada kindly furnished records of mackerel tagged in Canadian waters and recaptured off the United States coast.

In the meantime the major activity of the investigation, aimed at discovering the causes for fluctuations in the mackerel catch, including the interviewing of fishermen, the measuring of samples of their catch and the collecting of catch records suitable for abundance indices proceeded regularly. By 1935, partial analysis of these data appeared to afford insight into many phases of mackerel biology and it was decided to report upon the material accumulated up to the end of the 1935 season.

In studying this wealth of material I have had the able assistance of Mildred S. Moses in preparing tabulations and performing computations, the helpful counsel of Henry B. Bigelow, and the use of facilities at the Harvard Biological Laboratories.

In 1937 the study of this subject was interrupted by other duties and could not be resumed until 1947, with facilities at the Stanford University's School of Biology and with the counsel of Willis H. Rich, at whose suggestion and encouragement the investigation was originally started in 1925.

SYNOPSIS OF RESULTS

The mackerel is found in the western Atlantic from North Carolina to the Straits of Belle Isle and is sufficiently abundant for commercial fishing from the Chesapeake Capes on the south to the Magdalen Islands and the Gaspé Peninsula on the north. During the season of fishing it is most abundant in the open waters of the inner third or half of the continental shelf.

The mackerel appears in April near the southerly end of its range and by July is found from southern New England to the Gaspé coast. In September it begins to disappear from the most northerly regions and in December it vanishes from all places. During the summer season the smaller and younger sizes are usually found closer to the shore line than the adults.

When mackerel disappear in the fall they go southward and offshore to the zone of warm water which flanks the outer edge of the continental shelf and during wintertime occupy this relatively narrow strip of water running more or less parallel to shore, but some 20 to 100 miles distant from it, from Cape Hatteras northward surely to the southern edge of Georges Bank and possibly as far as Sable Island. While there they probably occupy middepths and so are seldom seen or caught. In this location their food supply probably is uncertain and may depend on local swarms of plankton whose occurrence is irregular.

The pronounced schooling habit of the mackerel is dependent on a special tropism involving vision, and hence schools may disband and reform according to diurnal variations in light. Luminescence probably is important in keeping schools together at night in the spring and fall. Schooling tends to be according to sizes, perhaps owing to a connection between size and swimming ability. This in turn is probably dependent on the ratio of volume to surface which of course increases with size of body.

During spring, summer, and fall, the mackerel stay in the warm surface layer of the ocean because they are prevented from descending below the thermocline by the comparatively low temperature of the underlying waters. Variation in availability to fishermen, depending as it does on sighting schools at the surface, is therefore probably dependent on the varying depth of the thermocline. Fishing is best moderately close to shore where in summer the thermocline lies only 15 to 20 meters (8 to 11 fathoms) deep, and, as a rule, poorer farther offshore where the thermocline may be as deep as 40 to 50 meters (22 to 27 fathoms).

Mackerel feed principally on plankton but the possibility that the larger individuals may in late summer subsist mainly on young fishes should be examined. Feeding is so much better in the summertime than in winter that the fat content of mackerel increases from a minimum in April to a maximum in August.

Two subdivisions are detectable in the western Atlantic mackerel population: A southern and a northern contingent which perform different spring migrations, occupy different areas in the summertime, and withdraw in the fall by different routes. The southern contingent comes from its offshore winter habitat toward the Virginia, Maryland, and New Jersey coasts in April, thence migrates northeastward to occupy the western part of the Gulf of Maine in summer. The northern contingent migrates toward the southern New England coast in May and thence goes northeastward to occupy the Gulf of St. Lawrence in summer. During the spring migration both contingents are joined by additional members of their kind which move from offshore directly toward the coast joining the main bodies as they pass along on their northeastward journey. For a short while in May both contingents are together in the area off southern New England, otherwise their courses are fairly independent. In the fall migration, both contingents approximately retrace their spring courses in returning to the winter habitat; but the northern contingent travels through more westerly waters in fall than in the spring, passing through the western part of the Gulf of Maine, and then disappearing off Cape Cod. The southern contingent, on the other hand, disappears, sometimes north of and sometimes west of Nantucket Shoals. The disappearance of both contingents north of the areas of their spring appearance may be due to their descent to deeper levels as the thermocline is lowered or obliterated by autumnal chilling.

DISTRIBUTION

RANGE

The mackerel is found on both sides of the Atlantic in the Northern Hemisphere, extending from the Mediterranean Sea to Norway in the eastern Atlantic and from North Carolina to Newfoundland in the western Atlantic. Since those of the eastern Atlantic are racially distinct from those on the western side (Garstang 1898), we need not consider them here.

The southernmost record on this side of the Atlantic is of two individuals taken in a pound net near Beaufort, N. C. The northern limit is the Strait of Belle Isle.[1] Reports of mackerel along the south and west coasts of Newfoundland are not uncommon, but occurrence seems not to be consistent enough to support a regular fishery for mackerel in Newfoundland. The region habitually occupied (in the fishing season) is from the Chesapeake Capes on the south to the Magdalen Islands and the Gaspé Peninsula in the Gulf of St. Lawrence on the north; in other words, between the thirty-seventh and forty-ninth parallels of north latitude.

Although the mackerel is distinctly an open-sea species, it is rarely found beyond the waters overlying the continental shelf; and while mackerel have been found at one time or another in the waters overlying the entire shelf, the greatest concentrations during the fishing season appear to be within its inner third or half. Often mackerel are found very close to the shore line, occasionally even inside of harbors and inner estuaries. Usually it is only the small sizes that are found in the semi-enclosed waters, the adults generally keeping to the open water, though they too enter some of the more or less open bays in the spring.

It is difficult, if not impossible, to determine whether the species is more abundant in the southern half of its range (that is, off the coast of the United States) than it is in the northern half of its range (that is, off the coast of Canada). Of the total annual catch along the North American coast in recent years, more than two-thirds have been taken off the coast of the United States and less than one-third off the coast of Canada; but this does not necessarily reflect the relative abundance, because the principal methods of fishing and also the intensity of fishing differ widely in the two countries. In the United States there is a fishery by pound nets and traps along shore, a minor offshore fishery using drift gill nets, and also a much more important offshore fishery using purse seines. In Canada fishing is confined almost entirely to pound nets, traps, and gill nets operated almost exclusively in inshore waters. It is likely that the international boundary, extended seaward, would divide the mackerel population into parts that are more nearly equal than total catch statistics indicate.

[1] Hearsay evidence cited by Goode, Collins, Earle, and Clark (1884: 3–4) of occurrence farther north along Labrador has yet to be confirmed by authentic records of capture.

SEASONAL CHANGES IN DISTRIBUTION

Along the Atlantic seaboard of North America the mackerel is a seasonal visitor, appearing in the spring, remaining during summer and autumn and then disappearing. Judging from the location of catches, mackerel appear first early in April about 30 to 40 miles offshore abreast of the coast line between Chesapeake and Delaware Capes. Soon they approach closer to the coast and during April and May they are found successively farther up coast until they reach southern New England. At this time or shortly afterward they also appear along the Nova Scotian coast. During the ensuing 2 to 4 weeks they disappear from the waters south of Cape Cod and spread throughout the western portions of the Gulf of Maine and the Maritime Provinces of Canada up to the Gaspé Peninsula, where they remain until sometime in September. During that month they begin to disappear from the most northerly region and withdrawal proceeds from north to south during October and November until finally in December they disappear from all coastal waters. These changes in distribution are charted, by months, in figure 2.

While the above description holds true for mackerel generally, there are differences that should be

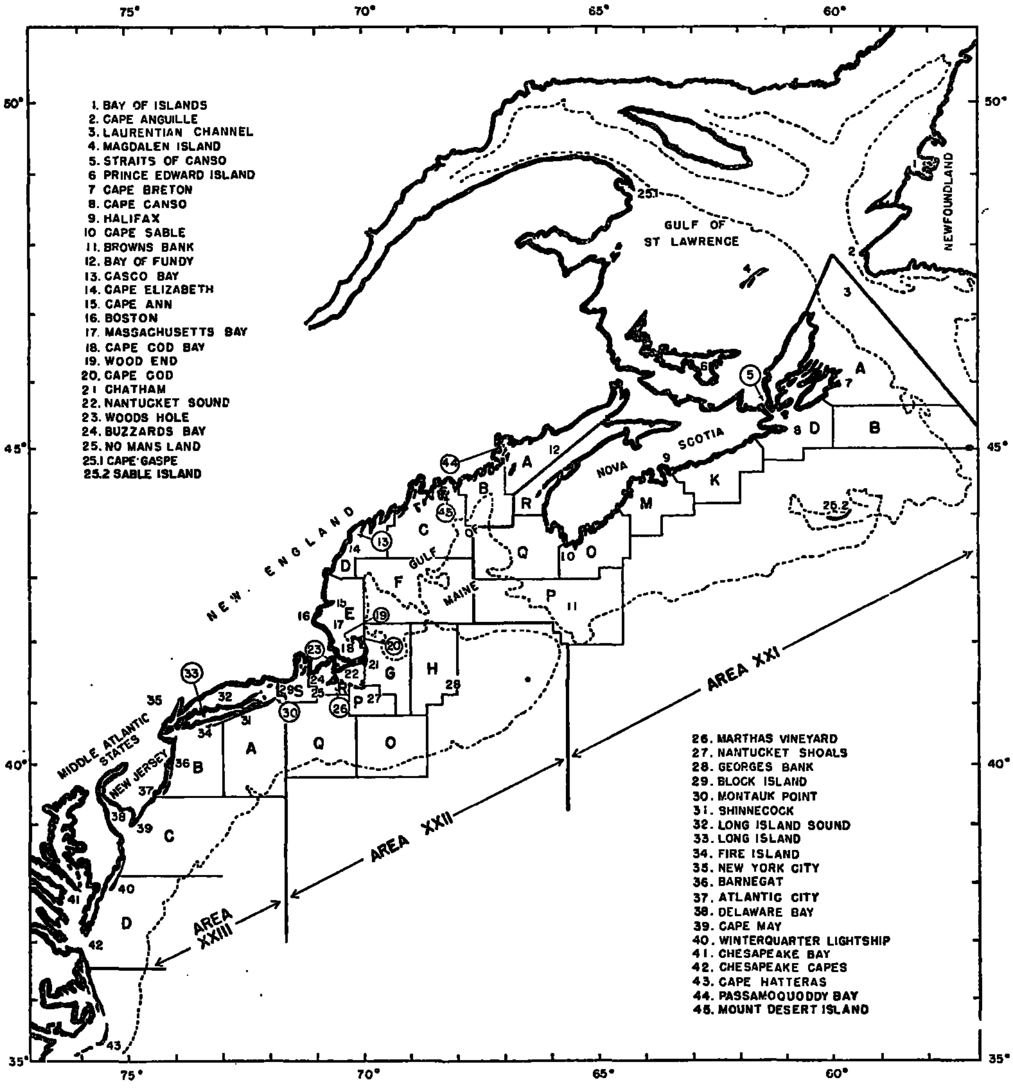

FIGURE 1.—Geographic features, landmarks, and delineation of statistical areas mentioned in this report. The statistical areas are those adopted by the North American Council on Fishery Investigations except for the lettered subareas of area XXVIII which were adopted for the purpose of this report, only, and have no official status. The broken line marks the 100-fathom contour.

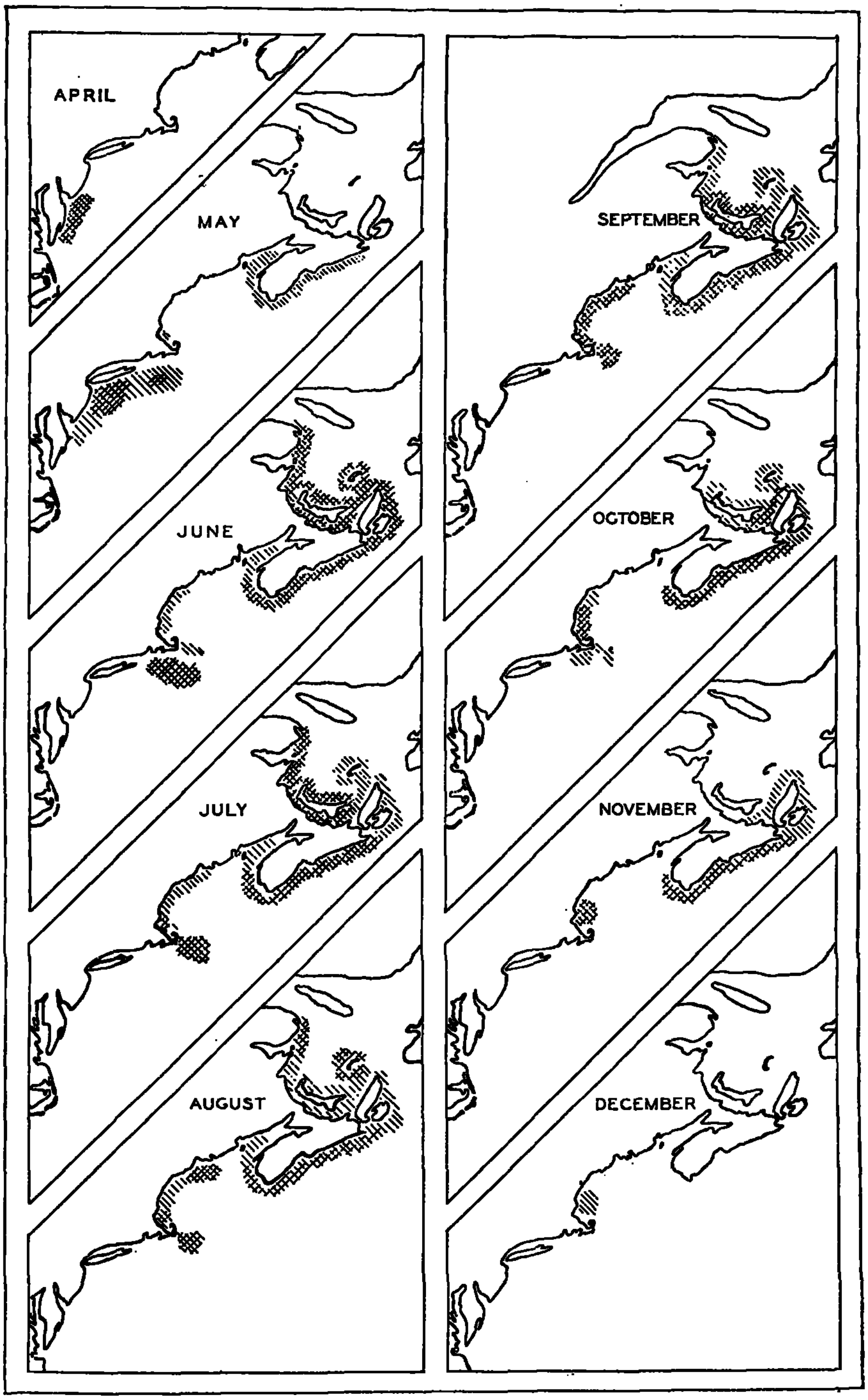

FIGURE 2.—Approximate seasonal distribution of the mackerel as indicated by location of the commercial fishery in the various months of the fishing season.

noted in the distribution of various size categories: (1) Juveniles, (2) yearlings, and (3) adults.

The juvenile sizes are fish from the current spawning season, hence less than a year old, and range from 2 inches up to about 8½ inches in length. Early in summer they are too small to be retained by the meshes of commercial nets, but toward late summer and fall, though not sought after, they are caught incidentally. To fishermen they are known as "tacks" and "spikes." Drift-gill-netters never take them in quantities, though we have an occasional sample of fish whose teeth caught in the twine of gill nets. Purse seiners usually avoid them because they plug the meshes of the seine, sometimes causing loss of gear. Some of the largest sizes of juveniles are, however, caught by purse seiners late in fall. Pound nets, traps, and weirs are the form of gear taking them most consistently. The schools of juveniles are deflected by the coarse-meshed leader of these forms of gear and turn offshore into the fine-meshed pound, where the smaller ones may be taken by dip net before they slip out through the meshes while the pound is hauled; the larger ones, of course, are retained through the hauling process and regularly form a part of the commercial catch. It is the catch by this form of gear that provides most of the information on distribution of juveniles. Due to the selective nature of fishermen's catches of those small sizes, the conclusions must be inferential.

Their distribution early in summer is probably determined largely by the location of the grounds on which they were spawned and on their subsequent drift from these grounds (Sette 1939: 83–191). In United States waters, they are found most consistently along the shore from Long Island to Cape Ann. The maximum concentrations appear along the southern shore of Massachusetts, though some have been occasionally taken along the coast of New Jersey and the coast of Maine. Doubtless, such as survive on the spawning grounds of the Gulf of St. Lawrence would be found along the shores of that Gulf, presumably mostly along its easterly portions, but published records of this are lacking.

Although the available records of occurrence are almost entirely from along the very shore line, this may be because there is no form of gear employed offshore which will catch the juveniles. Late fall catches of these sizes by purse seiners sometimes have been at a moderate distance from shore (up to 20 miles) and it is probable that large bodies of these small mackerel exist offshore as well as inshore.

In the inshore locations, the juvenile mackerel seem to stay all summer, into late fall and even early winter, catches of them having been made as late as December. From their distribution, there is little indication of any extensive migrations before their disappearance.

Yearling mackerel range from about 20 centimeters (8 inches) in the spring to about 35 centimeters (14 inches) in late fall. They are called "blinks" and "tinkers" by fishermen and in the trade. The term "blinks" is usually applied to the smaller ones, "tinkers" to the larger ones of this category.

During summer and fall, their distribution parallels that of the adults (p. 254) but their appearance in the spring is usually later than that of the adults. Occasionally schools are taken during the spring run of adults in both pound nets and purse seines (drift gill nets almost never take them at any season); but it is not until July and August that they are taken regularly in large numbers. From that time onward they are taken all along the coast from southern Massachusetts to Maine. Although samples of yearlings have been secured from Passamoquoddy Bay and from the vicinity of Halifax (Pennant, Nova Scotia), Dr. Cox found no "small" mackerel at the Magdalen Islands in 1925 (North American Council on Fishery Investigations, 1932, p. 27) and samples taken during this investigation from the catches of United States mackerel purse seiners fishing off the Nova Scotian coast have never contained yearling mackerel. It is likely that yearlings are much less abundant, as a rule, off Canada than off the United States. Like the juveniles and the adults, the yearlings disappear from coastal waters in late autumn and early winter.

The adult mackerel are known simply as mackerel by the fishermen, sometimes with the qualifying adjectives "medium" or "large." They are fish of 35 centimeters (14 inches) and upward and include all aged 2 years and older. They are the most desirable sizes and usually form the bulk of the catch. Their distribution corresponds with the general description at the beginning of this section.

WINTER HABITAT

LOCATION

Whence the mackerel come in the spring and whither they go in the autumn have been subjects of conjecture for many years. Bigelow and Welsh (1925: 197) surmised that they winter "on the upper part of the continental slope at a depth rather greater than the otter trawlers reach—say at 100 to 200 fathoms—but so close at hand that odd fish stray or remain on the banks." The present available data support this view as to the general winter location. It suggests, however, somewhat different conclusions as to the depths inhabited in the wintertime.

That the late autumn chilling of the water drives the mackerel from their customary summer haunts appears so obvious that most investigators have accepted this assumption as fact. It is true that the months during which the mackerel are absent are the coldest months of the year but there is no experimental evidence as to the minimum temperature that can be withstood by the species. As far as observational evidence is concerned, mackerel have been found in abundance in temperatures as low as 8° C. (fig. 14). They are often present in water of 7° C. in sufficient numbers to make commercial fishing profitable. Below this temperature they have been taken only as stragglers in American waters where there is record of one occurrence in water as cold as 4.5° C.[2] Thus it appears that the American mackerel prefers temperatures above 8° C., that it frequently tolerates temperatures down to 7° C., and that its toleration may extend to temperatures as low as 4.5° C.

This being true, the winter temperature in the northern portion of its range, that is in the Gulf of St. Lawrence and along the inner portions of the continental shelf of Nova Scotia where ice often forms in the wintertime, is certainly too low for this species. The inner parts of the Gulf of Maine with winter temperatures from 2° to 3° C. must also be too cold for mackerel. South of Cape Cod in cool winters when temperatures of 2° to 4° C. usually prevail over the inner half of the continental shelf, the mackerel should be normally absent; but there are instances such as the winter of 1932 (Bigelow 1933: 8–27) when water as warm as 7° C. persisted throughout the winter almost to the shore line and north nearly to New York. Obviously, temperature alone cannot explain the absence of mackerel from these waters during such exceptionally warm winters, and thus we may not assume their disappearance in the fall to be a simple direct response to temperature.

Yet it is reasonable to look for their winter habitat where temperatures approach those prevailing in their summer habitat. Waters with such temperatures flank the North American coast from 30 to 100 miles offshore, their inner border lying near the edge of the continental shelf where depths increase rapidly beyond the 100-fathom contour (fig. 3). It is not necessary to look farther than this, for mackerel have never been found south of Beaufort, N. C., or far enough beyond the continental shelf to indicate that they wander far out into truly oceanic waters.

The constancy in location and warmness of this flanking zone of water as a regular winter home for the mackerel is of particular significance. Although the temperatures of each profile in figure 3 pertain to only 1 year, it is highly probable that the warm zone has the same position year after year. This is certainly true along the continental edge between Cape Cod and Cape Hatteras. This region has been examined hydrographically in five different winters with very little variation except in the unusually warm winter of 1932. In that year nearly the entire continental shelf south of the middle of New Jersey was covered with water 7° C. or higher, but even then the temperatures at the edge of the shelf were very little different than in cold winters. Hydrographical surveys of the southern edge of Georges Bank in the winter have been less frequent, but examination of early spring conditions in 1929, 1930, and 1931 reveal no striking variations.[3] It may be assumed, therefore, that the mackerel can always find temperatures surely suited to its existence at one depth or another by moving offshore to about the continental edge along the southern part of Georges Bank or to the outer third of the continental shelf between Cape Cod and Cape Hatteras, and possibly suited to its existence along the edge of the Nova Scotian Banks. It remains to be seen what direct evidence there may be of the actual presence of mackerel in this warmer zone.

The occasional capture of mackerel incidental to the fishery for other species in the winter has been reported often in the literature. Goode, Collins,

[2] In European waters, large quantities have been taken by trawlers in northern parts of the North Sea, notably Great Fisher Bank, in the wintertime when 6° and 7° C. water prevails on those grounds, and in the English Channel where they are also trawled in the wintertime, the temperatures according to Bullen (1908: 284–285) are between 8° and 9° C. However, the European mackerel differs structurally from the American mackerel, sufficiently to be regarded as racially distinct, so it may be physiologically different as well. Hence, it is wise not to lay much stress on the evidence provided by the European representatives of the species.

[3] Unfortunately, there are no data on an extremely cold winter when it is possible that the warm zone may shift to a more offshore position. The disappearance of the tilefish in 1881 (Bigelow and Welsh 1925: 354) has been thought to have been caused by such a shift and if this supposition is correct, it must mean that the warm zone shifts far enough offshore so that it does not come into contact with the sea bottom at the continental edge. However, just as the tilefish disappearance may be taken as evidence of possible offshore shifting of the warm zone in severe winters, it also constitutes evidence that such shifts are extremely rare, for as far as is known this has happened only once during the past century. Even then it apparently had no effect upon the mackerel which may have been wintering on or near the tilefish grounds, for mackerel reappeared in normal numbers during the summer following the tilefish disappearance.

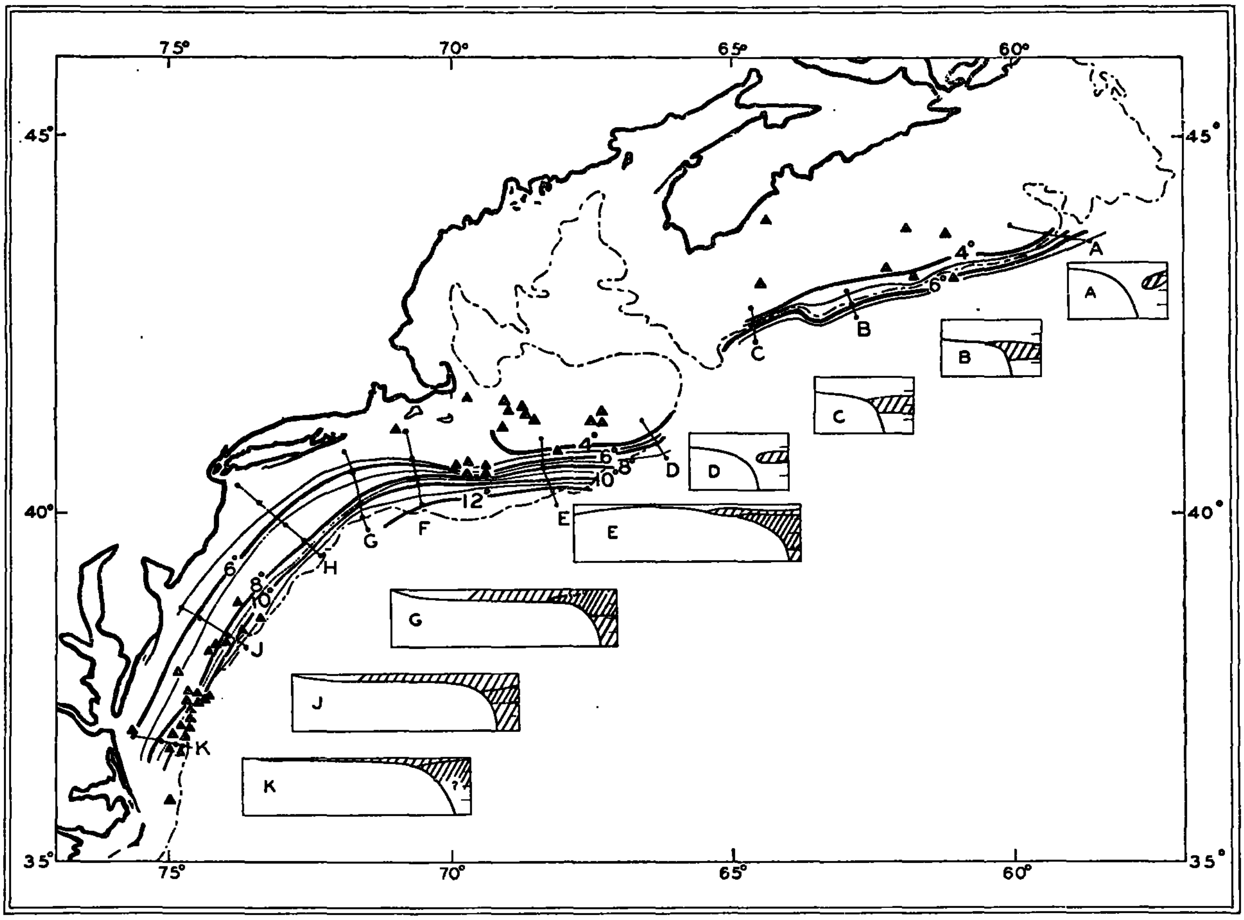

FIGURE 3.—Winter captures of mackerel (triangles) and winter temperatures. The isotherms mark the greatest inshore extension of water of designated temperature; insets A to D represent a width of 80 miles, E to K a width of 35 miles, and all represent depths of 400 meters (218 fathoms). Light shading designates temperature above 6° C. and heavy shading temperatures above 10° C. Sources of temperature data are: Section A, C. G. S. *Acadia* Stations V, 6–8–9–10, May 30, 1915 (Bjerkan 1919: 384). Sections B and C, *Atlantis* Stations 2510–11–12–15–16–17, March 6 and 15, 1936 (Bull. Hydrographique Cons. Perm. Internat. pour de l'Explor. de la Mer). Sections D and E, *Albatross II* Stations C20044–45–46–47–66–67–68–69, March 11–12 and 22–23, 1920 (U. S. Bureau of Fisheries Rept. 1921: 154, 160). Section F to K, *Albatross II* Stations 20618–19–20–21–22–23–24–25–26–28–29–30–31–32–34–35–36–37–40–41–42–43, Feb. 5–10, 1930 (Bigelow 1933: 113).

Earle, and Clark (1884: 98) list 7 or 8 taken in a gill net on Georges Bank on a January 3 or 4, a number taken by a schooner on Georges Bank, in March 1856, tinkers taken from the stomachs of cod, sometimes 5 or 6 from one fish, and used for bait on Georges Bank in February 1878; 30 caught on a trawl line set on Middle Bank in January 1868 or 1869, and "two fine fat fresh mackerel were found among the kelp at Green Cove on Friday, December 28, 1878," reported by the Yarmouth (Nova Scotia) Herald. Bigelow and Welsh (1925: 196) give additional instances of mackerel taken from cod stomachs on Georges and La Have Banks and off the coast of New Jersey in winter, also occasional catches by otter trawlers in the South Channel and on Georges Bank in February and March. Such records can now be augmented materially by instances that have accumulated during the course of the present investigations. These are listed in table 1, and their positions appear in figure 3.

TABLE 1.—*Winter records of mackerel*

Locality	Date	Depth (fathoms)	Quantity	Size	Remarks
In the offing of Nova Scotia:					
Western Bank, 50 to 100 miles west of Sable Island.	Jan. 9–16, 1931			12–15 centimeters	Lot of pollock containing a number of small mackerel.
Do	do		2	Large	
Do	do		Few	Small	
La Have Bank	Dec. 12, 1931		100 pounds		
Lat. 43°10′ N., long. 61°40′ W	Feb. 3, 1932	4–5	95 pounds	26.8–28.7 centimeters	
Lat. 43°50′ N., long. 61°50′ W Lat. 43° 45′ N., long. 61°10′ W	Feb. 15, 1932	32–60	100 pounds	Tinker	
Lat. 43°05′ N., long. 64°25′ W	do	50–60	75–100 pounds	Small	
Lat. 43°20′–30′ N., long. 62°5′–15′ W	do	50–70	60 pounds		
Lat. 43°55′ N., long. 64°25′ W	Feb. 1, 1934	70	5	15–20 centimeters	Found alive in stomachs of hake and pollock.
Emerald Bank	Jan. 8, 1935	30–42	1	1½ pounds	
North of Emerald Bank	Feb. 14, 1935	53–55	Many	13–15 centimeters	
Lat. 43°15′ N., long. 61°00′ W	Mar. 13, 1935	50–60	35	About 2½ pounds	
Browns Bank	Mar. 28, 1935	60	1	41 centimeters	
In the offing of New England:					
Georges Bank	Jan. 18, 1929		36	Small	
Lat. 41°11′ N., long. 69°00′ W	Feb. 9, 1929	50	1	48.5 centimeters	Debris and mucus in stomach.
Do	do	50	3	Tinker	In stomach of a pollock.
60 miles southeast Highland Light	Mar. 12, 1929	70	1	44 centimeters	Stomach empty.
Do	do	70	6	Tinker	
7 miles south of South Shoal Lightship	Dec. 23, 1929		100 pounds	1½ pounds	
Southeast part of Georges Bank	Jan. 21, 1930	42	1	32.5 centimeters	Very thin.
90 miles southeast Highland Light	do	38	1	31 centimeters	Very thin; stomach empty.
80 miles southeast Highland Light	Mar. 31, 1930	36	1	30 centimeters	Very slender; much sand on lls, gill rakers, and mouth.
Southeast part of Georges	Jan. 10, 1931	27	1	21 centimeters	
Southeast ½ east Highland Light	Jan. 16, 1931	28–30	12	17.5–21 centimeters	
78 miles southeast ½ south Highland Light	Jan. 21, 1931	60	1	44.2 centimeters	Weighed 2 pounds in round condition.
Lat. 40°50′ N., long. 68°00′ W	Jan. 22, 1931		19	12–20 centimeters	In pollock; cod and haddock also eating them.
Southwest Georges	Mar. 25, 1931		40	Tinker	
Do	do		1	19 centimeters	In stomach of a haddock.
Georges Bank	Dec. 21, 1931		65 pounds		
Do	Jan. 1, 1932		1	Large	
Off South Shoal Lightship	Jan. 7–14, 1932		200 or 300	Mixed	Fishing boats report catching a number of mackerel of mixed sizes. 1 steamer got as many as 200 or 300.
Lat. 40°40′ N., long. 69°50′ W	Jan. 5–13, 1932		1		
Lat. 40°40′ N., long. 69°20′ W	do		174	17–40 centimeters	Temperature 4.5° C.
Lat. 40°30′–40′ N., long. 69°20′ W	do		66		
Lat. 40°40′ N., long. 69°20′ W	do		12		11 were in stomach of 1 pollock; 1 in stomach of another.
Lat. 41°35′ N., long. 69°40′ W	Feb. 15, 1932	60–75	35 pounds	Small	
Lat. 41°20′–30′ N., long. 68°30′–50′ W	do	70	12	Large	
Lat. 41°10′–30′ N., long. 69°00′–10′ W	do	45–60 90	About 6 do	Tinker Large	
Georges Bank	do		About 50		
Do	Feb. 19, 1932			Large and tinker	A number of vessels caught mackerel both large and tinkers. A large school of large mackerel was sighted.
South Channel	Mar. 23, 1932		120 pounds		
Lat. 41°10′–20′ N., long. 67°10′–20° W	Dec. 3, 1932	26	1	31.6 centimeters	Temperature 10.5° C.
Lat. 41°10′–20′ N., long. 67°20′–30° W	do	27–31	18	17.1–20.3 centimeters	
Lat. 41°20′–30′ N., long. 67°10′–20′ W	Dec. 6, 1932	27	2	30.7 and 34.4 centimeters.	
Lat. 41°10′–20′ N., long. 67°10′–20′ W	Dec. 7, 1932	27	1	19.2 centimeters	
Nantucket Shoals	Dec. 12, 1932		290 pounds		
Do	Dec. 23, 1932		300 pounds		
20 miles southwest of No Man's Land	Dec. 5, 1934	29	50 pounds	All sizes	
Southeast part of Georges Bank	Jan. 9, 1935	35–45	4	Medium	
Lat. 40°41′ N., long. 69°40′ W	Dec. 3, 1935	27	51	14–24 centimeters	Temperature 7.3° C.
In the offing of the Middle Atlantic States:					
Lat. 38°13′ N., long. 73°49′ W	Mar. 2, 1931	52	9		In hake stomachs; 4 in 1, 3 in 1, and 2 in 1.
Do	do	52	1	Small	In hake stomach.
180 miles south of Cape May, 30 miles east of Bodie Island.	Mar. 10, 1931	30	1	25	
70 miles south ¼ west Winterquarter Lightship.	Mar. 17, 1931	57	1	10 centimeters	"Spike."
52 miles east by south Cape Charles	Feb. 2–3, 1932	43–59	6	Small	3 to pound.
45–50 miles east by south Chesapeake Lightship.	Feb. 13, 1932	42–46	3	Small	2 in hake stomachs.
65 miles east-northeast Chesapeake Lightship	Feb. 17, 1932	38–60	Several	Small	
45 miles east by south Chesapeake Lightship	Feb. 25, 1932	38–40	1	Small	
20 miles southeast Winterquarter Lightship	Apr. 7, 1932	35–40	18	25.5–42.5 centimeters	Thin and in poor flesh.
Lat. 36°50′–60′ N., long. 74°30′–40′ W	Jan. 4, 1933		1	44.5 centimeters	Very large and fat.
60 miles east by north ½ north, Chesapeake Lightship.	Jan. 12, 1933	45	1	30–35 centimeters	Large, in good condition, showed fatness.
40 miles east ½ south Chesapeake Lightship	Feb. 3, 1933	45	1	31.5 centimeters	Very thin. Crustacea and worms in stomach.
62 miles east-southeast Cape May	———, 1933	40	About 50	50 centimeters	Very large and fat. Stomachs crammed full of shrimplike crustacea 1 inch long.
50 miles east by south Chesapeake Lightship	Feb. 19, 1933	32	1	33 centimeters	Stomach partially filled with fragments of copepods, Euthemisto, and unidentified fragments.

TABLE 1.—*Winter records of mackerel*—Continued

Locality	Date	Depth (fathoms)	Quantity	Size	Remarks
In the offing of the Middle Atlantic States—Con.					
100 miles northeast by east Chesapeake Lightship.	Feb. 18, 1934	60	1	2 pounds	Thin.
58 miles east by north—east by north ½ north Chesapeake Lightship.	Mar. 3, 1934	51–60	3	37–45 centimeters	
45 miles east ½ north Chesapeake Lightship	Mar. 4, 1934	58	1	46 centimeters	
106 miles northeast by east Chesapeake Lightship.	Mar. 12, 1934	43–50	10 pounds		
70 miles east by north ½ north Chesapeake Lightship.	Mar. 23, 1934	60–65			Very thin.
63 miles east by north ½ north Chesapeake Lightship.	Mar. 28, 1934	55–63	7	29–39 centimeters	
65 miles east-southeast Five Fathom Lightship.	Feb. 8, 1935	58	20 pounds		
East-southeast Cape Henry	Feb. 14, 1935	90	2 tinkers, 1 large		
55 miles east by north Chesapeake Lightship	Mar. 2, 1935	55	11 pounds	29–44 centimeters	
100 miles southeast Cape May	Mar. 28, 1935		35 pounds	1–2 pounds	

The significance of these records must be weighed in relation to the distribution of fishing in the wintertime, for the lack of records from any particular area would be meaningless unless fishing took place in that area. Thus, the lack of winter catches along the southern edge of Georges Bank is due to the failure of fishermen to trawl there.[4] Similarly, the dearth of any winter records between the western portion of Georges Bank and the offing of Delaware Bay has no significance because no fishing takes place near the edge of the shelf in this sector during the wintertime. From about the offing of Delaware Bay to Cape Hatteras, on the contrary, numerous otter trawlers fish intensively during the entire winter along the continental edge and accordingly there are a number of instances in which mackerel were caught on these grounds. Thus, where fishing takes place in the warm zone in the wintertime, mackerel appear in the catch, and only portions of the warm zone that are not fished in the wintertime fail to contribute winter mackerel records.

There are, however, two features of this series of winter records that are contrary to the theory that the warm zone constitutes the winter habitat of mackerel. These are, first, the numerous specimens of mackerel taken on Georges Bank and along the coast of Nova Scotia considerably inshore of the warm zone and in water that presumably was much colder than is considered suitable for mackerel, and secondly, that even in the sector between the offing of Delaware Bay and Cape Hatteras where mackerel have been taken by otter trawlers, the numbers encountered are so very few that they cannot be taken as representing the main body of the mackerel population.

Since it is hardly likely that there are warm pools or lateral extensions of warm water along the bottom on Georges Bank (hydrographers have never encountered them), the records of mackerel well up on the bank must be accepted as evidence of their presence in rather cold water; indeed one of the catches was made in water that tested 4.5° C. at the time. Either our notions of the temperatures tolerated by mackerel are erroneous, or for brief periods of time small groups may stray away from the main population. That these records of stray mackerel exist is more likely owing to the thoroughness with which the waters there are dredged by the trawlers rather than to the occurrence of quantities of mackerel.

Winter catches of mackerel in the sector in the offing of the Middle Atlantic coast between Delaware Bay and Cape Hatteras nearly all fall within the warm zone at the continental edge as might be expected. Although their location agrees well with the theory set forth above, the number of records and the quantities of fish taken are far too low for a region supposed to harbor the main bodies of mackerel in the wintertime and where winter trawling is intensively practiced. This can hardly be attributed to deficiencies of the otter trawl as a means of catching mackerel for mackerel are regularly taken by trawl in the wintertime along the slope of the North Sea plateau toward the Norwegian Channel and in the English Channel. Hence it must be concluded that the American mackerel are not concentrated near bottom in the wintertime.

It is also apparent that mackerel are not at the surface in the wintertime as has often been remarked upon in the literature. Exceptional reports of the

[4] During the period 1931–33 the location of fishing during each trawler trip was ascertained in connection with the Bureau of Fisheries investigation of the haddock fishery. Among the thousands of fishing locations which were recorded only one fell within the area bounded by the 6° C. isotherm and the edge of the bank.

sighting of such schools as have appeared in the literature may be discounted (Bigelow and Welsh 1925: 196) on the basis that the reports are not authenticated by specimens from such schools, the inference being that some other scombroid or even clupeoid species was concerned. Furthermore, mackerel fishermen often have striven to extend the fishing season by searching for fish earlier in the spring and later in the fall than the regular season. During the 10 years of this investigation when the activities of the mackerel fleet were under close observation, seiners have scouted in early spring farther to the south and farther offshore than the area in which the first catches are customarily made. In the fall also, they have often persisted in looking for mackerel some weeks after the final catches were made; and although such searches extended farther offshore and farther southward than the ordinary range of the fishery, they have been in vain.[5] Then too, the trawlers that frequent the warm zone in the offing of the Chesapeake Capes each winter would surely recognize mackerel schools if they saw any, for these same fishermen, as a rule, engage in mackerel fishing in the summertime and would not only be quick to report any schools sighted in the wintertime but also would very likely outfit for seining and try to catch them, for the winter prices would make the fishery quite lucrative if considerable quantities could be caught. Hence it must be concluded that mackerel in disappearing in the fall, sink below the surface [6] and if they reappear at the surface subsequently, it is only for short periods of time and at infrequent intervals.

In summary, it may be concluded that the winter home of the mackerel is in the warm zone along the continental edge from Cape Hatteras to the middle of the southern edge of Georges Bank, for here the water is surely warm enough and enough stragglers have been taken to indicate that the main population is nearby. It may possibly extend even as far to the northeast as the offing of Sable Island, for 6° C. water extends that far and stragglers have often been taken on the Nova Scotian banks in the wintertime. Although present in this zone of warm water, they do not regularly appear at the surface nor do they stay close to the bottom. In all probability they are in middepths, perhaps above rather than below about 100 fathoms. Whether their schooling habits are preserved in the wintertime or whether the individuals are widely scattered, must remain a mystery probably until means of fishing the middepths have been devised.

[5] In December of 1932, for instance, schools of mackerel were reported from the easterly portions of Georges Bank and at least one seiner cruised to these grounds but failed to find the mackerel. Again in December 1933, the schooner *Old Glory*, Capt. Frank Foote, sailed to the southerly offshore grounds for mackerel and although a school was sighted 25 miles southeast of Fire Island Lightship, deficiency of the gear prevented a catch, and when the vessel reoutfitted and returned some days later, no mackerel schools were to be found.

[6] A bit of experimental evidence on this point is afforded by the action of mackerel held in a large outdoor pool at Woods Hole in 1932. These frequently were schooling at the surface during summer months but toward the end of September when the water cooled they stayed well below the surface and even when food was thrown on the water, appeared reluctant to rise to the surface as formerly was their habit. Unfortunately, the occurrence of a heavy rain flooding the harbor and making the water markedly turbid at this time leads to uncertainty as to whether turbidity, decrease in salinity, or lower temperatures caused the change in habit.

PROBABLE CONDITIONS OF EXISTENCE IN THE WINTERTIME

Whether or not food is of any consequence to the mackerel in wintertime is called into question by early theories of hibernation of the mackerel which include such fanciful suppositions as inspired the statement of a French Admiral whom Ehrenbaum (1914: 10) quotes as declaring that "his men had seen thousands of mackerel in the bays of the Greenland coast in the spring, the fish having buried their heads in the mud, and hibernating in that position, as a result of which they became blind, and were thus very easily caught." Needless to say, such evidence of the mackerel's food requirements in the wintertime need not be taken seriously, since mackerel are now known not to inhabit Greenland waters; but Ehrenbaum, whose extensive study of this species entitles his views to great respect was not convinced that the European mackerel may not be in at least semihibernation during the wintertime, for he stated (1914: 13):

> There is thus no longer any doubt that the mackerel at certain seasons of the year seek the bottom, and the lower water layers, and although they do not appear to spend the whole of this period in passive hibernation, but rather to be, at times, eager for food, it is nevertheless highly probable that they hibernate for a part of their stay at the bottom, viz, from November to January, when, according to the observations of Irish investigators, as also my own, the taking of food is as a rule suspended. During this time, the stomachs of mackerel taken with the trawl are found to be entirely empty, and not until February and March do we find a slowly increasing percentage of fish containing food.

Bigelow and Welsh (1925: 197), commenting on Ehrenbaum's view of mackerel hibernation, say:

> It is not likely, however, that the American mackerel do so, though they may be semitorpid or at least very sluggish during the cold season, the presence of mackerel in the stomachs of other fish as well as the fact that they sometimes have food in their own stomachs in midwinter, proving that they move about more or less even then, though they certainly feed very little, for not only

are most of the European fish trawled at that season empty, but European and American mackerel alike are thin when they reappear in the spring.

I agree with Bigelow and Welsh that there must be some feeding activity in the wintertime. If, as is supposed, mackerel at this season are at mid-depths, some activity would be required and some energy consumed in maintaining this position. That some of the needed energy is acquired currently by feeding is indicated by the food in the stomachs reported by Bigelow and Welsh, and observed by F. E. Firth during the present investigations. That they fare less well in winter than in summer and are forced to draw on stored energy, is proved by the low average fat content in early spring (p. 268). It also appears that not all portions of the population are equally successful (or unsuccessful) in obtaining food in the wintertime, for of the winter-caught specimens that came to the hands of F. E. Firth during the course of the present investigation, some were fat and some were lean. This suggests that food is not distributed uniformly, or that the concentrations of mackerel and of mackerel food do not always coincide.

What little is known about plankton (the principal food of mackerel) is consistent with the view that food is generally scarce in this area in the winter and that it may be spotty. In the Gulf of Maine, Bigelow (1928: 190–191) found *Calanus finmarchicus* (the dominant plankton species of the region and the most important food organism for mackerel) so scarce in February and March (1920) as to yield hauls of only 3,900 per square meter on the average. Whereas in May and June (1915) the average for all stations was 86,000 per square meter. Thus, in the Gulf of Maine, the winter populations of *Calanus finmarchicus* appeared to be less than one-twentieth as large as the summer population. On the continental shelf between Cape Cod and Chesapeake Bay, this copepod is also very scarce in the wintertime. Bigelow and Sears (1939: 306) found tow-net catches to be only one-eighteenth as large in February as in April 1930, and only one-twentieth-ninth, one-ninth, and one-tenth as large in February as in May of 1930, 1931, and 1932, respectively.

Not only is there a general scarcity of plankton in the wintertime, but the waters at the outer edge of the continental shelf where the mackerel are supposed to winter, have as little plankton as the waters farther inshore, and south of Cape Cod, even less. However, among all the plankton tows taken along the edge, both by Bigelow and by ourselves, there was one at the southern edge of Georges Bank that yielded 103,000 *Calanus* per square meter (Bigelow 1926: 190–191) which is an abundance comparable to spring or early summer in the Gulf of Maine. Bigelow regarded this as a local swarm. Towings along the continental shelf in the wintertime have neither been closely enough spaced to indicate how many such swarms exist at a given time nor have they been made at enough different times during winter to prove or disprove their existence as a characteristic winter phenomenon. Their occasional occurrence, suggested by the catch at the southern edge of Georges Bank, would not only enhance the suitability to mackerel of continental edge waters in the wintertime but would also account for the fatness of some winter-caught mackerel despite the leanness of most.

SCHOOLING HABITS

MECHANISM OF SCHOOLING

One of the most characteristic habits of the mackerel is its tendency to associate in dense schools. On the basis of observations and experiments principally on *Pneumatophorus grex*, a related species of similar schooling habit, Parr (1927) evolved the theory that the school is maintained by simple reactions which "may be regarded as automatically controlled by a special kind of tropism giving responses of approach and adjustment of direction to the stimulus of a perceived prospective companion." That perception is by visual means appears adequately proved by Parr's observations and experiments and has particular significance in connection with the formation and stability of schools.

As Parr pointed out, if the aggregation into schools depends on vision, it should take place during the daytime and the schools should be broken down during every sufficiently dark night. If this is true, the nightly reshuffling of individuals should tend to keep the population homogeneously mixed. At certain seasons, however, the break-down of schools obviously does not take place at night, for purse seiners locate and catch schooled mackerel at night both in the springtime and in autumn. At these seasons the schools are located by the luminescence which is associated with them. This occurrence of schools at night need not be contrary to Parr's theory, for obviously the luminescence may be as effective as daylight in permitting the visual perception necessary for schooling. However, there should be a tendency toward greater permanence of schools in spring and autumn, which might be reflected in greater divergence between schools in respect to certain characters such as size-composition. This has not been so obvious for me to have noted it, but admittedly the data have not been collected or analyzed in a way which would be adequate to demonstrate this point.[7]

ADVANTAGES OF THE SCHOOLING HABIT

In addition to his inquiry as to the method in which the schools are maintained, Parr (1927: 31) discussed the usefulness to the species of the schooling habit, pointing out that if individuals of a much preyed-upon species like sprat or herring traveled around separately, "scarcely a single one of them would escape the enemies sufficiently long to be able to propagate, while the occurrence of a great number of specimens united in schools among scattered enemies may give a certain percentage a chance to survive and continue the existence of the species." This, however, overlooks the fact that the enemies of schooling fish often are banded together and thus tend to overcome this advantage of their prey.

In view of this, it appears to me more reasonable to suppose that the advantage of schooling, if any, would lie in the increased ability to capture prey rather than to elude predators. This is suggested by observation on the feeding activity of mackerel held in confinement in an outdoor pool open to tidal circulation (p. 352). When food was offered to these mackerel in the form of ground squid or fish, i. e., in relatively large particles compared with plankton, the mackerel darted toward certain particles and secured them individually. When feeding thus the schooling habit was broken down and although the individuals congregated in the vicinity of food their actions were not coordinated. On the other hand, when not so—feeding, the mackerel collected in a definite school coursing around the pool in a fair degree of unison though even at such times their actions were less concerted than when feeding on plankton. Such feeding took place very close to the surface, usually in calm weather and often in the early morning or late evening. At least it was most easily observed at such times.

When feeding on plankton the mackerel assembled in a much more compact school than at other times. The school swam in a path describing a small circle or ellipse perhaps 8 or 10 feet in diameter and lying in an inclined plane, the upper limb of the ellipse touching the surface, the lower limb about 2 or 3 feet deep. On the descending segment the individuals swam vigorously, perhaps at twice the speed customary in coursing movements, obviously getting up speed. As they returned up the ascending segment of the ellipse, they opened their mouths to the fullest extent and extended their operculums widely, obviously to pass the maximum of water past the gill rakers. In this condition the school formed a group of miniature tow-nets spaced hardly more than their own diameter apart. If it be supposed that copepods (the principal element in their diet) are capable of darting 1 or several centimeters at a time through the water, as observation indicates they do, they might elude one such miniature tow-net; but with a group of miniature tow-nets as closely spaced as these, the success of a copepod in eluding one of them would frequently only put it in the path of another. Thus mackerel, acting in concert probably would average more copepods each than if they acted individually.

This theory supposes that the copepods and other planktonic food organisms are capable of detecting a mackerel at a small distance, and it needs support from critical experiments or observations indicating the sensory ability of a copepod in such a situation. If they do not possess this faculty the individual mackerel would be at no disadvantage as compared with a school in catching copepods.

Despite the lack of proof that schooling is an advantage in plankton feeding, there is strong indication that schooling is related to this method of feeding in the fact that schooling is so prevalent among species whose principal food is plankton. Furthermore, those schooling fishes (bluefish, tuna, bonito) which do not subsist primarily on plankton, feed instead mainly upon schooling fish, crustacea or cephalopods (menhaden, herring, sardines, euphausids, squid). Here the relation of predator to prey is essentially similar, i. e., a menhaden eluding one bluefish would be in the path of another, if the bluefish were in schools.

[7] To do this would require that each sample be sufficiently large to describe the size (or age) composition of a school. With limited resources it seemed better to take small samples from each of many catches (schools) rather than larger samples from fewer catches (schools). However, even these small samples might yield information if studied by statistical methods developed for quality control (Shewhart 1931).

SCHOOLING ACCORDING TO SIZE

A further feature of schooling, significant to the study of age composition, is the tendency of individuals of the same size to school together. Fish of the year, as far as we know, always school separately from the rest. Yearlings usually do, but, judging from samples, may sometimes join schools of adults, especially when the latter are predominately in their third year. The adults—third-year fish and upwards—seem not to separate themselves according to age or size in any sharply defined manner. Nevertheless there is often enough difference in the size distribution among samples from different catches to suggest some tendency of mackerel in a given size range to band together in schools distinct from those of another but overlapping range.

A physical explanation of the tendency for mackerel of different sizes to form separate schools is suggested by the activities of fish whose swimming was timed as they circled around the live car in which they were enclosed. Among several dozen mackerel thus observed together, there were two yearlings, while the remainder were of juvenile size. The juvenile mackerel schooled together traveling in circuits around the enclosure at the rate of 10 feet per second and keeping in the middle or upper levels. The two yearling mackerel traveled in company with each other around the enclosure at the rate of 19 feet per second, i. e., distinctly faster than the small ones, always keeping below the small ones, sometimes circling in the same direction, sometimes in the opposite.

There is a simple explanation for this difference in speed if the work performed by the mackerel is proportional to its weight and if it serves mainly to overcome friction between water and the surface of the fish.[8] Then large fish should move faster through the water because the weight of musculature increases as a cube of length and the area of the surface only as the square. So, with less surface friction to overcome per gram of muscle in large fish than in small the "cruising" speed of the former should exceed the latter for a given output of energy per unit weight of muscle.

[8] The work done in displacing water as the mackerel moves should increase in proportion with the weight, if stream-lining is equally efficient in all sizes. But since musculature is also proportional to the weight, the expenditure of the same amount of energy per unit weight at a given speed should accomplish the displacement of water for small as well as large fishes. Therefore, the work of displacing water should not differentially affect the speed of small as compare with large fishes.

Moreover, there probably are lower and upper limits on swimming speed imposed by the inherent capacity of the mackerel's physiological processes and these are reinforced or perhaps even narrowed by special features of the physiological and physical systems involved in the mackerel's swimming.

For instance, a lower limit on swimming speed is imposed by the mackerel's respiratory requirements. F. G. Hall (1930) found that the mackerel depends on swimming to produce sufficient flow of water past its gills for its respiration. This no doubt accounts for the generally observed facts (1) that mackerel are always swimming and never at rest and (2) that when the scope of swimming movements is restricted by putting them into small aquaria they soon die. Thus there must be a certain limit below which the swimming may not fall without disequilibrium between respiration and metabolic requirements. Although the existence of such a lower limit was established by Hall's experimental demonstration that respiration of the mackerel depended on swimming, he neither located this limit nor determined whether or not it varied as a function of size.

An upper limit would be imposed by the amount of energy the mackerel may expend in swimming without causing disequilibrium in its metabolic system. If resistance to passage of a mackerel through the water depends not only on its surface-volume ratio but also is a function of speed such that the resistance increases more than proportionally with speed, then the upper limit would tend to be sharpened. An inordinate amount of energy would be required to swim even moderately faster than that point at which the energy expended on swimming is currently replenished and exhaustion would quickly ensue.

Obviously the swimming rate is dependent on a number of physical and physiological interactions and my single set of observations on the swimming rates of the two sizes of mackerel is hardly sufficient to prove that the rate is dependent primarily on size. Indeed the considerable range in sizes of individual fish found in a single school argues against it.

With speed directly dependent on size one might expect the sorting, by sizes, to be fairly precise, for each size of fish would have a particular speed differing from that of other sizes, and only fish of one size could stay together. Actually, rather diverse sizes are found in the same school. This can occur if the smaller fish put forth relatively more exertion than the larger ones. This probably takes place within a moderate size range. The size composition in a school perhaps is in a state of dynamic equilibrium where the tropistic tendency for aggregation causing uniform speed is opposed to the physical tendency toward different swimming speeds. Within certain size ranges the former tends to keep the individuals together, while the latter tends to separate them. This would produce the effect observed: that mackerel school together according to size but that schools contain individuals of enough diversity in sizes to provide extensive overlapping in the size range.

VERTICAL DISTRIBUTION

The American mackerel is generally regarded as a surface fish because practically all of the catch is taken at or near the sea surface. But at times some of them are on bottom for they are occasionally taken by trawlers in autumn and winter, and it cannot be assumed *a priori* that they may not also inhabit intermediate depths. It has already been indicated (p. 261) that in winter most of the mackerel probably inhabit mid-depths. What their lowermost limit is in summer must be determined by indirect means, for gear that is effective in mid-depths has yet to be developed.

Bigelow and Welsh (1925: 195) were of the opinion that "there is no reason to suppose that they ever descend more than a few fathoms during their [summer] stay, the supply of small crustaceans on which they feed being invariably richer above than below 50 fathoms depth in the Gulf of Maine." The vertical gradient of temperature in the summertime, in my opinion, affords additional reason to suppose that they stay in the upper levels and that the temperature influence would tend to keep them even nearer the surface than 50 fathoms, which, after all, is a considerable depth from the standpoint of fishermen using surface gear such as the purse seine.

Temperatures in the western part of the Gulf of Maine during July 1932 (fig. 4) prove the existence of a very pronounced thermocline in the region where mackerel were being caught at the time. At a typical station (A) the temperature was 16° C. (60° F.) at the surface and at 10 meters, but fell to 8° C. (46° F.) at 20 meters, and to 6° C. (42° F.) at 30 meters. Although other stations varied from this in detail, all had temperatures above 13° C. (55° F.) at the surface and all had temperatures below 7° C. (45° F.) at the 30-meter level. At most of them the temperature gradient crossed the 7° C. line near the 20-meter level.

While mackerel have been found in temperatures as low as 4° or 5° C., it is not likely that they would voluntarily enter or stay in water of temperatures lower than 7° or 8° C., for they are rarely found in surface waters as cold as this and only in the wintertime have they been found at any level in lower temperatures. Hence it is likely that the thermocline in the summertime forms a barrier or floor, constituting a lower limit of depth-range.

This floor may move up and down during the season; and its depth varies from place to place. It is formed by the warming of surface layers in the spring and summer and destroyed by their chilling in autumn. During the season when it is in existence, stormy periods lower it and calm warm periods raise it. It tends to be higher in inshore areas and lower in offshore areas; but vertical turbulence, which may attend currents or be induced by storms, modifies this rule. Judging from such few of the temperatures given by Bigelow (1926: 978–997) as are pertinent,[9] the 20-meter level shown in figure 4 is fairly typical for the western part of the Gulf of Maine in early summer. Later in the season and farther offshore the thermocline tends to be deeper, perhaps with 40 or 50 meters as the lower limit. The probability that the mackerel are located at levels too deep to show at the surface in offshore waters where the thermocline lies deeper may explain the dearth of catches (p. 297) from over the central deeps of the Gulf of Maine. However, it is also possible that they seldom occur at any depth in that area.

In summary, it appears that the vertical range of the mackerel is limited by temperature. During the height of the fishing season and throughout the major portion of the fishing area, they must be kept within 15 to 20 meters (8 to 11 fathoms) of the surface. At certain times and places they are free to descend to greater depths, but probably not much below 40 or 50 meters (22 to 27 fathoms) and usually not that deep.

From the standpoint of studying fluctuations in abundance and age composition, the additional question arises: Does their vertical distribution render all of the mackerel accessible to fishermen at all times during the summer, or only part of them

[9] Unfortunately, most of the serial temperatures did not include observations between the surface and 40–50 meters, hence, do not fix the position of the thermocline except to indicate that it was above rather than below 50 meters

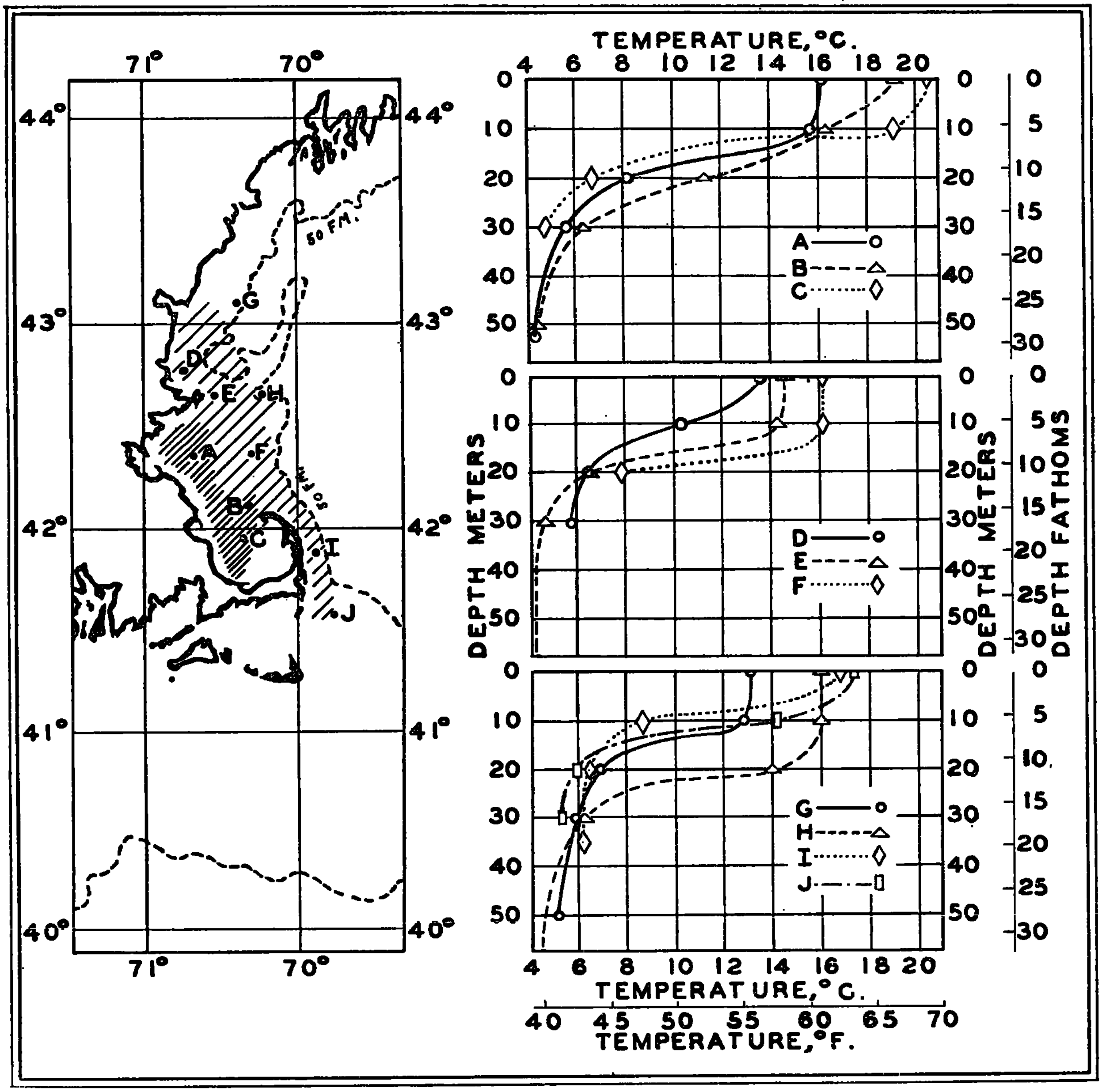

FIGURE 4.—Temperature gradients (vertical) in mackerel fishing waters. At the left are shown the areas where many catches were made (heavy shading), the areas where few were made (lighter shading), and the places where the temperatures were taken (lettered dots). On the right are the temperature gradient curves for each of the lettered positions. The catch data refer to the period, July 16–31, 1932, and the temperatures were taken July 22 and 23, 1932.

part of the time? Purse seines of ordinary size reach down to 20 fathoms, but their effectiveness depends not only on how deep they reach but also on how deep the schools can be seen and thus located before the seine is set.

In the daytime the schools are betrayed by a rippling of the water if they are at the surface, or by dark, shadowy, and sometimes reddish patches in the water if they are somewhat below the surface. How deep they may be detected depends on the height of the observer above the water, the quality of illumination, the roughness of the sea surface, the turbidity of the water, the keenness of vision and the alertness of the observer. Thus the depth at which they can be located is highly variable and not readily ascertained. It is reasonable to believe that it seldom exceeds 10 fathoms and is usually less than that in the daytime.

On moonless nights, when the schools are visible as a luminescent patch in the water, it is probable that they can be seen at greater depths, because there is no interference from surface reflection. One instance illustrating the depth to which such luminescence is visible was reported by F. E. Firth in a letter written April 16, 1935, as follows: "Several, about 7, vessels went out Friday noon and returned Saturday P. M. without success." Captain Firth stated, "Saw a school firing deep in the water, made a set, pursed seine, got nothing, and the fish were still visible under the seine." He said, "the fish must have been down 25 fathoms, for his seine reaches down 22 fathoms. Water firing exceptionally well." This was, undoubtedly, an instance of remarkably good visibility. There is considerable variation in how well "the water fires"—to use fishermen's parlance—hence it cannot be expected that schools would always be seen at such great depths. It seems reasonable, however, to suppose that they can usually be seen down to a depth of 10 fathoms during night fishing.

Taking these considerations together, it is probable that the fishery is effective throughout the vertical range of the species only when favorable visibility coincides with a shoal thermocline. At other times, which must be frequent, a substantial portion of the mackerel population is inaccessible to the fishery on account of poor visibility, or because the fish are too deep, or combinations of these two impediments to the sighting of schools.

Although it is not possible to express the effect of vertical distribution quantitatively, it is obvious that the variations in the success of fishing may be modified considerably by the shifting up and down of the thermocline. When it is close to the surface, say within 10 fathoms, fishing should be good because nearly all of the population should be within vertical range of the fishing method. Unfortunately, serial temperature records are inadequate for determining the correlation between position of the thermocline and success of the fishery, but perhaps it is significant that fishing is less uniformly successful in spring and fall (when the thermocline is less well-defined) than in summer, and that even when fishermen sight mackerel in offshore waters where the thermocline is deeper it is only rarely that good catches are made there regularly over extended periods of time. The bathythermograph, developed after the close of this investigation, offers a new instrument for examining vertical temperature gradients speedily and in detail. Its application to this problem might demonstrate relationships that would be of high practical value in actual fishing operations as well as serviceable in biological research on population abundance and related subjects.

According to direct observations on mackerel in captivity during the present investigation and judging from fishermen's reports, the larger mackerel tend to swim deeper than the smaller ones. This is particularly true in mid and late summer. At such times fishermen often report that the schools of large individuals are deep and "hard to stop," meaning difficult to encompass with the seine. Accordingly, there may be a tendency toward catching a larger proportion of small mackerel than of large ones whenever and wherever the thermocline is relatively deep. This probably is the explanation of the "disappearance" of the large mackerel in the late summer of many seasons (p. 268). For these reasons it is probable that the fishermen's catch in the aggregate undersamples the larger mackerel and oversamples the smaller ones within the range of commercially desirable sizes.

This is one aspect of mackerel behavior among many others which may be grouped together under the heading of "availability." By this is meant all of the various elements in the behavior of the fish and of the fishermen which cause the catch to be out of proportion to the stock of fish. With pelagic fishes such as the mackerel, where the vertical as well as the horizontal extent of distribution affects the quantity caught, there is opportunity for availability to have a much more pronounced effect on the quantity caught than with nonpelagic fishes; and there is evidence that effects of availability extend also to the size categories caught.

It has become standard procedure in studying marine fish populations to use the commercial catch per unit of fishing effort as an estimate of abundance and the size composition or age composition of the commercial catch as an approximation of the size or age composition of the stock. This has worked well, notably with demersal fishes. With pelagic fishes the element of availability is so strong that it is safer to assume that the catch per unit of effort only indicates apparent abundance—not abundance itself, also that the distribution of sizes or ages in the catch registers something other than the size or age distribution of the general stock in the sea. When these more limited assumptions are adopted, most of the established techniques for studying the dynamics of recruitment, natural mortality, and catch mortality of fish populations are no longer applicable. If they are applied, nonetheless, they are likely to lead to anomalous results.

In view of this, it appears likely that progress in understanding the dynamics of the mackerel population will be impeded until more is learned about the reactions of the mackerel to its environment and the quantitative effects these have on commercial catches as samples of the abundance and size composition of the mackerel stock. The discussions of this and the preceding sections are intended to point out some of the features which appear significant and some of the lines of study which might prove fruitful of results.

FOOD

According to Bigelow and Welsh (1925: 201), the American mackerel feeds chiefly on plankton, of which copepods form the dominant part, and among the copepods *Calanus finmarchicus* is by far the most important. In Europe the same is true in spring and early summer but in late summer and autumn the mackerel there turns its attention more to small fishes of various species.

Present observations, admittedly limited in extent, agree with those of Bigelow and Welsh. It is suggested, however, that the difference between the feeding habits of the mackerel in American waters and those in European waters in late summer may be more apparent than real, for we have found that the larger ones usually are not caught in quantity in late summer in American waters, and it may be that their search for larger food animals like euphausids and young fish leads them away from surface inshore waters at this time. Examination of stomach contents of such large mackerel as are occasionally caught offshore and in deeper water in late summer should be instructive on this point.

Whatever mackerel eat they are more successful in obtaining food after they have reached coastal waters in the spring than during their winter stay along the edge of the continental shelf. In April when mackerel first appear on the fishing grounds their fat content is very low and it increases markedly during ensuing months, according to analysis of the oil content of the flesh by Stansby and Lemon (1941: 10–11). Their values, supplemented by additional information communicated to me by Dr. Stansby, are summarized in table 2 While the data leave no doubt as to substantial fattening during the spring and early summer months, with the oil in the flesh increasing from about 4 percent in April to nearly 20 percent in August, the course of events during the remainder of the season is not clear. The values seem to fluctuate from sample to sample through a range from 6 to 19 percent. This, together with the wide variation between individuals within samples indicated by the minimum and maximum values, suggests that there is considerable difference in the success of individuals and groups of individuals either in feeding sufficiently or upon sufficiently nutritious food to provide an excess, over metabolic requirements, for fat storage. With some of the high oil content values attained as early as August, it also appears that feeding, on the whole, is usually better prior to August than after. However, the wide variation precludes any conclusion as to whether there is an average gain or loss of fat through the late summer and autumn months.

TABLE 2.—*Oil content of mackerel*

Date fish were caught	Number of fish analyzed	Oil content, percentage		
		Maximum	Minimum	Average
Apr. 18, 1935	13			3.9
Apr. 22, 1935	8	7.6	2.7	4.8
May 3, 1935	4			8.0
May 21, 1935	4			9.0
June 1, 1935	6			9.8
June 5, 1934				[1] 6.8
July 23, 1934	13	17.3	6.1	10.6
Aug. 13, 1934	7	25.6	10.6	17.5
Aug. 15, 1934	7	21.6	16.0	19.2
Sept. 11, 1934	20	11.4	2.0	6.5
Oct. 1, 1934	25	16.2	3.0	10.1
Oct. 20, 1934				[1] 15.7
Nov. 17, 1933	12	15.2	2.2	8.2
Nov. 17, 1934				[1] 19.5

[1] This value was derived from Stansby and Lemon's (1941) table 4, by taking the simple average of the percentage of oil content in the 31½- to 36½-inch, 36½- to 38-inch, and 39- to 42-inch size categories. The number of fish in the sample was not given.

MIGRATION OF ADULT MACKEREL

That mackerel migrate seasonally is generally accepted, but concerning the direction and extent of their travels there are two schools of thought—one that they migrate great distances from north to south when they leave the coast in the fall and back again in the spring; the other, that they sink and move directly out to deeper water in the fall and merely rise and move inshore in the spring. The controversy between the schools was lively in the latter part of the nineteenth century in connection with the dispute between the United States and

Canadian Governments concerning the right of United States fishermen to participate in the mackerel fisheries in Canadian waters (Goode, Geo. B., et al., 1884: 95). With both sides basing their argument on fragmentary data largely from testimony of unscientific observers, the question was in the realm of conjecture and remained there at least until 1908 (Kendall 1910: 293). Latterly, with more facts at hand, with respect to European as well as American mackerel, there was a decided leaning toward the school favoring the on-and-off-shore as against the north-and-south migration (Bigelow and Welsh 1925: 191).

With the more extensive, systematic, and detailed information available from the present studies, it now appears that neither school was wholly wrong or wholly right, for a critical comparison of all evidence points definitely toward the existence of a complex combination of the two (or three, if we include the vertical) sorts of movement. The general course of the migrations is diagrammatically charted in figures 5 and 6. Proof of the essential correctness of the routes shown requires consideration of their winter habitat, the existence of two migrating populations, a northern and a southern contingent, and various other relations which will be taken up in detail. But for the convenience of those who may not be interested in proofs and details, a summary of the migration will be given here.

SUMMARY DESCRIPTION OF MIGRATION

Although both the northern and the southern contingents are supposed to spend the winter in the zone of warm water, some thirty to one hundred miles out to sea along the continental edge from Virginia to Nova Scotia, it is probable that the members of the southern contingent tend to be at the southerly end of this zone, and those of the northerly contingent at the northerly end.

The southern contingent first appears in the surface waters overlying the continental shelf somewhere between Cape Hatteras and the offing of Delaware Bay, and usually in the early days of April. Though at first some thirty to fifty miles offshore, they soon come closer inshore occupying the inner third or half of the continental shelf which is about fifty miles broad at Delaware Bay. From here they move northward and eastward at a rate not faster than the progressive northerly warming of the surface water and reach the offing of southern New England during the month of May. During the northerly journey they are joined by additional schools moving in from the edge of the continental shelf in wavelike incursions. Although the southern contingent always tarries a month or more in the vicinity of southern New England, toward the end of June or early in July its members make their way around Nantucket Shoals and reach the Gulf of Maine where they make their summer sojourn.

The northern contingent makes its appearance during the latter half of May forming a wave advancing toward the coast along a broad front, perhaps from Hudsonian Channel eastward. The western end of this wave strikes the southern coast of New England, the middle portion, southern Nova Scotia and the eastern, the more easterly portions of Nova Scotia. Once inshore, the members of this contingent migrate along shore. Those that strike the coast of southern New England mix temporarily with the southern contingent among which they are detectable by their different (usually larger) sizes. But after staying only a week or two they separate from the southern contingent and toward the end of May some filter into Massachusetts Bay, but the major portion are next to be found on the Nova Scotian coast reaching there during the early days of June about the same time as those that approached that coast directly. During June, the run is heavy along the entire length of the Nova Scotian coast, Cape Breton, and eastern portions of the Gulf of St. Lawrence. During this June run there are perhaps additional minor waves of mackerel coming shoreward from the outer edge of the Nova Scotian shelf if any have wintered in the more chilly waters of this region (p. 261). Most of the northern contingent probably summers in the Gulf of St. Lawrence though part may remain along the coasts of Maine, Nova Scotia, and Capte Breton Island.

In withdrawing from the coastal areas in the fall, the movements of the two contingents, for the most part, are simply the reverse of their approach in the spring. The southern contingent in retiring from the Gulf of Maine goes southeastward past Cape Cod and in some years then trends westerly off No Man's Land and Block Island. This usually take place in September or October. About the same time, though sometimes earlier and sometimes later, the northern contingent begins retiring from Canadian waters. In doing so, a large portion, if not all, passes through the Gulf of Maine providing the basis for the late fall fishery off Cape Anne in October, November, and December. They, too, leave the Gulf of Maine by going toward the offing of Cape Cod, but have never been observed southerly or westerly of that area. During the fall migration, as during the spring migration, there is a brief period when the two contingents are mixed. The fall withdrawal differs from the spring approach mainly by the mixing of the two contingents north rather than south of Nantucket Shoals; the disappearance of each contingent while still well north of the points at which they first appeared in the spring; and the occupation by the northern contingent of the western portion of the Gulf of Maine to a greater extent and for a longer period in the fall than in the spring.

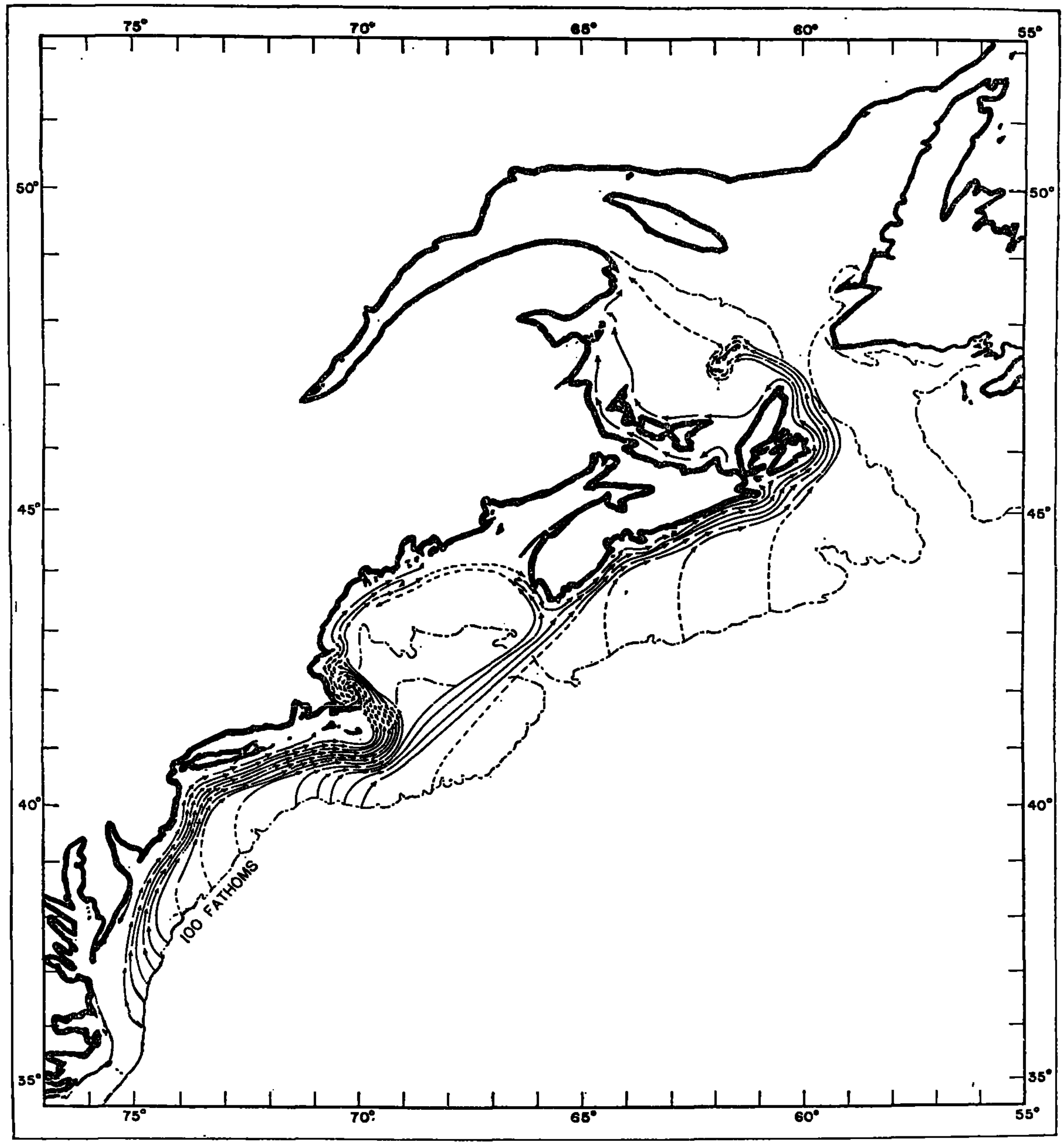

FIGURE 5.—Diagrammatic representation of the spring migration. The number of arrowshafts is roughly proportional to the relative number of mackerel believed to traverse the several localities. The number of arrowheads is roughly proportional to the relative amount of commercial catch taken in the several areas. Lines of dashes indicate weak evidence as to the origin or route of migration.

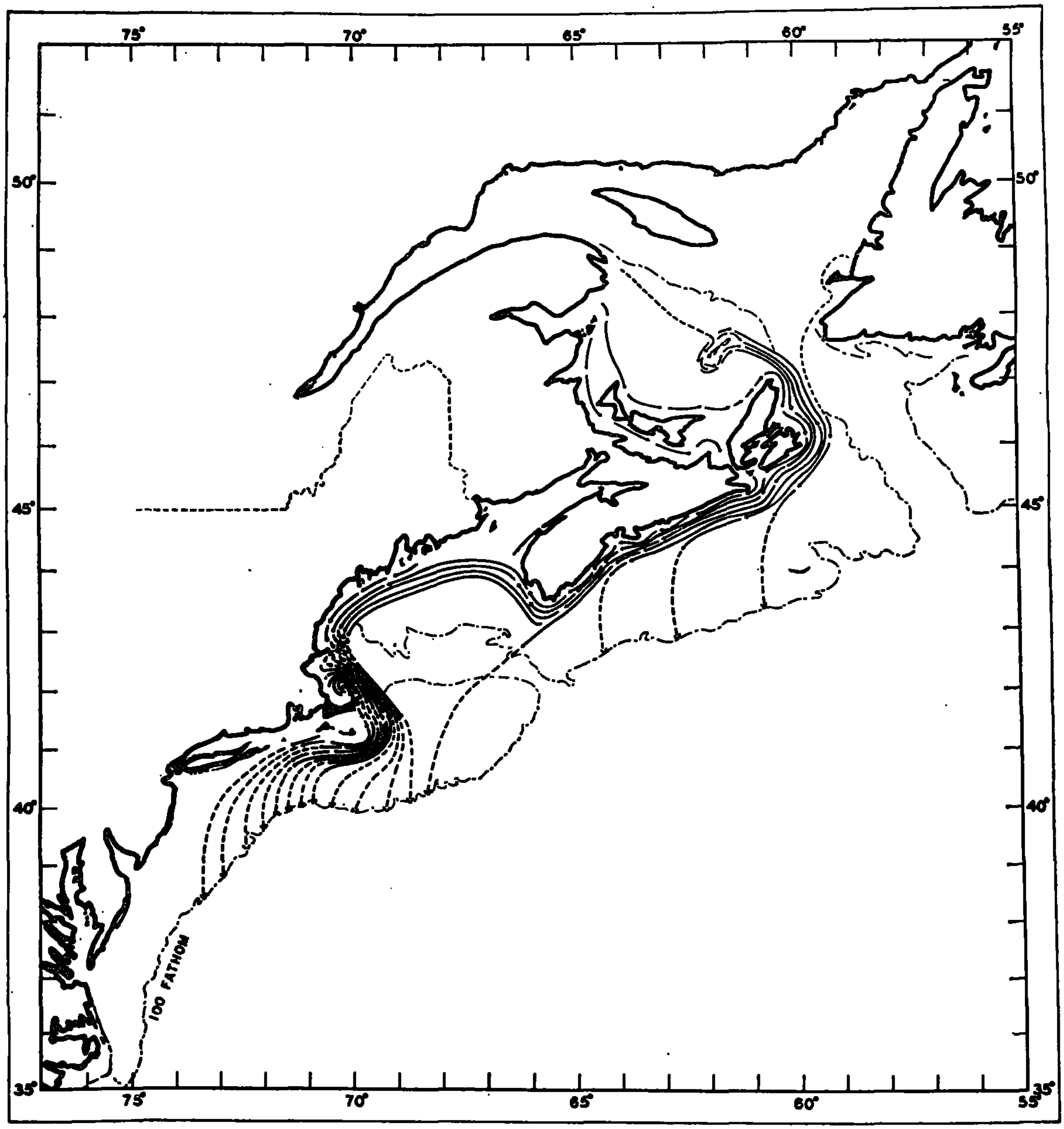

FIGURE 6.—Diagrammatic representation of the fall migration. The number of arrowshafts is roughly proportional to the relative numbers of mackerel believed to transverse the several localities. The number of arrowheads is roughly proportional to the relatve amount of commercial catch taken in the several areas. Lines of dashes indicate weak evidence as to the route or destination of migration.

The supporting evidence rests almost solely on the observed size composition of the mackerel population at various times and places, together with the time sequence of the appearance of the population—or certain portions of it—at the various points along the coast. This evidence, although indirect, has a notable advantage over the more direct method of tagging. It enables one to deal with a much larger portion of the population and to obtain a much more definite estimate of the relative numbers of individuals involved in the movements (i. e., distinguish mass-movements from stragglings) than can be gained from the relatively small numbers usually tagged. Nevertheless, tagging experiments were done, which furnish confirmation (p. 307).[10]

DISTINCTION BETWEEN NORTHERN AND SOUTHERN CONTINGENTS

To account for the several phenomena observed in the migration study it has been necessary to recognize the existence of two subdivisions of the mackerel population which differ in their migrating habits, and which it is convenient to designate as southern and northern contingents. It is not necessarily implied that these are genetically distinct races of the species such as were believed to exist in European waters by Garstang (1898: 235–295) on the basis of differences in morphological characters. For the purpose of discussing the migrations it is preferable to regard the two contingents as subdivisions of more or less stable nature enduring through several seasons, but not necessarily from one generation to another.

The phenomena that indicated two subdivisions or contingents within the population along the North American coast are (1) the prevailing dissimilarity in size composition of the spring population along the Nova Scotian coast ("Cape Shore" in the parlance of mackerel fishermen) from the spring and summer population along the New England and Middle Atlantic coasts; and (2) the pronounced but transient alteration of sizes in the population off southern New England that takes place each year, usually in late May. The nature of these phenomena will be illustrated by the data of 1927, the relation between them will be demonstrated with the data of 1932 and finally their persistence or annual recurrence during the period of this investigation will be shown.

Because the size composition of the mackerel population was simple in 1927, the data of that year afford a favorable opportunity to illustrate both of the phenomena under consideration. In the population along New England and Middle Atlantic States, which will be termed "southern contingent," the 1923 class was so predominant that the length-frequency curves of that season were almost always characterized by a nearly symmetrical simple curve with a mode at 39 centimeters (two lowermost and three uppermost panels of fig. 7). The population along the Nova Scotian coast, which will be termed "northern contingent," on the other hand was dominated by the 1921 class as is evident from its simple mode at 41 centimeters (broken-line curve in middle panel of figure 7).[11] But the composition of the population off southern New England was altered during a brief period, so that frequency distributions of samples in the last half of May and again in the first half of June were essentially bimodal, with modes at 39 and 41 centimeters (the third and fourth panels from bottom in fig. 7). The simplest explanation of this altered size composition is that both northern and southern contingents for a time occupied the same area, were caught indiscriminately by the fishermen, and occurred in a mixture in the samples drawn from the catch. Since the alteration in size composition off southern New England (May 16–31) antedated the appearance of the larger fish along the Nova Scotian coast (June 1–15) it appears that the northern contingent in its migration first passed along the southern New England coast, mixed temporarily with the southern contingent already there, and then went on to the Nova Scotian coast, leaving the southern contingent behind.

This explanation may be tested to see whether it is fully in accord with the facts by combining the northern contingent as sampled off Nova Scotia with the southern contingent as sampled off southern New England before and after the mixing period, and comparing the resultant "synthetic" curve with the altered distribution found off southern New England, which may be termed the "mixed population." For purposes of this test the data of 1932 are more suitable than those of other years because fishing took place both off Nova Scotia and off southern New England during the periods that are critical to this experimental synthesis and hence both populations were well-sampled in that year.[12]

If the data of May and June of 1932 be summarized in reasonably short time intervals and by subareas as in figure 8, it is obvious that the southern contingent of that year was characterized by a dominant mode at 43 centimeters and a subdominant

[10] In using this order of presentation we are following the procedure actually used in arriving at the present results. Preliminary examination of tagging returns originally secured were unintelligible, and the data were laid aside for some years. It was not until the size composition study was completed that the tagging evidence was again consulted and found intelligible in the light of the hypothesis built up from the evidence gained by sampling the population.

[11] The irregularity of this curve is due to the scanty sampling afforded by the two catches from this area in 1927 and does not indicate multimodality or other complexities.

[12] In many seasons the fleet fishes either almost wholly off southern New England or almost wholly off Nova Scotia at this time so that sampling usually is deficient in either one place or the other.

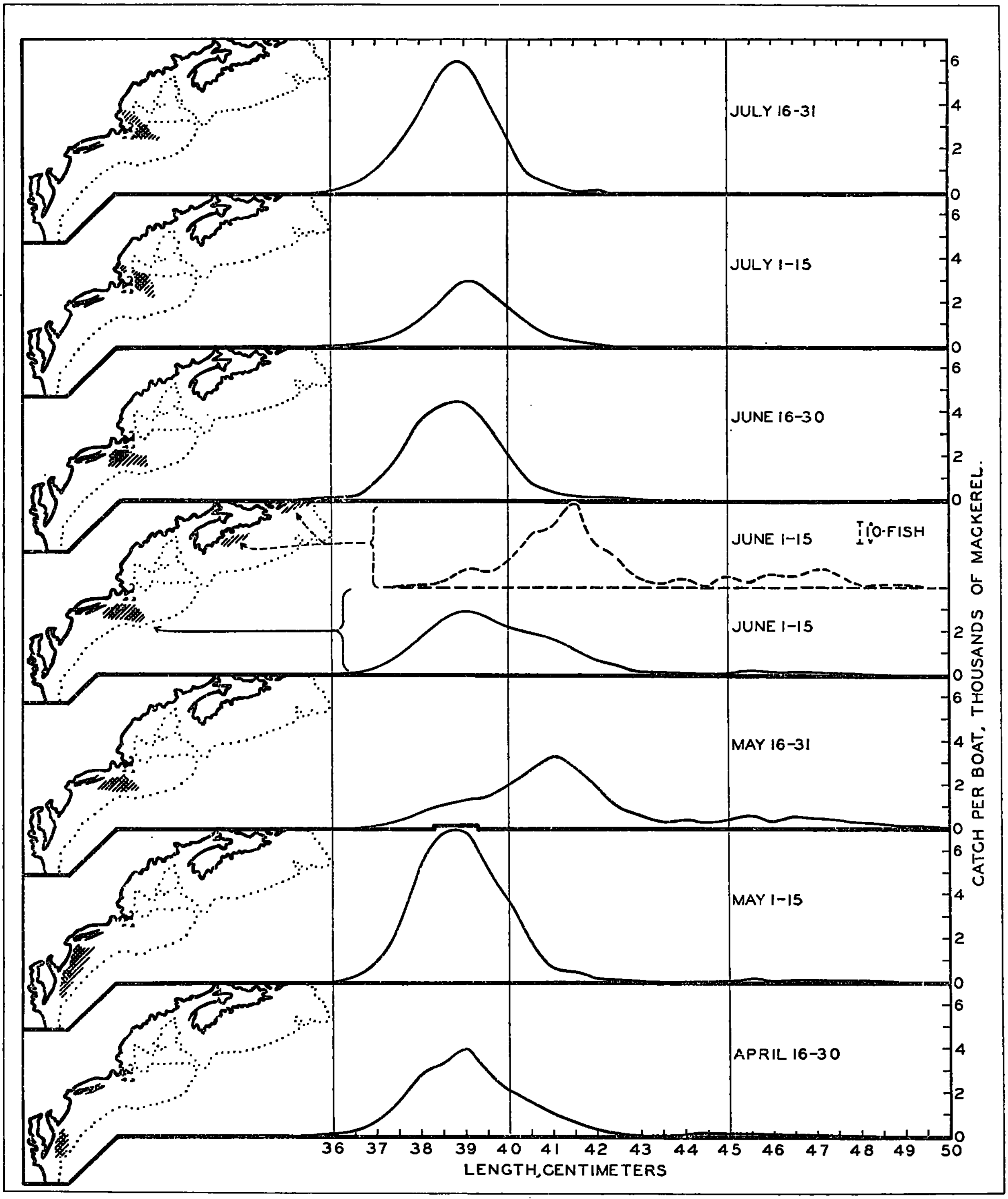

FIGURE 7.—Changes in the size composition of the mackerel in purse-seine catches in the spring of 1927. The areas under the curves are proportional to the catch per unit of effort except for the broken curve of samples from the coast of Nova Scotia, June 1–15. The shaded areas in the chart insets at the left indicate the localities of fishing during each half month.

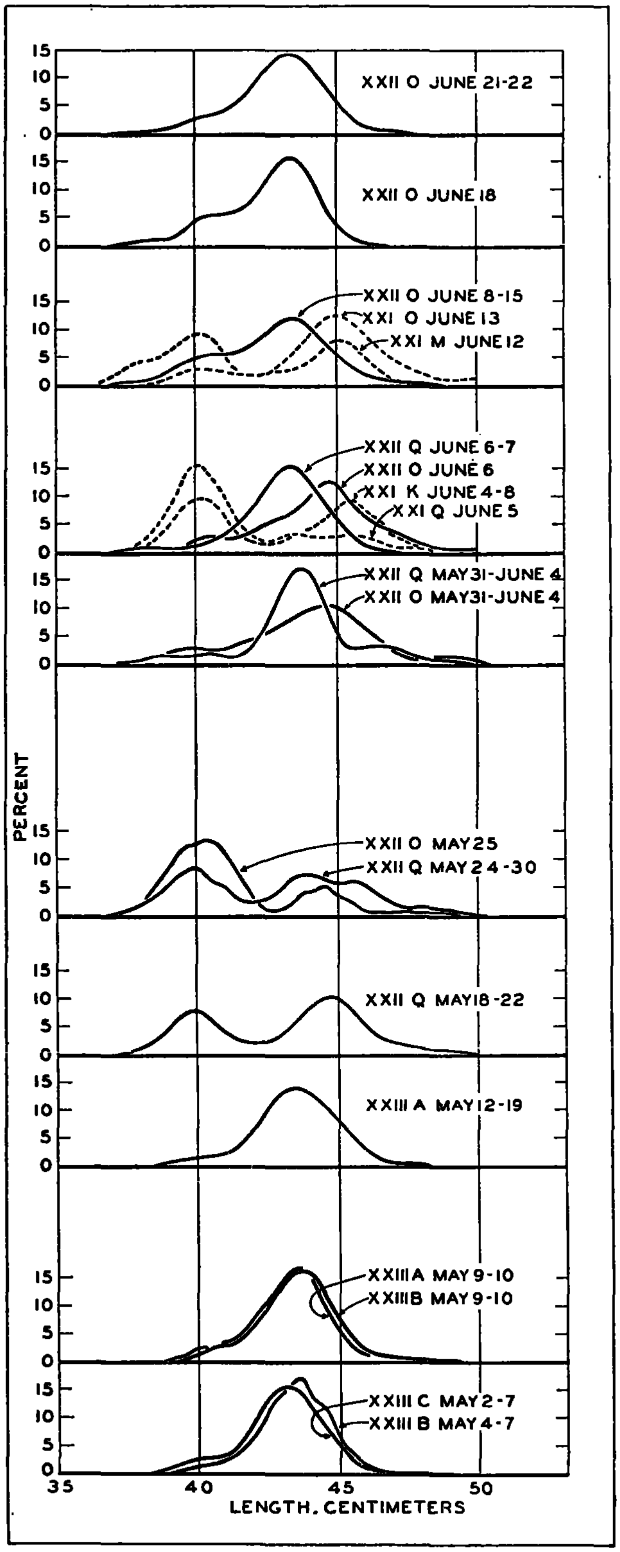

FIGURE 8.—Size composition of mackerel in purse-seine catches in the spring of 1932. The spaces between base lines are approximately proportional to the time between weighted mean dates of groups of samples included in the distribution plotted on the respective base lines. Samples pertaining to each area and period were simply grouped by direct addition without weighting, smoothed by a moving average of three, and reduced to equal areas by converting to percentages.

mode at 40 centimeters and the northern contingent by nearly equal modes at 40 centimeters and at 45 or 46 centimeters. With these criteria the samples are readily classified into three groups as in tables 3, 4, and 5 representing northern, southern, and mixed population, respectively. Taking as ingredients length distributions of the northern and southern contingents smoothed as shown in figure 9, it was found by successive trials that combined in the ratio of 68 northern to 32 southern they formed a curve approximating the mixed population. Graphic indication of goodness of fit is given in the middle panel of figure 9. The chi-square test (Fisher 1932: 80) also indicates a tolerably good fit, there being as high as 1 chance in 10 that the difference might be exceeded owing to random causes alone.[13]

Hence the size composition of the so-called mixed population is consistent with the hypothesis that the ingredients of the mixture were indeed of the northern and southern contingents as here defined. The size composition also indicated that during the period of mixing the northern contingent outnumbered the southern by approximately 2 to 1.

The fact that northern contingent mackerel appeared on May 18 in southern New England waters before their appearance on June 4 in Nova Scotian waters suggests that on separating out of the mixture off southern New England, this group went to the coast of Nova Scotia. Detailed examination of the curves of frequency distribution are still more suggestive of such a movement, for in

[13] That portion of the curve above 41.5 centimeters fits much better (P=0.30) than the portion below (P=0.01). The poorness of fit below 41.5 centimeters may be attributed to sampling deficiencies rather than to significant differences in the populations concerned because a large part of the contribution to chi-square is from the excess at 39.5 and deficiency at 40.5 and 41.0 centimeters in the observed mixture and these in turn result mainly from the frequency of area XXII O, May 31 to June 4 which dominates the grouped mixture. If the five components in the mixture be recombined after giving equal weight to each (percentage frequencies) the above-mentioned excess and deficiencies are very much reduced, showing that the distribution of sampling during the period of mixing has somewhat altered the shape of this portion of the curve. Although this might be overcome by a system of weighting, this was not done because it would have interfered with the chi-square test.

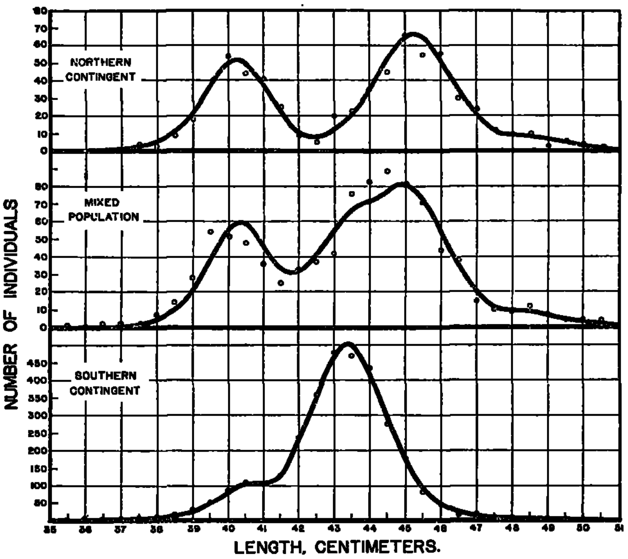

FIGURE 9.—Relationship of northern and southern contingents to the "mixed" population. In the upper and lower panels the circles represent observed numbers, the lines represent the graphically smoothed curves. In the middle panel the circles represent observed numbers, the line represents the combination of northern and southern contingents in the ratio of 68 to 32. Data were derived from tables 3 to 5.

TABLE 3.—*Size composition of the northern contingent in June 1932*

[Letters at head of columns specify subareas (fig. 1)]

Length in centimeters	Area XXI				Total
	K	Q	O	M	
	June 4–8	June 5	June 13	June 12	
	Number	*Number*	*Number*	*Number*	*Number*
37.5	1		1	2	4
38.0		1		2	3
38.5	7			2	9
39.0	11	3	2	2	18
39.5	21	7	5	4	37
40.0	38	5	7	4	54
40.5	25	8	6	5	44
41.0	30	2	4	2	38
41.5	15	3	6	1	25
42.0	5	1	3		9
42.5	1		2	2	5
43.0	8	1	10	1	20
43.5	6	3	11	1	21
44.0	12		20	2	34
44.5	16		27	2	45
45.0	28	3	30	5	66
45.5	27		25	3	55
46.0	27	2	21	3	53
46.5	16		13	1	30
47.0	12	1	11		24
47.5	4		6		10
48.0	3		6		9
48.5	6		2	1	9
49.0	3				3
49.5	2		2		4
50.0			3		3
50.5			2		2
52.0	1				1
Total	325	40	225	45	635

TABLE 4.—*Size composition of the southern contingent in May and June 1932*

[Letters at head of columns specify subareas (fig. 1)]

Length in centimeters	Area XXIII					Area XXII					Total
	C	B		A		Q		O			
	May 2–7	May 4–7	May 9–10	May 9–10	May 12–19	May 31–June 4	June 6–7	June 8–15	June 16–20	June 21–22[1]	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
35.5	1										1
36.0								3			3
36.5										1	1
37.0	2							1	1		4
37.5			1					3		2	6
38.0	1	1					2	2	1	2	9
38.5	2				1	1	1	7	2		14
39.0	6					2	2	17	1	2	30
39.5	10	2	1	1	4	1		24		6	49
40.0	20	3	6	2	2	1	3	31	7	10	85
40.5	17	6	8	3	4	2	3	42	9	12	106
41.0	21	4	12	1	7	2	5	34	6	11	103
41.5	30	10	9	4	6		8	34	7	20	128
42.0	62	20	26	6	18	2	18	46	12	25	235
42.5	102	26	37	9	28	8	16	71	12	48	357
43.0	131	52	46	11	38	13	36	77	25	49	478
43.5	96	39	73	15	38	15	27	91	23	52	469
44.0	87	46	54	14	35	21	28	73	19	48	425
44.5	62	26	43	7	28	10	13	54	8	25	276
45.0	27	20	26	3	22	3	12	34	6	23	176
45.5	16	6	10	2	12	2	5	21		6	80
46.0	5	4	6	1	9	3	2	11		2	43
46.5	2		2		2	3		4	1	2	16
47.0	2	1	3	1	1	3	1	5		1	18
47.5	1				2	1		3		1	8
48.0	1	2	2		1	1	1				8
48.5	1	1	1			1		1			5
49.0			1							2	3
49.5			1		1		1				3
50.0					1		1				2
50.5								1			1
Total	705	269	368	80	260	95	185	690	140	350	3,142

[1] Includes 20 from H.

TABLE 5.—*Size composition of the mixed population in May and June 1932*

[Letters at head of columns specify subareas (fig. 1)]

Length in centimeters	Area XXII					Total
	Q		O			
	May 18–22	May 24–30	May 25	May 31–June 4	June 6	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
35.5				1		1
36.0		1				1
36.5	1		1			2
37.0				2		2
37.5		1		1		2
38.0	1	3	2	1		7
38.5	3	6	2	3		14
39.0	6	7	9	6		28
39.5	10	16	10	18		54
40.0	13	14	11	14	1	53
40.5	9	15	11	10	3	48
41.0	3	4	13	15	1	36
41.5	3	6	3	12	1	25
42.0	2	3	2	23	3	33
42.5	3	4		27	3	37
43.0	4	7	1	24	6	42
43.5	7	14	2	51	2	76
44.0	13	14	6	42	8	83
44.5	14	9	2	55	9	89
45.0	15	11	5	41	9	81
45.5	11	9	1	46	4	71
46.0	6	10		22	6	44
46.5	4	8		25	1	38
47.0	3	1	1	7	3	15
47.5	2	2		4	2	10
48.0	1	2	1	4	1	9
48.5	2	3		7		12
49.0		1		5	1	7
49.5		1	1	2		4
50.0				4		4
50.5				3	1	4
Total	136	172	84	475	65	932

area XXII–Q,[14] May 24 to 30, there is a prominence in the distribution at 45.5 centimeters which is comparable to a prominence at the same position in the Nova Scotian samples of area XXI–K, June 4 to 8. By May 31 the prominence in southern New England is more marked in the vicinity of 45.0 centimeters which may be compared to the similar prominence in the Nova Scotian material of area XXI–O and area XXI–N, June 12 and 13. In other words, there is a lag of about 10 days between the appearance of certain categories of mackerel in southern New England and the appearance of the same fish in Nova Scotian waters. This corresponds to the average lag between the first appearance of northern contingent mackerel in southern New England and first appearance in quantity of mackerel in Nova Scotia in the various years between 1926 and 1932 (p. 270).

To determine whether or not the change in size composition just noted for 1927 and 1932, and attributed to the existence of a northern contingent distinct from a southern contingent, is a regular event recurring year after year among the mackerel caught off the United States coast during the spring, each year's length-frequency distributions, grouped by statistical subareas and by relatively short periods of time, similar to the groupings used for 1932 in tables 4 and 5 and figure 8 were examined. On the basis of position and dominance of modes it was possible to distinguish distributions obviously representing a mixed population intermediate between the southern contingent (as represented in distributions displaying a stable combination of modes consistently through April, part of May and

[14] See fig. 1 for delineations of areas.

TABLE 6.—*Statistical areas and time periods characterized by mixed population in May and June in the years 1926 to 1935*

[Unless otherwise indicated only purse-seine-caught mackerel are included]

Statistical area	Time period	Number of mackerel
	1926	
XXIII B, XXII O, Q	June 14–15	100
XXII P, R	May 28–29 (caught by gill net)	120
XXII Q, R	June 1, 12 (caught by gill net)	180
XXII P	June 1, 11, 15 (caught by gill net)	160
XXII D	June 11, 14, 15 (caught by gill net)	140
XXII E	June 1–15 (caught by gill net)	1, 159
Total		1, 859
	1927	
XXII Q, S	May 16–20	240
XXII, P, Q, S XXIII A	May 21–25	990
XXII O, P, Q	May 26–31	670
XXII O, P, Q, S	June 1–5	1, 240
Total		3, 140
	1928	
XXIII A, XXII Q	May 25	160
XXII P, Q, R	May 26–31	589
XXII P, Q	June 1–2	220
Total		969
	1929	
XXII O	June 6–7	80
XXII E	June 12–17	187
XXII D	June 15	32
Total		299
	1930	
XXII S, Q	May 19	40
XXII Q, R	May 20	116
XXII Q	May 21–26	250
Total		406
	1931	
XXII Q	May 17–31	460
XXII S	May 22–23	102
XXII O	June 1	40
Total		602
	1932	
XXII Q	May 18–31	311
XXII O	May 25 to June 6	625
Total		936
	1933	
XXII Q	May 18–25	220
	1934	
XXIII A	May 14–17	740
XXII Q, R, S	May 17–19	792
XXII O, Q	May 22 to June 2	3, 841
Total		4, 373
	1935	
XXII Q	May 20 to June 10	3, 805

June, and through July) and the northern contingent (as represented in distributions from purse-seine catches off the coast of Nova Scotia). The statistical subareas and periods of time characterized by the mixed population type of distribution are listed in table 6 together with the number of mackerel contained in the samples available from each. These samples were pooled and their length-frequency distributions summarized in table 7. The remainder of the May and June samples from areas XXII and XXIII representing the southern contingent, are similarly given in table 8 and the Nova Scotian samples (area XXI) representing the northern contingent are given in table 9. The three series, converted to percentages, are shown in figure 10. In this figure the curves have been drawn through the unsmoothed percentage-frequency values. Where they are markedly irregular it is due to the small numbers involved as can be seen by reference to tables 7, 8, and 9.

TABLE 7.—*Length frequencies, by half-centimeter classes, of mackerel in the mixed population, as represented by samples from the statistical subareas and dates listed in table 6*

Length in centimeters	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
27.0	----	----	----	----	----	----	----	----	----	4
27.5	----	----	----	----	----	----	----	----	----	1
28.0	----	----	----	----	----	----	----	----	----	2
31.0	----	----	----	----	----	----	1	1	1	1
31.5	----	----	----	----	----	----	----	1	3	29
32.0	----	----	----	----	----	----	2	4	3	50
32.5	----	----	----	1	----	----	----	2	5	101
33.0	----	----	----	----	----	----	----	12	8	134
33.5	----	----	----	----	----	----	1	9	6	117
34.0	----	1	----	----	1	----	----	11	16	115
34.5	----	----	----	----	----	1	----	5	43	73
35.0	----	----	----	----	----	1	----	14	104	36
35.5	1	----	----	----	----	----	1	12	202	33
36.0	4	----	----	2	1	----	1	2	329	68
36.5	17	2	----	----	----	1	2	8	374	137
37.0	34	19	----	1	2	3	2	2	358	275
37.5	45	55	1	----	----	3	2	2	220	382
38.0	71	118	4	----	1	5	7	1	142	498
38.5	84	184	20	----	1	29	14	3	69	448
39.0	82	219	42	1	1	25	28	----	52	296
39.5	110	246	77	----	1	42	54	2	31	194
40.0	127	309	89	7	1	34	53	3	49	104
40.5	166	384	129	8	5	14	48	3	80	43
41.0	166	423	122	21	4	8	36	5	89	44
41.5	139	341	121	37	10	20	25	8	128	34
42.0	108	215	81	37	14	36	33	3	103	46
42.5	67	114	62	45	21	39	37	5	125	38
43.0	41	62	48	52	28	44	42	8	156	47
43.5	29	39	31	27	47	41	76	10	202	80
44.0	39	30	16	15	47	56	83	10	262	68
44.5	47	29	13	12	54	53	89	7	263	63
45.0	75	39	14	4	42	39	81	16	260	62
45.5	76	65	10	10	32	29	71	20	240	70
46.0	76	31	8	3	16	28	44	16	148	44
46.5	85	51	17	2	12	11	38	7	131	31
47.0	62	44	16	4	11	13	15	3	68	14
47.5	25	38	13	1	18	4	10	2	39	6
48.0	38	30	7	2	13	6	9	1	29	7
48.5	14	22	10	2	8	8	12	----	10	7
49.0	20	10	11	2	11	2	7	2	9	1
49.5	5	9	1	3	2	3	4	----	10	2
50.0	2	5	2	----	2	3	4	----	3	----
50.5	3	4	2	----	----	1	4	----	2	----
51.0	----	1	2	----	----	----	----	----	1	----
51.5	1	1	----	----	----	----	----	----	----	----
Total	1,859	3,140	969	299	406	602	936	220	4,373	3,805

TABLE 8.—*Length frequencies, by half-centimeter classes, of mackerel in the southern contingent as represented by all May and June samples from areas XXII and XXIII other than those included in table 7*

Length in centimeters	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
18.0	----	----	----	----	----	1	----	----	----	----
19.0	----	----	----	----	----	2	----	----	----	----
19.5	----	----	----	5	----	8	----	----	----	----
20.0	----	----	----	7	----	9	----	----	----	----
20.5	----	----	1	9	----	23	----	----	----	----
21.0	----	----	----	3	----	13	----	----	----	----
21.5	----	----	2	7	----	25	----	----	----	----
22.0	----	----	6	8	----	15	----	----	----	----
22.5	----	----	7	18	----	10	1	----	----	----
23.0	----	----	13	24	----	5	2	----	----	----
23.5	----	----	12	42	2	1	1	----	----	----
24.0	----	----	15	51	5	3	2	----	----	----
24.5	----	----	7	49	7	----	2	----	----	----
25.0	----	----	7	47	13	----	12	----	----	1
25.5	----	----	4	36	27	1	18	----	3	1
26.0	----	----	4	39	16	----	49	----	1	1
26.5	----	----	----	27	20	----	51	----	1	1
27.0	----	----	3	29	5	1	99	----	----	2
27.5	----	1	----	29	11	1	117	----	1	3
28.0	----	----	----	15	7	3	179	----	----	2
28.5	----	1	----	15	3	6	230	----	1	2
29.0	1	1	----	22	6	2	289	1	1	1
29.5	----	1	----	39	2	2	258	5	3	----
30.0	----	----	----	51	3	5	300	10	10	----
30.5	----	----	----	27	2	----	281	37	17	----
31.0	----	----	----	18	4	----	229	71	24	4
31.5	----	----	----	4	2	1	191	183	57	10
32.0	----	----	----	1	5	1	113	271	102	74
32.5	----	----	----	2	13	2	64	346	119	143
33.0	5	----	----	3	35	4	33	351	89	271
33.5	7	----	----	7	106	11	9	280	94	306
34.0	10	----	----	16	326	27	7	222	105	308
34.5	16	1	----	19	526	46	4	174	148	220
35.0	26	8	----	41	663	83	2	101	338	145
35.5	53	5	----	50	631	69	2	55	617	49
36.0	170	26	1	58	370	65	3	49	781	37
36.5	379	57	1	48	202	49	1	22	802	56
37.0	727	212	9	36	73	48	4	10	584	136
37.5	1,078	552	23	21	45	88	6	8	313	285
38.0	1,141	1,085	113	21	31	180	9	12	186	539
38.5	887	1,428	340	8	21	228	15	5	66	663
39.0	562	1,520	829	29	11	269	32	21	47	724
39.5	284	1,216	1,247	92	17	256	53	21	39	499
40.0	156	816	1,410	265	30	164	89	33	69	309
40.5	124	420	1,154	557	64	150	108	52	79	149
41.0	72	225	724	923	137	187	105	68	129	104
41.5	65	129	414	977	256	312	133	113	177	96
42.0	42	66	163	1,001	400	538	238	147	212	154
42.5	30	34	78	682	374	673	361	230	316	168
43.0	30	23	38	429	385	770	485	301	423	295
43.5	23	15	21	183	313	638	478	298	539	353
44.0	34	20	17	98	189	483	425	234	558	451
44.5	37	14	10	44	119	294	281	198	449	417
45.0	54	27	13	30	76	165	179	135	335	351
45.5	67	40	17	20	37	96	81	59	185	270
46.0	63	33	17	27	26	49	44	34	83	161
46.5	45	30	22	15	19	25	16	14	40	72
47.0	56	21	24	27	17	21	20	11	33	32
47.5	32	14	18	19	7	21	9	6	5	10
48.0	23	11	11	15	10	16	8	8	4	5
48.5	14	13	7	11	4	22	7	7	1	2
49.0	11	2	6	9	3	10	3	3	1	2
49.5	7	1	4	8	5	3	3	3	4	2
50.0	5	3	1	6	7	7	2	----	2	1
50.5	1	----	1	2	2	3	1	----	----	----
51.0	1	3	0	2	2	----	----	----	1	----
51.5	2	----	1	----	----	1	----	----	----	----
52.0	----	----	2	----	----	----	----	----	----	----
53.0	----	----	----	2	----	----	----	----	----	----
Total	6,340	8,074	6,817	6,425	5,692	6,211	5,744	4,209	8,194	7,887

In the three series all samples were drawn from purse-seine catches except those for 1926, in which samples from the drift-gill-net fishery were included to augment the very scanty data from late May and early June when most of the purse-seine fleet was off Nova Scotia, and so afforded very few samples from

TABLE 9.—*Length frequencies, in half-centimeter classes, of mackerel in the northern contingent as represented by samples from the spring purse seine fishery along the Nova Scotian coast, area XXI*

Length in centimeters	1926	1927	1928	1929	1930	1931	1932
33.0	------	------	------	------	------	------	------
33.5	------	------	------	------	1	------	------
34.0	------	------	------	------	------	------	------
34.5	------	------	------	------	1	------	------
35.0	------	------	------	------	------	------	------
35.5	------	------	------	------	------	1	------
36.0	1	------	------	1	------	1	------
36.5	1	------	------	------	1	------	------
37.0	5	------	------	------	------	1	------
37.5	6	------	------	------	------	3	4
38.0	24	1	------	------	------	11	3
38.5	52	2	------	------	------	14	9
39.0	105	8	3	------	------	27	18
39.5	199	7	1	------	1	22	40
40.0	259	13	10	1	------	11	57
40.5	271	24	12	6	------	5	45
41.0	239	28	30	15	------	4	40
41.5	115	38	38	28	------	3	26
42.0	76	19	55	55	------	2	9
42.5	44	13	57	79	1	2	5
43.0	29	4	45	109	7	4	23
43.5	22	2	30	97	6	7	26
44.0	32	4	22	127	12	12	41
44.5	40	1	6	94	12	18	53
45.0	48	5	9	62	10	15	74
45.5	44	3	6	33	18	17	62
46.0	58	6	4	16	7	13	60
46.5	54	5	4	23	5	5	32
47.0	44	8	2	22	4	7	28
47.5	29	6	3	15	4	5	10
48.0	16	1	1	12	2	------	15
48.5	14	1	1	7	------	------	10
49.0	9	1	------	6	------	1	4
49.5	8	------	1	2	------	2	5
50.0	6	------	------	5	------	1	3
50.5	5	------	------	5	------	------	2
51.0	2	------	------	1	------	------	------
51.5	1	------	------	1	------	1	------
52.0	1	------	------	------	------	------	1
52.5	1	------	------	------	------	------	------
53.0	------	------	------	------	------	------	------
53.5	------	------	------	------	------	------	------
54.0	------	------	------	------	------	------	------
Total	1,860	200	340	822	92	215	705

the area in which the mixed population occurred.[15] For convenience in referring to the modes in the frequency distributions of figure 10, identifying letters have been inserted at about the modal positions. The modes are composed of either a single year class or of groups of year classes as is obvious from the fact that they progress toward larger sizes through successive years.

For the first 4 years, 1926 to 1929, mode A was consistently present and dominated the northern contingent, progressing from 40.5 centimeters to 43.5 centimeters. Mode B similarly was consistently present and dominated the southern contingent, progressing from 37.8 centimeters in 1926 to 41.5 in 1929. The mixed population appears to have elements of both modes with A definitely represented most strongly in 1926 and 1927. In the next 2 years, when evidently there was more nearly equal representation of the two groups, there is a mode intermediate between A and B.

In 1930, mode A continued dominant in the northern contingent but the shape of the curve is irregular due to chance fluctuations within the small sample of Nova-Scotian-caught fish available in that year. Mode B of the southern contingent probably should be located at 42.0 centimeters but a hump appears at 43.0 centimeters. The latter may be due in part to random sampling fluctuations and in part to the presence of a few samples that might better have been included with the mixed population. A new and strong mode at C appears in the southern contingent.

In 1931, there is a combination of modes which has already been examined in detail in the 1932 material. Mode A continues present in the northern contingent, B in the southern contingent, and C in both contingents. The latter is definitely stronger in the northern contingent where it appears to have strength about equal to that of mode A but relatively weaker in the southern contingent where it seems less than one-fourth as strong as mode B. As above remarked, this relationship continues in 1932, when also mode ED (see also p. 286) makes its appearance in the southern contingent.

Subsequent to 1933 there is less clarity, due to lack of samples from the coast of Nova Scotia, and to the less-well-marked separation of modes. Nonetheless, the before-noted relationships within the A–B–C modal complex persisted through these last 3 years about as might be expected from the previous years. The new mode at E is difficult to interpret for lack of Nova Scotia material to serve as a model by which to judge the northern contingent's length composition.

From 1926 to 1932, however, it is clear that the catches of mackerel from the late spring runs off southern New England are separable into two groups of markedly different length composition. One group, which has been named southern contingent has a size composition which is clearly distinct from that in the run that appears off the coast of Nova Scotia and which has been termed northern contingent. The other group in the catches off southern New England forms frequency distributions such as might be expected if the northern contingent mixed with the southern contingent in these areas. The data for 1933, 1934, and 1935 are

[15] In general, throughout this report, the combining of purse-seine and drift-gill-net data has been avoided inasmuch as the latter gear may be size selective and possibly be misleading. In this particular case, the gill-net samples dominate both the distribution representing the mixed population and the distribution representing the southern contingent, and it is quite obvious that net selection was not sufficient to obscure the difference between the two, although the modes may be slightly displaced in the gill-net material as compared with the purse-seine material.

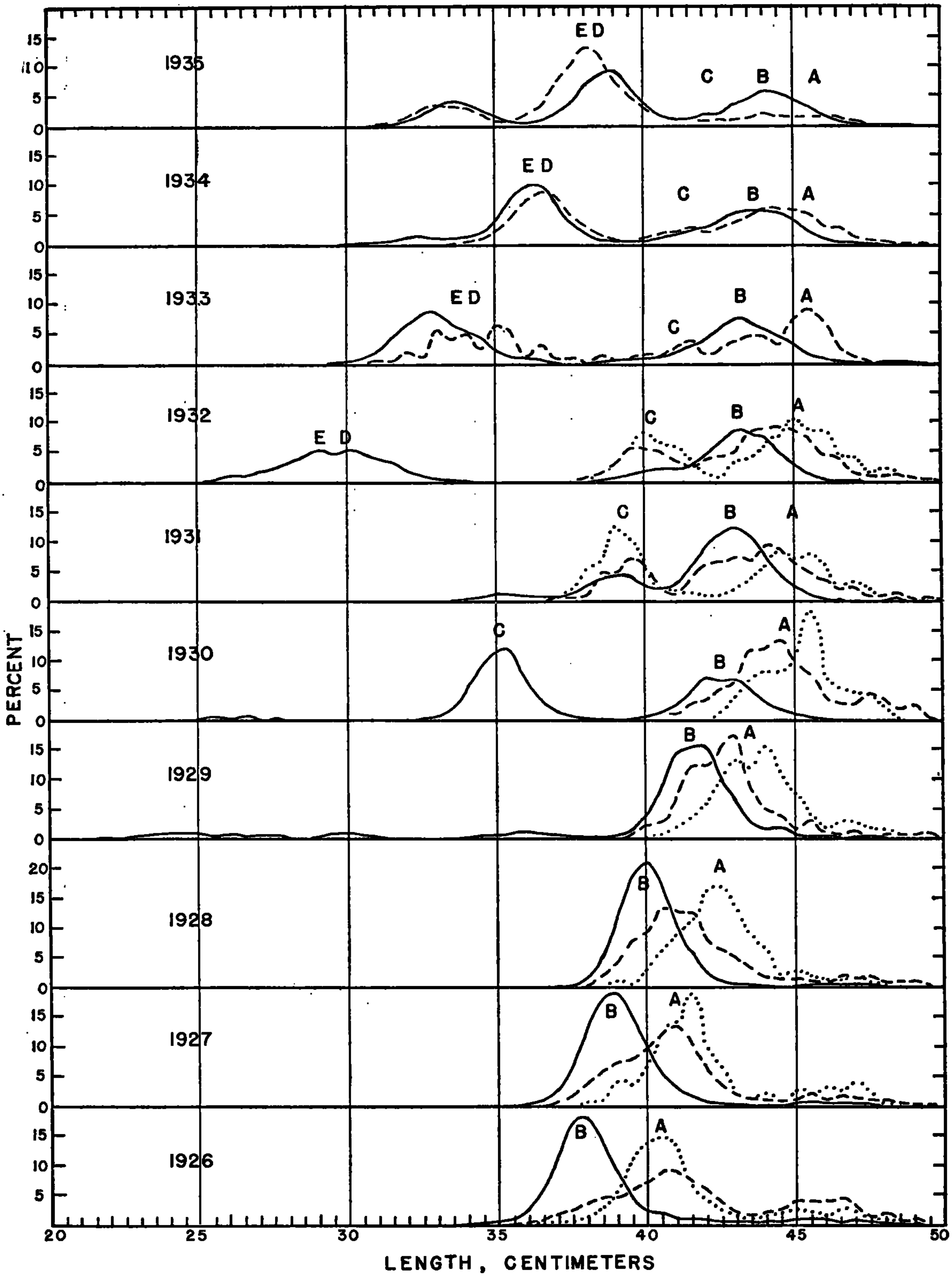

FIGURE 10.—Distribution of lengths of mackerel during May and June for the years 1926 to 1935, in three catagories—those referable to the southern contingent (solid line), northern contingent (dotted line), and to the mixed population (dashed line) comprising elements of both.

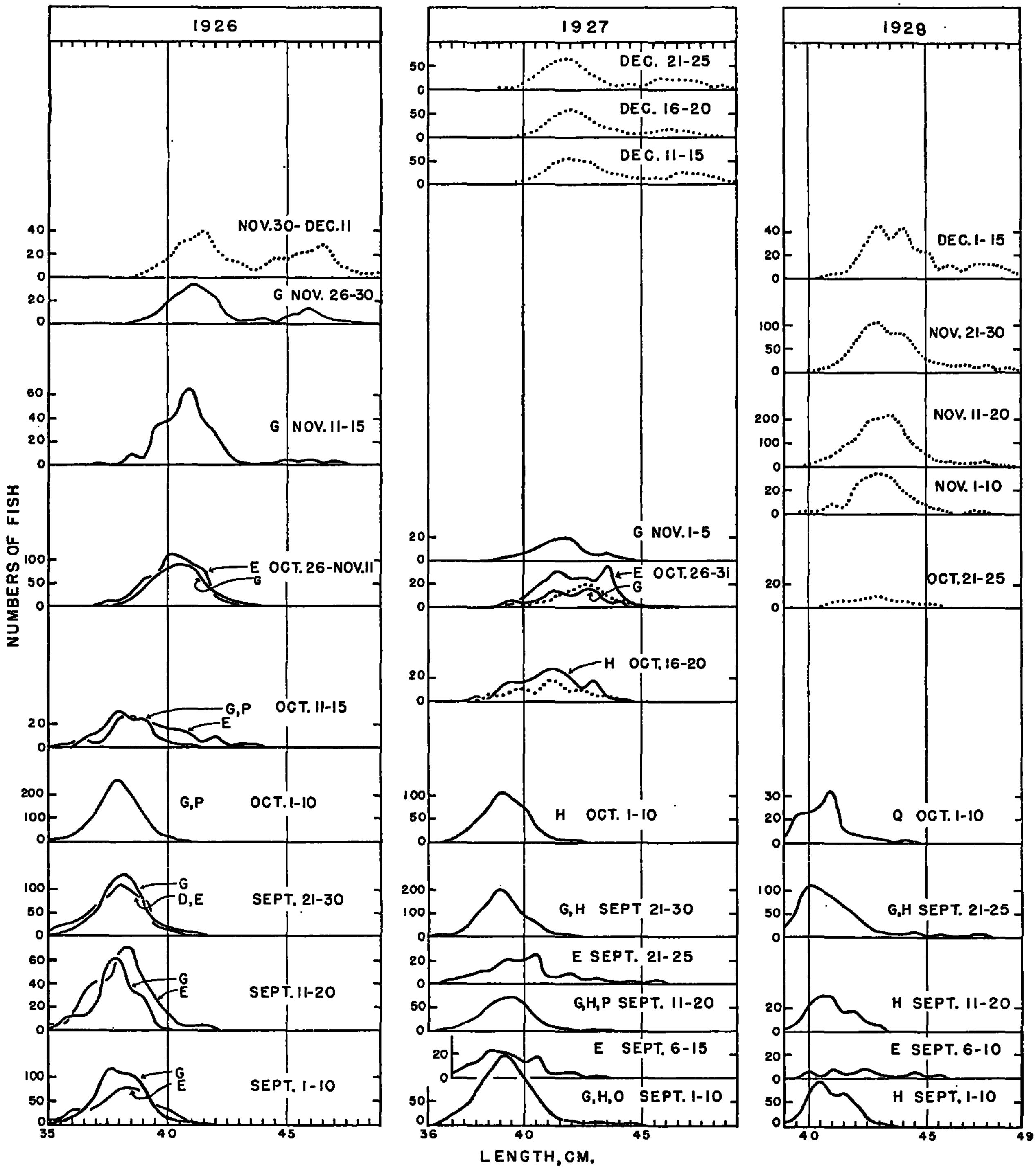

FIGURE 11.—Length composition of medium and large mackerel in catches off New England during the fall months in 1926, 1927, and 1928. Solid lines represent purse-seine catches from the subareas of statistical area XXII designated by letters. Dotted lines represent drift-gill-net catches, all of which were made in subarea E of statistical area XXII. The base lines of the curves are spaced vertically in approximate proportion to calendar date.

less decisive but they are not inconsistent with this conclusion.

In the fall of the year there is a characteristic change in size composition similar to the one that takes place in the spring. This is demonstrated in detail in figure 11 for three autumns—1926, 1927, and 1928. In preparing this figure, working graphs were drawn for the samples from each subarea of statistical area XXII (the only area fished by the American fleet at this season of the year) for each short time interval of 5 days and often less. Space does not admit of reproduction in such detail of these many curves. For this reason the data were grouped in longer time intervals, usually 10 days for figure 11, wherever this could be done without obscuring essential details. However, the source of samples and the aggregate numbers of individual measurements available daily from each area are given in tables 20 and 22 and the frequency data either by weekly or by 10-day periods in tables 21 and 23. The curves of figure 11 were drawn through the unsmoothed frequency values and are irregular where the numbers are few.

When the irregularities associated with small numbers are disregarded, it is evident that in each of the 3 years from the 1st of September to the 10th of October the catches from the various areas through the successive time periods were of essentially uniform size composition.[16] Following October 10 the few samples available from mid-October indicate that the size composition had become unstable. The mode which had been pronounced and relatively constant throughout September and the first 10 days of October at about 38 centimeters in 1926, 39 centimeters in 1927, and 40.5 centimeters in 1928 tended to disappear; and there was a marked accretion of fish several centimeters longer. These tended to form a mode at a point where formerly there was a mere "tail" in the distribution. By the last days of October there were practically no fish left at lengths which had been modal during September and early October. Instead a strong mode appeared at about 41 centimeters in 1926, 42 centimeters in 1927, and 43 centimeters in 1928. In addition to the dominant mode there is a secondary one at 41 to 42 centimeters in most of the curves.

[16] There is a relatively small but consistent difference between the mackerel caught north of Cape Cod (subareas D and E) and those southeast and south of Cape Cod (subareas G, H, O, P, and Q). The significance of this small difference will be discussed in later sections on the summer sojourn and the fall return. For the time being it is sufficient to note that the difference within this segment of time and space is far less than the change that took place after October 10 in all 3 years.

For purposes of discussion the period of stability through September and early October may be called "early fall," the mid-October period of instability may be called the "midfall transition" and the period of stability through November and into December may be called "late fall."

Using these designations it is obvious that the population of early fall has a size composition entirely different from that in the late fall. The difference is too extreme to be attributed to anything other than a change in the population between early and late fall—in other words—the existence of two populations; one succeeding the other in the same region. It is apparent, too, from figure 11, that the midfall transition is a period when elements of both populations are evident in the samples. These appear in the panel for October 11–15 in 1926 and for October 16–20 in 1927.

It is further evident by comparison of the curves of figure 11 with those in the three lower panels of figure 10, that the early fall population had a length composition identifying it with the spring southern contingent while the late fall population may similarly be identified with the northern contingent as it was sampled by the spring catch off Nova Scotia. The midfall transition has its mixed population comparable to the spring mixed population which was studied in some detail, but the sampling was too sparse during the midfall transition to repay intensive examination of the material.

Length-frequency distribution curves for short time intervals during autumn for the remaining 7 years of the investigation prove that the change from one population in early fall to another in late fall occurred consistently, year after year. Space does not permit reproduction of these hundreds of frequency curves, but the length compositions characteristic of the two populations are shown for all 10 years in the "fall" panels of figure 12.

The data for the curves in these fall panels were assembled as follows: Curves were plotted for each date-locality group of samples listed in table 23. September 1 was initially selected as the arbitrary starting point for each fall series but paucity of medium and large mackerel in the September catch and consequently in the samples during September in some years led to the inclusion of a portion of August in such years in order to get a representation of these sizes. From inspection of each season's series it was obvious that termination of the purse-seine fishery and initiation of the drift-gill-net

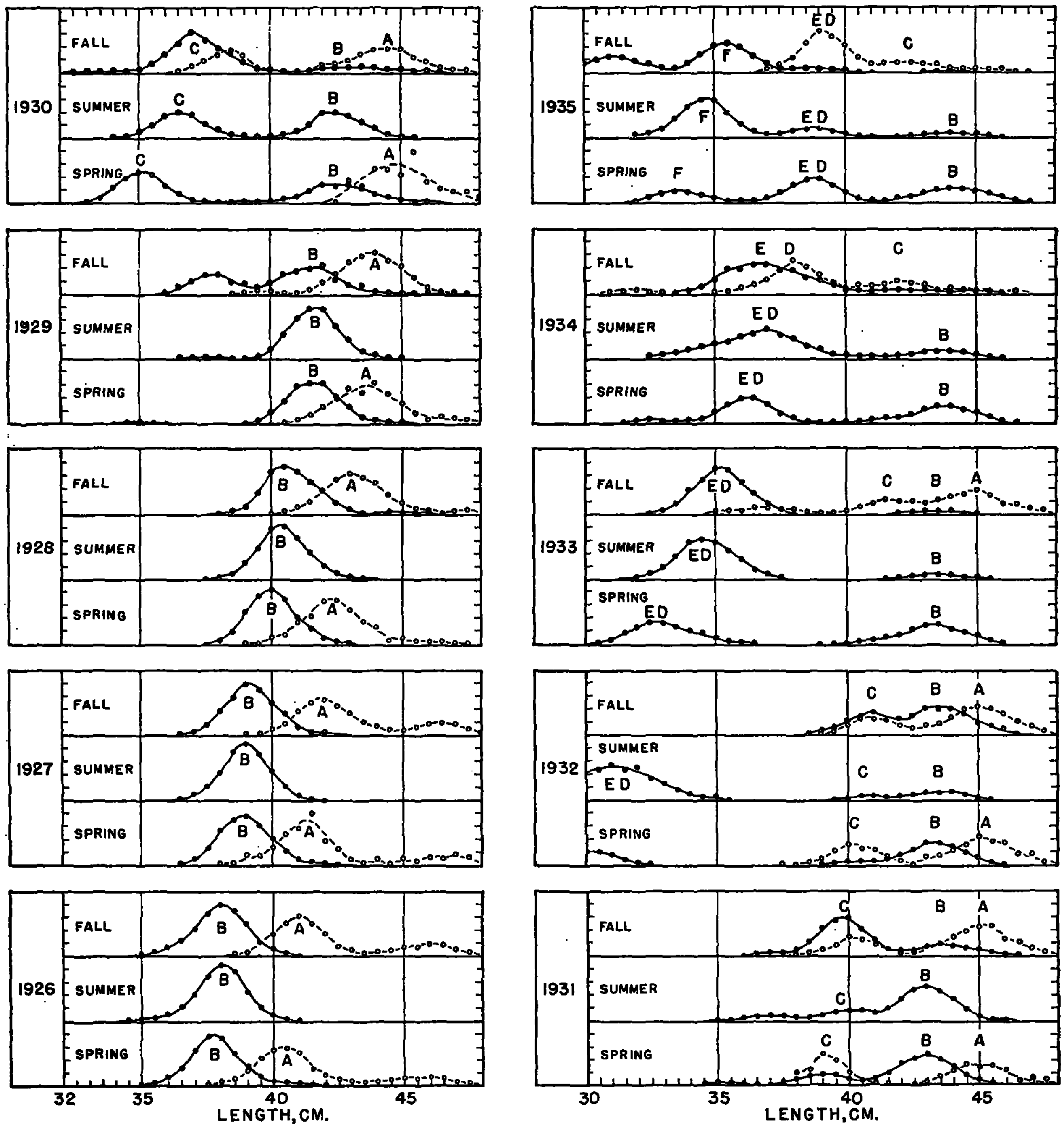

FIGURE 12.—Length-frequency distributions illustrating the size composition of the two types of mackerel population: southern contingent (solid dots and solid lines) and northern contingent (open circles and broken lines), during 10 seasons. The curves are on a percentage basis and the graduation marks on the vertical axis represent 5 percent intervals.

fishery nearly coincided with the "mid-fall transition" in all years except 1926. To avoid heterogeneity with respect to catching method, it was decided to include as early fall category all purse-seine samples up to date-group first showing, by a change in size composition such as registered October 11–15 in 1926 and October 16–20 in 1927 (fig. 11), evidence of a change in population, and to include as late fall category all drift-gill-net samples after the size composition showed stability by essential uniformity of the curves through successive 5-day (or weekly in some instances) periods. The resulting groups are listed in table 10 and the summed frequencies for early fall in table 11 and for late fall in table 12. These summed frequencies, converted to equal areas by computing the percentage of fish in each size class were plotted in the "fall" panels of figure 12 and smooth curves drawn either through the points or in such relation to the points that the deviations above and below were in balance and the square of each deviation (in actual, not percentage, numbers of fish) of the curve from the point is less than the number of fish in the class. This is intended to fulfill, roughly, the requirement that the smoothed curve "fits" the empirical data, with a confidence above the P=0.05 level as judged by the chi-square test. Actually no rigorous test is possible for want of definitive knowledge as to the number of degrees of freedom absorbed in such "free-hand" curve fitting.

TABLE 10.—*Organization of data in tables 11 and 12*

Item	Included as "early fall" in table 11		Excluded from tables 11 and 12		Included as "late fall" in table 12	
	Period	Number of fish	Period	Number of fish	Period	Number of fish
1926:						
Purse seine	Sept. 1–Oct. 10	4,060	Oct. 11–Nov. 10	1,420		
Drift gill net					Nov. 11–Dec. 11	873
1927:						
Purse seine	Sept. 1–Oct. 10	3,030	Oct. 11–Nov. 10	580		
Drift gill net			Oct. 11–31	200	Dec. 11–25	1,260
1928:						
Purse seine	Sept. 1–Oct. 10	1,415				
Drift gill net					Oct. 21–Dec. 5	2,540
1929:						
Purse seine	Aug. 21–Sept. 20	1,044	Sept. 21–Oct. 10	55		
Drift gill net			Sept. 21–25	60	Oct. 21–Nov. 15	1,430
1930:						
Purse seine	Aug. 11–Oct. 25	3,015				
Drift gill net			Sept. 21–Oct. 20	70	Oct. 21–Dec. 5	2,453
1931:						
Purse seine	Aug. 11–Oct. 31	3,912				
Drift gill net			Oct. 21–Nov. 10	270	Nov. 11–Dec. 7	1,865
1932:						
Purse seine	Aug. 11–Oct. 5	1,751				
Drift gill net					Sept. 26–Dec. 15	2,535
1933:						
Purse seine	Aug. 27–Sept. 30	3,701	Oct. 1–Nov. 4	3,077		
Drift gill net					Oct. 29–Dec. 14	3,197
1934:						
Purse seine	Sept. 21–Oct. 20	2,338				
Drift gill net					Nov. 13–Dec. 5	1,209
1935:						
Purse seine	Sept. 1–Nov. 11	115				
Drift gill net					Nov. 1–Dec. 20	3,602

TABLE 11.—*Length composition of mackerel in the "early fall" period, 1926 to 1935*

Length in centimeters	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Total
23.0										1	1
25.0										1	1
26.0										1	1
27.0										1	1
27.5										6	6
28.0										16	16
28.5										55	55
29.0									1	115	116
29.5										225	225
30.0					1					397	398
30.5					6					549	555
31.0	1				2				2	673	678
31.5	1				5					632	638
32.0	4	2			8			2	4	518	538
32.5	7	2		1	15	1		8	7	344	385
33.0	13	8		5	20	2	1	36	9	243	337
33.5	11	1		2	18	1		103	12	197	345
34.0	10	2		6	30	2		229	22	378	679
34.5	11	1		4	25	3		389	64	719	1,216
35.0	28	2		6	43	6	3	597	119	1,121	1,925
35.5	66	3		1	107	10	2	615	231	1,262	2,297
36.0	130	4		10	221	13	1	447	217	1,099	2,142
36.5	243	20		30	345	37	3	350	257	748	2,032
37.0	416	53	2	50	468	55	2	175	261	397	1,877
37.5	672	130		74	388	51	2	68	206	175	1,762
38.0	799	295	6	75	274	110	5	26	216	175	1,977
38.5	700	437	15	50	215	208	14	21	145	169	1,962

TABLE 11.—*Length composition of mackerel in the "early fall" period, 1926 to 1935*—Continued

Length in centimeters	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Total
39.0	502	599	41	43	124	419	36	7	129	217	2,093
39.5	203	536	115	30	49	518	55	8	74	141	1,691
40.0	144	389	236	45	35	558	94	11	39	95	1,581
40.5	44	257	254	81	18	400	134	11	33	57	1,266
41.0	15	96	235	92	29	226	152	34	19	33	916
41.5	17	55	174	103	39	119	107	40	37	22	704
42.0	9	39	130	113	53	111	110	65	29	23	675
42.5	4	13	66	58	57	123	129	75	30	33	576
43.0	2	20	37	39	58	148	177	85	32	44	633
43.5	2	12	11	36	77	174	170	75	33	44	625
44.0	2	11	9	12	63	166	185	81	22	53	591
44.5	3	8	17	12	50	124	141	60	30	41	478
45.0	4	8	11	6	46	115	87	45	26	31	372
45.5	4	5	10	8	21	74	63	17	17	32	247
46.0	4	5	8	8	31	61	41	11	9	15	185
46.5	2	3	5	9	17	29	14	2	2	13	94
47.0	1	5	9	8	16	17	10	2	2	2	70
47.5	3	3	7	6	11	12	7	4			52
48.0	4	3	4	4	13	8	3				39
48.5	5	1	4	8	7	2	2	2	2		33
49.0	1	1	4	5	4	6				1	21
49.5	2	1	2	2	1		1				9
50.0	1		2		2						5
50.5					1	1					2
51.0				1	1	1					3
51.5					1						1
52.0				1		1				1	3
54.0			1								1
Total	4,060	3,030	1,415	1,044	3,015	3,912	1,751	3,701	2,338	11,115	35,131

TABLE 12.—*Length composition of mackerel in the "late fall" period, 1926 to 1936*

Length in centimeters	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Total
28.5										1	1
29.5									1		1
30.0				1							1
30.5						1			4		5
31.0									8		8
31.5									12		12
32.0									22		22
32.5									6		6
33.0									9		9
33.5								1	3		4
34.0					1		1	14	5		21
34.5					1		1	11	4		17
35.0					2		5	37	10		54
35.5					1		3	54	14	2	74
36.0				1	4		1	54	32	3	95
36.5				1	14		2	82	46	9	154
37.0	1				59	2	3	86	67	52	270
37.5	1	1		1	107	5	1	76	104	108	404
38.0	2			5	167	12	4	63	152	199	604
38.5	10			6	208	26	4	40	125	414	833
39.0	14	7		10	165	49	16	33	90	569	953
39.5	51	5	3	20	71	77	41	31	52	506	857
40.0	72	27	11	15	42	141	101	62	32	395	898
40.5	109	58	34	10	26	117	167	105	40	222	888
41.0	132	116	76	13	25	86	152	140	36	123	899
41.5	109	161	133	28	25	46	136	184	47	141	1,010
42.0	78	174	226	67	80	27	102	166	57	130	1,107
42.5	34	145	350	110	86	30	75	159	50	146	1,185
43.0	21	106	394	174	111	55	94	143	39	118	1,255
43.5	12	64	364	213	173	84	110	181	24	113	1,338
44.0	15	47	315	224	212	135	177	220	27	72	1,444
44.5	20	34	198	185	225	178	255	250	18	61	1,424
45.0	28	26	123	154	228	215	265	291	24	63	1,417
45.5	32	43	60	91	145	216	253	227	17	45	1,129
46.0	40	52	50	37	101	129	202	145	12	54	822
46.5	38	59	38	26	56	103	143	136	10	23	632
47.0	22	57	39	14	41	54	80	84	3	17	411
47.5	13	30	51	14	28	36	47	50	4	12	285
48.0	6	16	25	7	17	17	34	21	1	2	146
48.5	5	12	23		9	9	21	17		1	97
49.0	4	5	14	2	7	7	16	15	1	1	72
49.5	1	5	6		3	2	13	13	1		44
50.0	2	2	2		4	5	4	3			22
50.5		5			2	1	3	2			13
51.0	1	2	4		2		1	1			11
51.5			1		3		2				6
52.0		1		1	1						3
52.5					1						1
Total	873	1,260	2,540	1,430	2,453	1,865	2,535	3,197	1,209	3,602	20,964

The resulting sets of curves shown in the panels labeled "Fall," in which the curves of the early fall category have been drawn with solid lines and those of the late fall with broken lines, demonstrate that there was a marked difference between the early and the late fall populations every year. The difference was comparable in degree and in character to the differences previously noted in spring. That is, the fall fishery gives evidence of regularly drawing on two different contingents of mackerel, just as was found true of the spring fishery.

NATURE OF THE TWO CONTINGENTS

In applying a name to the two recognizably different parts of the mackerel population the term "contingent" was selected in order to avoid terms such as "race," "subspecies," or "variety," which have acquired particular technical connotation through their use in fisheries and in micro-systematics. The search for a technically noncommittal term has resulted in the choice of a word that is appropriate only in the sense of one of its less common meanings, that is, "any of the local groups of an assemblage" (Webster's New International Dictionary of the English Language, second edition, unabridged, G. & C. Merriam Co., 1944). As used here, the adjective "local" should be omitted from the definition, since it is not desired for the time being, at least, to imply any specific local geographical affinity.

Having adopted a noncommittal term, it is possible, without prejudice, to discuss the nature of the two groups within the mackerel population which are here designated as southern contingent and northern contingent.

For purposes of this discussion the principal reference will be to figure 12. The composition of the frequency distributions described by the curves in the panels labeled "fall" has already been given. The curves in the panels labeled "spring" are the same ones as given in figure 10 omitting the so-called mixed population and smoothing as described for the curves of the fall panels. The curves of the panels labeled "summer" simply are summed frequencies of all mackerel catches sampled between the end of the spring period and the beginning of the fall period (i. e., June 30 of each year, to the particular date listed in table 10 for the beginning of the "early fall" period) converted to percentage and smoothed as described for the curves in the fall panels. Although this assemblage of curves involves omission of some blocks of data [17] it contains all of the characteristic length-frequency groupings found in the catches of the United States vessel fishery for mackerel during the 10-year period except the "mixed" populations of spring and fall as these were defined in the preceding section. The curves on the intermediate size compositions during these periods of mixing are essential to this discussion but could not be included in figure 12 without either making a confusing tangle of lines or multiplying the panels beyond graphic utility.

Reviewing, now, the times and localities represented by the various blocks of data: the catch off the United States coast south of Cape Cod in the springtime was composed purely of the southern contingent except for a brief period in late May and early June (figs. 7 and 8) when members of the northern contingent mixed with them (broken-line curves in fig. 10). In late May and early June also, in years when American mackerel vessels fished along the coast of Nova Scotia they caught only the northern contingent there (broken-line curves in the spring panels of fig. 12). After the brief period of mixing along the United States coast in late May and early June, the catch reverted to southern contingent mackerel and continued to be comprised of such mackerel through summer and early fall. At the latter time or shortly thereafter the southern contingent disappeared and with its disappearance the purse-seine fishery usually terminated. However, at this time northern contingent mackerel appeared in the Gulf of Maine and continued to furnish catches to the drift-gill-netters through late fall and sometimes well into December, before they disappeared and the mackerel fishing season ended.

From this succession of events, practically the only possible conclusion is that the southern contingent is a body of mackerel that appears in early spring well south of Cape Cod, proceeds northerly along the coast and into the Gulf of Maine to spend the summer, and then disappears again in midfall; whereas, the northern contingent appears in late spring briefly off southern New England, moves quickly to the coast of Nova Scotia, and passes out of the range of the modern American fishery, returning again in late fall through the Gulf of Maine as it moves to its winter grounds. Thus, the two contingents are bodies of mackerel of different size

[17] Omitted are (1) all small or yearling mackerel (because not here under consideration), (2) samples prior to May 1 and all drift-gill-net fishery samples of the spring period (these do not differ from the solid line curves in the spring panels of fig. 12 in any way that is material to the present discussion).

composition and different migrating habits. The southern contingent appears earlier in the spring, spends the summer in more southerly waters, and disappears earlier in the fall than the northern contingent. But a large part of the routes of both contingents is through the same waters, and at particular times of the year they are in the same waters together.

Recalling that the two principal spawning grounds of the American mackerel are widely separated, a southern one being in the great oceanic bight between Cape Cod and Cape Hatteras and a northern one in the Gulf of St. Lawrence (Sette 1943), and noting that the southern contingent is on the southern spawning ground in spawning season and the northern contingent, when last evident to our fishery, is well beyond this on a route leading to the Gulf of St. Lawrence prior to the time spawning takes place there, it would appear that the two contingents are well separated from each other when spawning. This separation during reproduction would favor an hypothesis that the two contingents were generically distinct races. Eventually this may prove to be true. For the present, however, it does not appear to be consistent with other evidence, some of which is contained in figure 12.

The most striking features of figure 12 are the prominent modes and their progression to successively greater fish lengths through successive years. Both of these features are so prominent and so consistent that there is no difficulty in identifying homologous modes. Several series of them have been marked with the letters A, B, C, etc. It is obvious that each mode is comprised of a single year class or a group of year classes and the progression of homologous modes is due to growth of the members of the particular year classes. Anticipating the results of a partially completed study of age, it is provisionally determined that mode A is comprised mainly of the 1921 class, mode B of the 1923 class, mode C of the 1928 class and mode D of the 1930 class. The latter apparently was a class of atypically slow growth during early life and was soon overtaken by the 1931 class, so that both the 1930 and 1931 classes contribute to the mode labeled ED from 1932 to the end of the series. Mode F is the 1932 class.

According to this interpretation, a number of year classes were missing or present in very small numbers. It is to the absence of year classes that the wide separation of the modes may be attributed. More important, it is the absence of different year classes in the two contingents, particularly during the first 7 years of the series, that underlies the characteristic difference of the contingents in size composition and permits them to be distinguished one from the other. The consistent absence of mode A in the southern contingent and of mode B in the northern contingent is a prime example of this.

On the other hand, some modes are not as consistently absent from one contingent or the other. Mode C, for instance, was present in both contingents. In 1930 when it first appeared this mode was most strongly represented in the southern contingent. In later years it tended to decline in the southern contingent and increase in the northern contingent. By 1933 and 1934 it had declined in the southern contingent so severely that it was barely perceptible while it still was prominent in the northern contingent. This suggests that members of a year class may transfer from one contingent to another. If this does happen, the genetic strains of the two contingents could not remain distinct.

However, the evidence that members of a year class transfer from one contingent to the other is far from conclusive. The curves of figure 12 are on a percentage basis and a given mode may be prominent or not, depending on the numbers of fish in the remaining portions of the distribution. Thus C declines in the southern contingent when ED joins the stock and fails to decline correspondingly in the northern contingent because new recruits such as ED did not join that contingent in proportionately as large numbers. However, the changes in C relative to B in the southern contingent and C relative to A in the northern contingent are not subject to this effect and could be changed only by a differential mortality, by an emigration out of or by immigration into the stock. The questions then become: (1) In the southern contingent did C decline relative to B due to a higher mortality than B or due to emigration from the stock? (2) In the northern contingent did C increase relative to A in the northern contingent due to a higher rate of mortality in A than in C or due to immigration of C into the stock of the northern contingent?

The first alternative in each instance would not be contradictory to the hypothesis of genetic separation of the two contingents while the second alternative would be. At present, knowledge is not sufficient to definitely select one alternative or the other.

There is the further question: Was the sampling of the two stocks sufficiently representative to warrant the drawing of conclusions from the proportionate heights of the several modes? While I have considerable confidence that the sampling of the catch was not seriously biased in favor of one group of sizes as opposed to another, a similar confidence cannot be placed in the nonselective nature of the fishermen's catch from the existing stock. Indeed, there is abundant indication, especially marked in some seasons, that the several size groups are selectively "available" to the fishery. One particularly marked phase of this will be discussed in a later section.

It is possible that some light may be thrown on this and the two preceding questions by further analyses involving abundance indices. Preliminary work of this nature has suggested that some year classes, as sampled by the commercial fishery, have disappeared from the stock drawn upon by the United States fleet at a moderate rate of about 20 percent per annum and others at a much higher rate in the neighborhood of 80 percent per annum during successive years in the fishery (Sette 1933, 1934). The ones disappearing at a slow rate were termed "persistent" year classes; the ones disappearing at a high rate "transitory" year classes. The rate of disappearance may be due either to mortality or to departure of members of the year class from the stock fished by the United States fleet, or a combination of the two. Since the southern contingent is the principal stock fished by the United States fleet, the departure of members from year classes in this contingent to join the northern contingent would produce the effect noted for the transitory year classes. Those year classes not departing from the southern contingent would diminish only from mortality and so would have some lesser rate of disappearance. Among the year classes classified as persistent or transitory (classes 1923 to 1929, inclusive), and also abundant enough to create prominent modes (classes 1923 and 1928), the 1923 class formed mode B which was consistently present in the southern contingent and consistently absent in the northern contingent, and the 1928 class formed mode C which was relatively more prominent in the southern contingent early in mature life and later became relatively more prominent in the northern contingent. Thus, provisionally at least, the weight of evidence, if not definitely in favor of the shift of individuals from one contingent to the other, at least is sufficiently suggestive of this to prevent adoption of the view that the two contingents maintain their integrity throughout life and from one generation to another, as would be necessary for postulation of genetically separate stocks.

An even simpler view as to the phenomenon underlying the existence of the two contingents, is that mackerel have a southerly distribution when young and comprise the southern contingent and that the mackerel extend their migration farther north as they enter the later years of life and comprise the northern contingent. This would be consistent with the evidence afforded by the 1928 class of mode C but would be utterly contrary to the behavior of the 1923 class of mode B which continued prominent in the southern contingent for more than 9 years and never was represented strongly enough in the northern contingent to be detectable.

Thus it does not seem possible, at present, to define the biological nature of the contingents more explicitly than to say that they are aggregates of mackerel migrating as units that are recognizable by the configurations of their length-frequency curves, and the configurations are sufficiently stable from spring to fall and from one season to another to suggest that the majority of the individuals retain their memberships in the same contingent through a number of years though not necessarily throughout life, nor from one generation to another.

In conclusion, it appears that the adult stock of mackerel contains two populations which migrate along the coast in the springtime, each composed of a different complex of year classes which causes the distinctive size composition by which they are recognized. The one most southerly in the place of its first appearance (off the Virginia Capes) and its final destination (the Gulf of Maine) is termed the southern contingent, while the one more northerly in the place of its first appearance (off southern New England) and in its final destination (Nova Scotia and the Gulf of St. Lawrence) is termed the northern contingent. During a portion of the migration (past southern New England) these contingents are mixed in demonstrable proportions. The southern contingent spends the summer and early fall in waters off New England and disappears in late fall. At about this time the northern contingent populates these waters, presumably on its way from Canadian waters to its winter quarters. Various aspects of the migrations of each contingent remain to be considered in detail. As yet, there is no positive evidence as to whether the two contingents inhabit the same waters in the wintertime and are then mixed, separating when their respective spring migrations are performed, or whether the southern contingent winters mainly in the southerly portion of the warm zone at the edge of the continental shelf, say abreast of Long Island and southward, and the northern contingent winters along the edge from abreast of Long Island and eastward. The respective localities of their first appearance render the latter supposition the more likely.

SPRING MIGRATION OF THE SOUTHERN CONTINGENT

First Appearance

The opening of the mackerel season has from early times held such interest that records of first catches were often published. Many of these were assembled by Sette and Needler (1934: 38–39), four by Goode, Collins, Earle, and Clark (1884: 9) and 10 more during the present investigations. From the date of earliest catch in each of the 56 seasons for which this datum is available (fig. 13) it may be calculated statistically that the average date for the opening of the season is April 11, that usually (two out of three times) it opens between April 3 and 19. Since mackerel often may be present some days before the first catch, the date of appearance of the mackerel (as distinguished from the date of catching) must be somewhat earlier and probably is somewhat less variable.

From the 29 available records on the locations of first catches listed in table 13 and plotted in figure 14, it is obvious that the first mackerel of the season are most frequently taken along the outer third of the continental shelf between the thirty-seventh and thirty-eighth parallels of latitude, though they occasionally are found as far south as latitude 35°20′ (near Cape Hatteras) or as far north as latitude 39°0′ (80 miles off Atlantic City) a spread of 200 miles parallel and 60 miles vertical to the coast line. When taken north of latitude 37° (mouth of Chesapeake Bay), they are inclined to be at the outer edge of the shelf, and when south of latitude 37° they may be either inshore or offshore.[18]

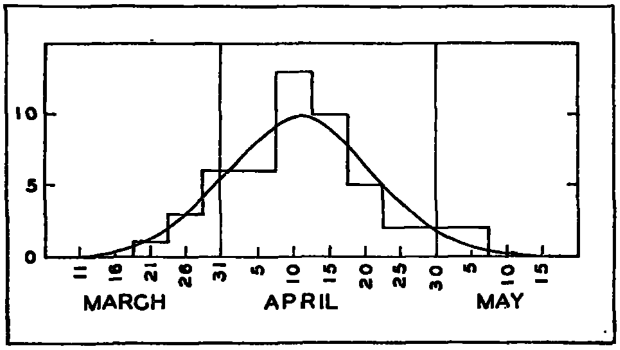

Figure 13.—Date of first catch of the season in various years during the period 1878 to 1935. The histogram represents the number of times the first catch fell in each 5-day period, and the smooth curve describes the corresponding normal probability.

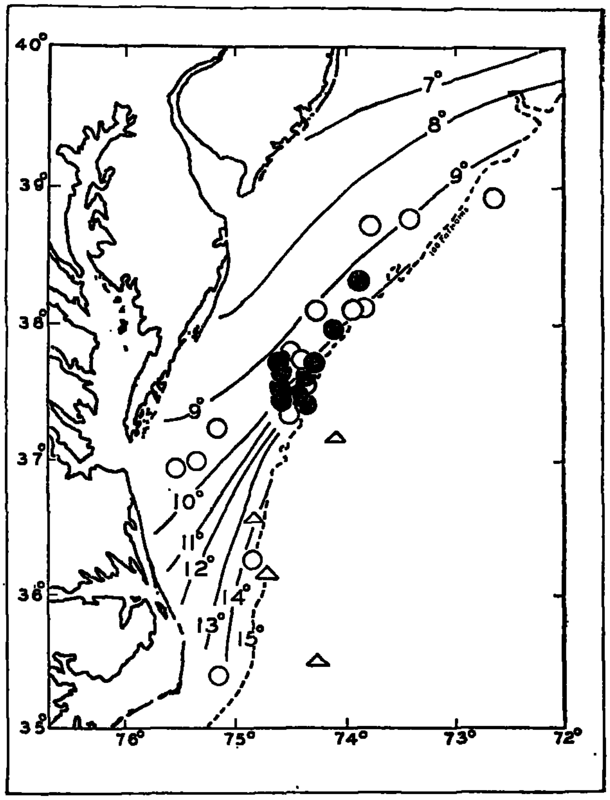

Figure 14.—Position of first catches in each of 29 seasons. Triangles represent seasons 1878 to 1881; open circles, various seasons, 1887 to 1925; solid-black circles, seasons 1926 to 1935. The isotherms relate to the period April 3 to 11, 1930, and illustrate the distribution of surface temperatures at this season.

[18] Although 3 of the 29 positions are well outside the continental shelf area, we are not inclined to place much emphasis on these offshore records because mackerel fishermen for the most part determine their position by "dead-reckoning" and on the long course runs in this southern fishery, a slight lack of precision in designating a bearing or estimating the speed of sailing might easily put the supposed position a number of miles from its true one; and as none of these catch records were particularly noted as being beyond soundings it may be doubted that they were as far offshore as indicated.

TABLE 13.—*Date and locality of "first catch of the season" of mackerel* [1]

Year	Date	Locality
1878	Apr. 16	Lat. 36°10′ N., long. 74°45′ W.
1879	Apr. 12	Lat. 36°35′ N., long. 74°50′ W.
1880	Apr. 1	Lat. 35°30′ N., long. 74°15′ W.
1881	Mar. 20	Lat. 37°10′ N., long. 74°05′ W.
1887	Apr. 21	Lat. 37°20′ N., long. 70°30′ W.
1895	Apr. 17	Lat. 36°20′ N., long. 74°50′ W.
1902	Apr. 9	100 miles south of Barnegat Light.
1903	Apr. 13	85 miles southeast of Barnegat Light.
1904	Apr. 7	30 miles east of Cape Henry.
1905	Apr. 10	40 miles off Cape Henry.
1911	May 1	70 miles southeast of Cape Henlopen.
1914	Apr. 22	50 miles east by north of Cape Charles.
1915	Apr. 9	100 miles east by south of Cape Henlopen.
1916	Apr. 5	80 miles east by south of Cape Henlopen.
1920	Apr. 14	35 miles southeast of Winterquarter Light.
1921	Apr. 7	Lat. 37°50′ N. in 32 fathoms.
1923	Apr. 9	Lat. 37°50′ N. in 30 to 40 fathoms.
1925	Apr. 13	35 miles southeast of Fenwick Island.
1926	Apr. 10	Lat. 37°35′ N., long. 74°35′ W.
1927	Apr. 18	70 miles south ½ east of Cape May.
1928	Apr. 9	25 miles southeast of Winterquarter Lightship.
1929	Apr. 8	75 miles south by east of Cape May.
1930	Apr. 5	80 miles south of Five Fathom Bank Lightship.
1931	Apr. 9	43 miles south of Fenwick Lightship.
1932	Apr. 15	49 miles south of Fenwick Lightship.
1933	Apr. 10	70 miles south-southeast of Cape May.
1934	Apr. 14	90 miles south of Cape May.
1935	Apr. 5	60 miles southeast of Cape May.

[1] Records of 1878 to 1881 from Goode, Collins, Earle, and Clark 1883, p. 9; records of 1887 to 1925 from Sette and Needler, pp. 38–39; records of 1926 to 1935 from present investigations.

VERNAL ADVANCE

After mackerel of the southern contingent first appear in coastal waters they are caught progressively farther north as indicated by figure 7. As earlier mentioned, this has been considered by some as a migration *en masse* of the whole population, by others as separate bodies of mackerel successively approaching coastal waters from directly offshore. My own observations lead to the belief that it is a mass migration but that the main body, as it moves northeasterly parallel to the coast is joined by lesser bodies of fish from farther offshore.

That it is a mass migration is supported by the almost complete disappearance of the mackerel from the region south of Long Island after the brief but productive fishing period in April and May, and by the relatively constant size composition of the population each spring as the fishery advances from the offing of Virginia to southern New England.

That additional schools join the main body as it advances along the coast is indicated (1) by occasional slight changes in size composition of the population, and (2) by the more frequent instances in which bodies of mackerel of slightly different size composition are taken well in advance of the main fishing area, as if the new school had come inshore at a point ahead of the main body.[19]

The passage up the coast is fairly rapid, the center of fishing shifting from the Virginia coast to the Massachusetts coast, a distance of 300 miles, in about 6 weeks. Reaching the neighborhood of southern New England in the midle of May, the southern contingent tarries for nearly 6 weeks; and it is not until nearly the first of July that it usually deserts this ground. In doing so the main body appears to go by way of the southern edge of Nantucket Shoals and through South Channel, judging from the daily shift of the fleets' catches. This does not preclude the possibility of considerable numbers going through Vineyard and Nantucket Sounds or passing right over the Shoals. That some take the route through the Sounds is indicated by catches in pound nets along their shores; that the main body does not do so is evident from the small quantities so caught.

Having passed Nantucket Shoals and arrived in the Gulf of Maine, the southern contingent has reached the grounds of its summer sojourn.

SPRING MIGRATION OF THE NORTHERN CONTINGENT

FIRST APPEARANCE

As previously noted, the mackerel that cause the abrupt alteration in the size composition of the population in southern New England each May are members of the northern contingent; and the alteration is evidence of their first appearance each spring. In Nova Scotia their first appearance is evident simply from the date of the first catch of mackerel. These dates appear in table 14. They refer mostly to the vicinity of Yarmouth. For the 6 years included in the table, the first appearance has been between May 12 and 28 in southern New England

[19] A further argument, based on spawning maturity, is that a "run" of mackerel reaching a given locality often consists of individuals about ready to spawn. Hence the new runs come from offshore rather than from along shore over grounds where mackerel had already spawned. This argument probably is baseless. Moore (1899: 5) found several size classes of eggs in the ovaries of spring-caught mackerel. The existence of such size groups in mackerel ovaries was verified by F. E. Firth (unpublished notes) in the present study. Although Moore's interpretation was that each size group was a season's batch of eggs, it now seems more likely that the groups are due to be spawned at intervals during the season, as was found for the pilchard, *Sardinops caerulea*, (Clark 1934), for the jack smelt *Atherinopsis californiensis* (Clark 1929), and for the grunion, *Leuresthes tenuis*, (Clark 1925). If this holds true also for the mackerel, appearance of near-ripe individuals in the catch is neither proof that they did not spawn previously nor indication that they came directly from offshore.

and between May 21 and June 4 in Nova Scotia. But the dates of appearance in southern New England of necessity refer not to the very first arrivals of members of the northern contingent, for a few such mackerel would not be detected among the larger numbers of individuals of the southern contingent already there. They refer rather to the arrival in southern New England waters of large numbers of the northern contingent, and for comparability the earliest date of catching large quantities in Nova Scotia must be used. These dates lie between May 24 and June 7 and the lag behind the southern New England appearance is from 0 to 22 days, averaging 12 days over the period in question.

TABLE 14.—*Dates of arrival and departure of the "northern contingent" off southern New England,*[1] *and dates of arrival off Nova Scotia*[2]

Year	Off southern New England		Off Nova Scotia		Number of days between arrival off Southern New England and first catches of large quantities off Nova Scotia
	Arrival	Departure	First catch	First catches of large quantities	
1926	May 28	June 15	May 25	May 28	0
1927	May 16	June 9	do	June 5	20
1928	do	June 6	June 4	June 7	22
1929	May 24	June 7	May 28	June 3	11
1930	May 12	June 2	May 24	May 24	12
1931	May 17	June 6	May 21	May 26	9

[1] As indicated by alteration of the size composition in purse seine catches.
[2] As reported by the Gloucester, Mass., *Times* and the Boston Fish Bureau.

The locality where the northern contingent appears has varied from year to year. During the period in question in southern New England, it has usually been along a rather broad front from as far west as the offing of the eastern end of Long Island (long. 72° W.) to as far east as the vicinity of the Nantucket Shoals Lightship (long. 69°40′ W.), a range alongshore of over 100 miles. Sometimes the first catches of mackerel have been made far inshore. In 1927, for instance, they were first taken close to Block Island. Whether or not this indicates the mackerel of this contingent usually keep to deep levels until close in to land before rising to the surface is not evident from our available information, because fishermen, as a rule, have not explored the offshore waters in this sector, their attention usually being occupied by the southern contingent up to the time the northern contingent appears.

The locality where the northern contingent first appears in Canadian waters in recent years has usually been at the southwesterly end of Nova Scotia.[20] During the 7 years 1926 to 1932, United States purse-seiners fishing off Nova Scotia have located their first mackerel at various points along the coast from off Yarmouth to Scatari Island, but on no occasion were these catches made on dates earlier than mackerel reported (by the press or by trade bulletins) at Yarmouth. Until additional data are available on this subject it would seem that mackerel strike in along a considerable extent of the Nova Scotia coast almost simultaneously but with a general tendency to arrive earliest at the southwesterly end.

VERNAL ADVANCE

Since the northern contingent appears in two widely separated regions, southern New England and Nova Scotia, the advance from each place will be considered in turn.

Off southern New England the northern contingent, having appeared along the coast from Long Island to Nantucket Shoals, rapidly moves eastward, usually reaching the southern border of Nantucket Shoals in about 2 weeks. From here the major portion goes to the coast of Nova Scotia and a minor portion enters the Gulf of Maine. The course taken is somewhat in doubt, but it is probable that the mass movement is directly across the outer portion of the Gulf of Maine (Georges Bank), with a small fraction rounding Cape Cod into Massachusetts Bay, and still others circling back from the southwestern tip of Nova Scotia, thence, along the coast of Maine and even down to Massachusetts Bay. Pound nets, traps, and weirs, located along the shores of that Bay, according to daily catch records during four recent years, usually take their first mackerel earliest at Gloucester, next at Provincetown, and last at Sandwich and Barnstable, strongly suggesting a north to south movement such as would result from the fish circling back. On the other hand, the usual absence of catches along the coast of Maine this early in the season casts doubt upon it.

Whatever course may be taken by those of the northern contingent that enter the inner parts of the Gulf of Maine, it is evident from the small catches here,[21] that only a small fraction of the northern

[20] Huntsman (1922), on the contrary, reported earlier appearance at Cape Breton (May 5) than at Yarmouth (May 16) in 1894.

[21] Later, when the southern contingent enters the Bay, the catches become large. That these larger catches are of the southern rather than the northern contingent is obvious from the sizes of the individuals caught.

contingent is involved and that the major portion goes to the coast of Nova Scotia where it supports an important Canadian shore fishery and where, in many seasons, American purse seiners make large catches offshore.

Information on the advance of the major portion of the northern contingent along the Canadian coast is somewhat meager. During the 10 years of this investigation, only in 1926 did the purse-seine fleet fish along the Nova Scotian coast over a long enough period to cast some light on this question. From table 15 it is evident that the fishery took place off the central portion in the first few days of June, off the eastern portion between the 5th and 10th and in the Canso region between the 11th and 15th of June. Although the fishery progressed along the coast, it cannot be assumed that the fish did.

TABLE 15.—*Progress of mackerel along the Nova Scotian coast in 1926 as indicated by the number of catches made by United States mackerel purse-seiners in each area each day*

Date	Area XXII O (southern Nova Scotia)	Area XXII M (central Nova Scotia)	Area XXII K (eastern Nova Scotia)	Area XXII D (Canso)
May 30		1		
May 31		1		
June 1		4		
June 2		3		
June 3				
June 4		2		
June 5		2	3	
June 6	1	1	1	
June 7		1	2	
June 8			2	
June 9			4	
June 10			2	1
June 11		3	7	5
June 12		1		8
June 13				5
June 14			1	
June 15				4

Samples of the catches taken during this period (table 16 and fig. 15) indicate considerable differences in size composition of the schools. Throughout the period there are two modes located at about 40 and 46 centimeters, respectively, but the relative numbers of fish in those modes shift from nearly equal representation in the early days to a marked preponderance in the 40-centimeter mode in the late days of the period. Moreover there are changes within these modes, the modal length in the 40-centimeter group shifting downward and in the 46-centimeter group shifting upward.

This, I believe, indicates (1) that in 1926 there was a mass movement of mackerel northeasterly

TABLE 16.—*Sizes of mackerel taken by purse seines along the Nova Scotian coast in the spring of 1926*

[Periods May 30 to June 2, June 4, to 9, and June 10 to 15 are represented by samples of 6, 13, and 29 catches, respectively]

Length in centimeters	May 30–June 2		June 4–9		June 10–15	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
36.0					1	0.1
36.5					1	.1
37.0			1	0.2	4	.4
37.5			2	.4	4	.4
38.0	1	0.2	5	.9	18	2.0
38.5	2	.5	12	2.2	38	4.2
39.0	8	1.9	24	4.4	73	8.1
39.5	11	2.6	52	9.6	136	15.1
40.0	24	5.7	71	13.1	164	18.2
40.5	36	8.6	81	15.0	154	17.1
41.0	35	8.3	89	16.5	115	12.8
41.5	26	6.2	38	7.0	51	5.7
42.0	18	4.3	25	4.6	33	3.7
42.5	15	3.6	17	3.1	12	1.3
43.0	12	2.9	11	2.0	6	.7
43.5	13	3.1	8	1.5	1	.1
44.0	22	5.2	5	.9	5	.6
44.5	25	6.0	7	1.3	8	.9
45.0	28	6.7	14	2.6	6	.7
45.5	24	5.7	16	3.0	4	.4
46.0	26	6.2	14	2.6	18	2.0
46.5	27	6.4	14	2.6	13	1.4
47.0	22	5.2	12	2.2	10	1.1
47.5	14	3.3	6	1.1	9	1.0
48.0	9	2.1	5	.9	2	.2
48.5	7	1.7	3	.6	4	.4
49.0	4	1.0	3	.6	2	.2
49.5	2	.5	2	.4	4	.4
50.0	4	1.0	1	.2	1	.1
50.5	3	.7	1	.2	1	.1
51.0	1	.2			1	.1
51.5	1	.2				
52.0					1	.1
52.5			1	.2		
Total	420	100.0	540	99.9	900	99.7

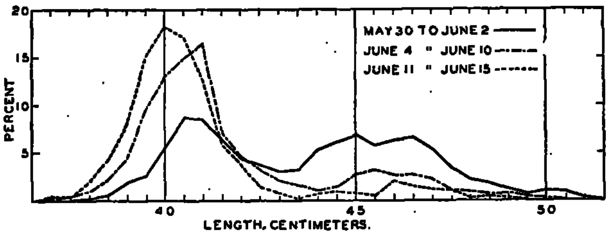

FIGURE 15.—Changes in mackerel population along the coast of Nova Scotia in the spring of 1926, as indicated by length-frequency distributions.

alongshore causing the fishery to shift in that direction, and (2) that schools from offshore (or from places not previously fished by the fleet from which our samples were taken) joined those already alongshore in sufficient numbers to change the size composition of the alongshore population. Inasmuch as the change in size composition took place in central Nova Scotia as well as eastern Nova Scotia and in the Canso region, the new schools joining those already there must have done so along a broad front extending from Halifax to Cape Canso.

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.

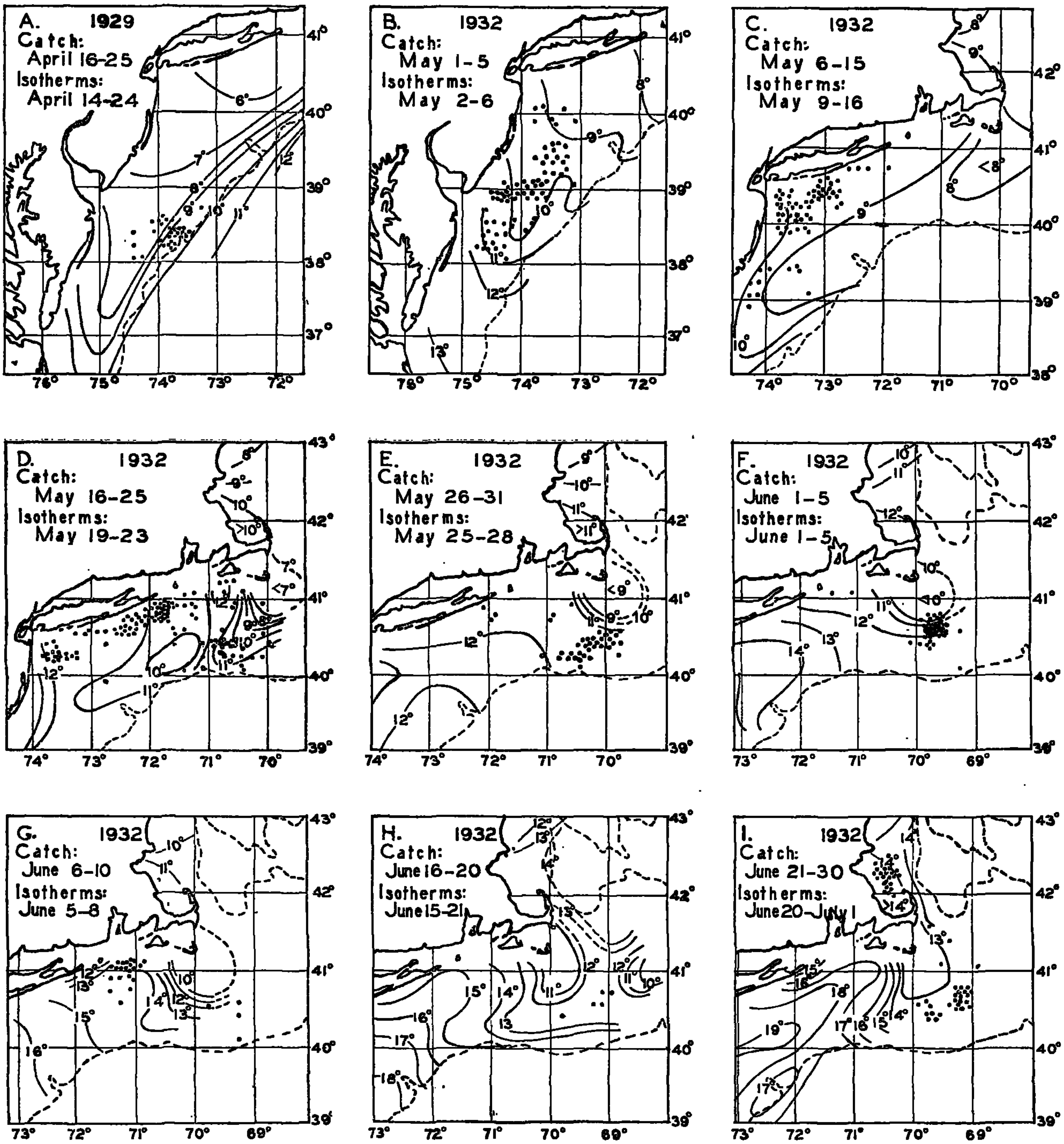

FIGURE 16.—Distribution of mackerel catches (shown by dots) during successive time intervals during the springtime in relation to surface temperatures (shown by isotherms for each degree centigrade).

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

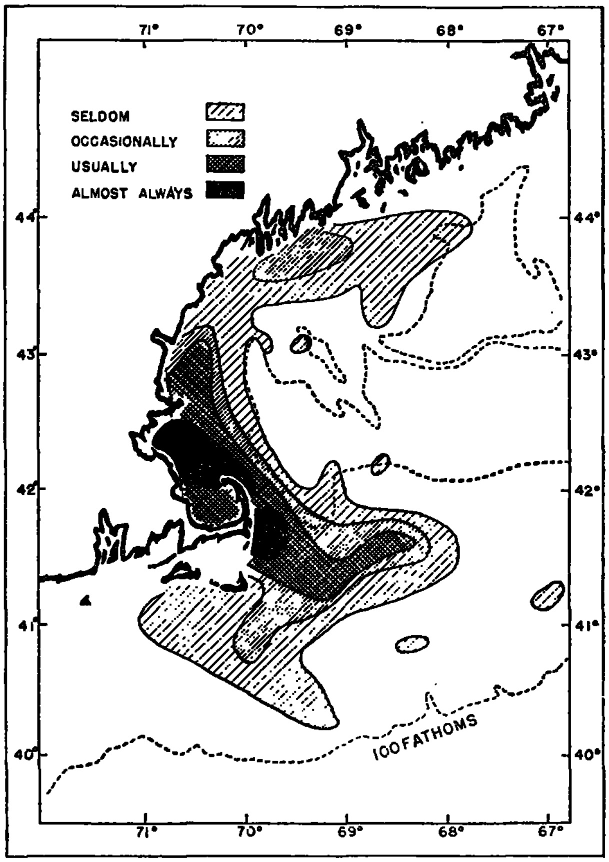

FIGURE 17.—Prevalent distribution of mackerel in the Gulf of Maine during July, August, and September, during the 10 years of investigation, as indicated by the number of seasons that catches were recorded from each 10-minute rectangle on the scale: "seldom," 1–2 seasons; "occasionally," 3–5 seasons;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

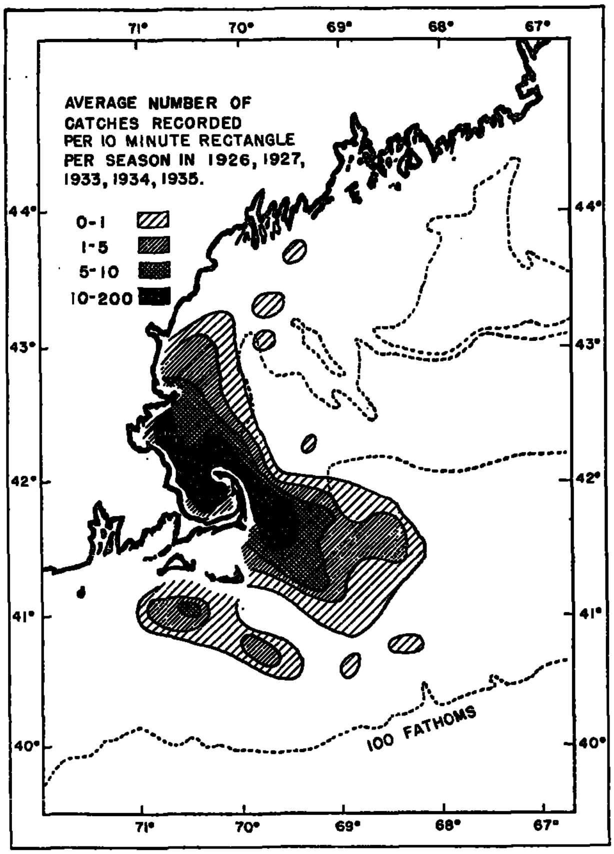

FIGURE 18.—Relative concentration of mackerel schools in 1926, 1927, and 1933–35 during the months of July to October, inclusive, as indicated by the average number of catches made per 10-minute rectangle per season by purse-seine vessels.

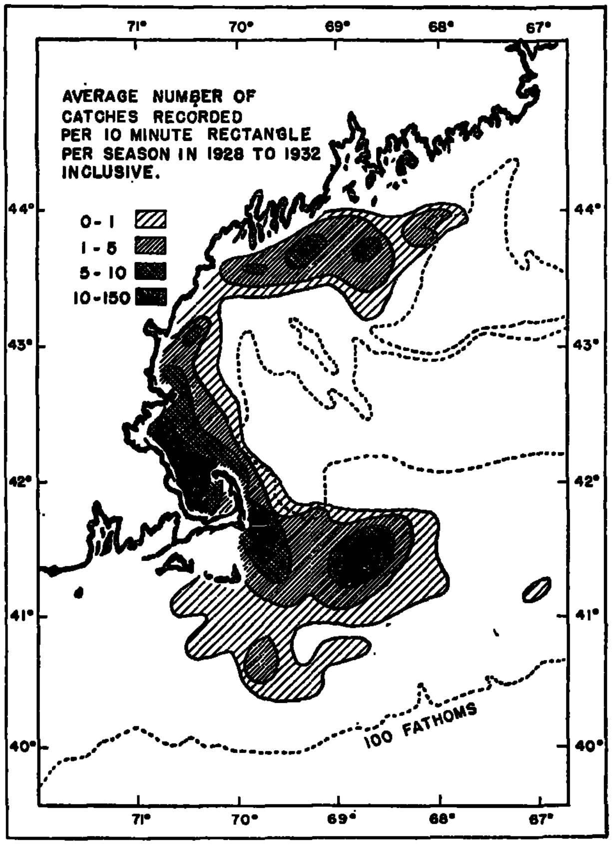

FIGURE 19.—Relative concentration of mackerel schools during July to October, inclusive, during the years 1928 to 1932, inclusive, as indicated by the average number of catches made per 10-minute rectangle per season by purse-seine vessels.

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 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

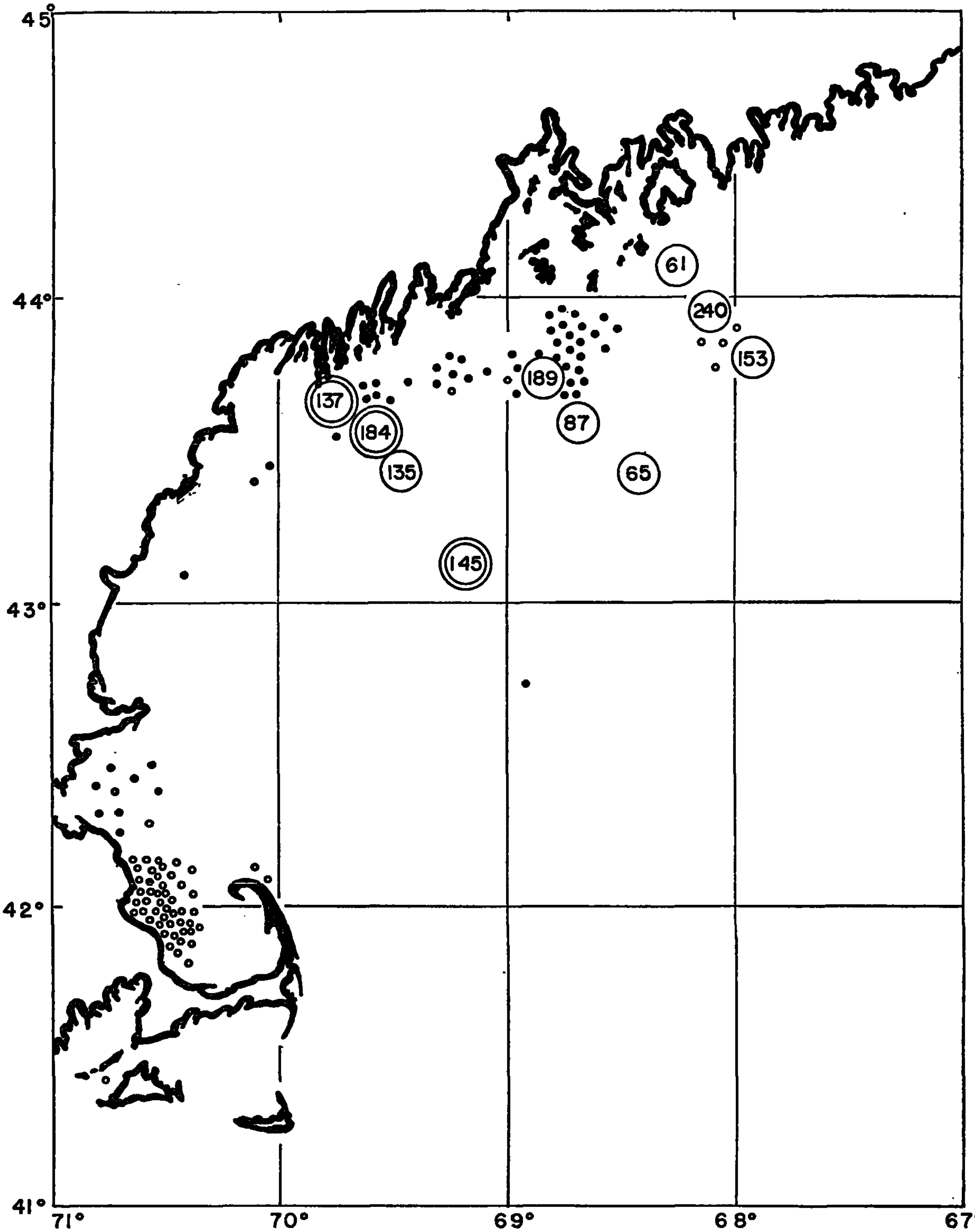

FIGURE 20.—Distribution of mackerel catches and of zooplankton in the upper 50-meter stratum of the waters of the Gulf of Maine in late August 1932. Solid dots indicate catches of large, and small, open circles catches of small, mackerel during August 6 to 20, 1932. Large circles indicate the position 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.

APPENDIX A.—LENGTH-FREQUENCY RECORDS

Most of the evidence upon which the conclusions of this paper rest consist of the results of tagging experiments and of the length composition of the mackerel stock as it is known from the measurement of samples from the commercial catch. The tagging results are recorded in appendix B. In this appendix will be given the basic records of size composition.

COMMERCIAL CATCH

From the statistics of 1927 to 1930 it may be estimated that the offshore fleet accounts for approximately 70 percent of the total catch and that miscellaneous alongshore fisheries, mainly inshore small-boat gill nets, pound nets, and traps, account for the remainder (Sette and Needler 1934: 16 and 23). Of the offshore fleet's catch, about 90 percent is taken by purse seiners and 10 percent by drift-gill-netters (Sette and Needler 1934: 23).

Purse-seine vessels, known as "seiners," are relatively large, averaging in 1929 about 35 net tons (register measure), and they carry crews of about 12 men, while the drift-gill-netters, known as "netters," are smaller, averaging below 20 net tons, and carry about 7 men. As might be expected, the seiner catches normally are larger than the netters' catches. Seiners fish throughout the "mackerel season" while netters typically fish only in spring and fall.

During this investigation Gloucester was the home port for most of the vessels of both fleets, with a few fishing out of Boston. Although based on Gloucester, the fleet delivered most of its catch to other ports. In a typical season about one-third of the seiner fleet sailed early in April to engage in the "southern" fishery off the Virginia capes, landing their early catches at Cape May, Wildwood, and sometimes Atlantic City, N. J. By May nearly the entire fleet was out and the fishing was off the New Jersey-Long Island coast, with most of the catch landed at New York. Toward the end of May the fishing area was mainly off the southern New England coast with some of the catch going to New York and some to Boston. At this time a portion of the fleet customarily sailed for the Nova Scotian coast ("Cape Shore"). These vessels brought their fares back to Boston and rarely made more than one Cape Shore trip. By mid-June the entire fleet was usually fishing in the Gulf of Maine and landing the fish at Boston and Gloucester. Boston usually received mackerel most regularly, with fares going to Gloucester for salting and canning mainly when the fresh-fish market and freezers were glutted with mackerel.

SAMPLING THE CATCH

With one man regularly available to sample the catch, it was possible to cover the entire range of the vessel fishery by starting at Cape May in April, shifting to New York as soon as landings were substantial there and, finally, to Boston as soon as a substantial portion of the landings were made there. Since it was not always possible to anticipate the shift of landings from one port to another, sometimes there was a gap of several days in the sampling series. On the other hand, it was possible sometimes to have samples taken at several ports simultaneously when extra employees were available.

Sampling was done daily, and samples were drawn from as many fares as time permitted. Often samples were taken from every fare arriving at the port, though when landings were numerous this was not possible. On the average, samples were taken from about 800 seiner catches and from about 200 netter catches each season. This was equivalent to about 28 percent of the total number of seiner catches and about 24 percent of the total number of netter catches per season.

In taking a sample, first the skipper or a responsible crew member of the vessel was questioned as to the date, time, and locality of catch, and the number of sets made. Then, as the mackerel were unloaded, a number of mackerel, taken at random, were measured. The standard number for a sample was 20 fish, but when opportunity afforded and special purposes were in view, 40, 50, or 100 fish were measured.

In addition to his sampling of the vessel fishery, the regular sampler was often able to take measurements of trap-caught mackerel from known sources shipped overland to the principal ports; also, at Woods Hole, Mass., Montauk, N. Y., and occasionally other alongshore localities, trap and pound-net mackerel were measured by personnel primarily engaged in other duties. The coverage of this pound-net and trap fishery was far less thorough and less consistent than the vessel fishery. It varied from 8 samples containing 300 fish in the season of minimum sampling to 250 samples containing 13,000 fish in the season of maximum sampling during the 10 years included in this investigation.

MEASURING THE FISH

Measurements were taken on a measuring board having a nose block at one end and a measuring scale inlaid along the middle of the board. Since it was often necessary to employ the measuring board in places where it could not be set on a horizontal surface, additional beveled blocks were set along the longitudinal margins of the board to form a trough that not only prevented the fish from sliding off the board but also gave some assurance that the fish was correctly positioned on the board. In measuring, the fish was laid on the board, after flexing when rigor mortis was present, so that the snout was lightly pressed against the nose piece and the longitudinal axis of the body lay along the graduated scale. The latter was graduated in half-centimeters and offset one-quarter centimeter from the nose block. By reading to the first graduation mark unobscured by the tail, a measurement was obtained which gives the straight-line distance from tip of the snout to the tip of rays at the middle of the fork of the tail to the nearest half centimeter. The length therefore corresponds to the measurement which Ricker and Merriman (1945: 185) have named "median length" and for which they recognize also the alternative designations of midcaudal length or fork length.

To avoid personal bias in favor of whole or half-centimeter marks, the measuring scale had uniform graduation marks and they were serially numbered. In addition to avoiding bias, this had the advantage of giving two-digit numbers for all listings and computations, the data being divided by two for conversion to centimeters only at the final stage of work.

SUMMARIZING THE DATA

Data on the locality of catch were received from the fishermen in terms of distance and bearing from headlands. For purposes of portraying the distribution of catches, they were plotted on mercator projection charts and summarized by 10-minute rectangles of latitude and longitude. But such fine divisions were not practical for summarizing the length-frequency records, so the much coarser pattern of statistical areas adopted by the North American Council on Fishery Investigations was used to classify the samples by catching locality. This system designates the larger regions by Roman numerals and their subdivisions by capital letters. Since the North American Council had not subdivided its area XXIII, we have divided it into subareas for the purposes of this investigation. The North American Council statistical areas and subareas as they existed at the time of this investigation, and our own subareas for area XXIII are shown in figure 1 for mackerel fishing waters. Some of the North American Council's subarea boundaries have since been revised but not in places materially affecting the locality designations used in this report.

For purposes of summarizing the records by periods of time, two basic units were used: 5-day periods and half-month periods. In 31-day months the final "5-day" period of a month actually contained the 6 days running from the 26th to the 31st, inclusive, and the final half-month contained 16 days running from the 16th to the 31st, inclusive. In 1933 and 1934 the purse-seine fleet operated under a system of limitations intended to curtail the landings. This system affected the activities of the fleet by time units of calendar weeks, and for these two seasons our data were summarized by calendar week and calendar biweekly units of time.

DATA INCLUDED

In the present study of migrations by the method of size-composition comparisons, use is made of the length-frequency distribution in geographical units of statistical subareas and in time units of 5-day periods (weekly periods in 1933 and 1934). The tables in this appendix are intended to give the source data and should be in the same units. However, to save space, the data have been combined by 10-day periods in certain instances where the frequency curves were similar in successive 5-day periods. Furthermore, to conserve space it has been necessary to omit certain entire categories of data. These were selected so as to minimize the loss of evidence significant to migrations. Omitted are:

1. All samples from pound-net and trap catches. These were taken intermittently, at only a few points along the coast and are not adapted to systematic portrayal of size-composition changes in time and space. Insofar as comparable place and time records are available, the size composition of mackerel catches of traps and pound nets in spring is

similar to that of the purse-seine catches in spring. In summer, however, the pound nets and trap catches lack the adult sizes of mackerel.

2. All samples from spring and summer drift-gill-net catches. These differ from the purse-seine catches slightly. Because the differences may be due to mesh selection, it is doubtful whether or not they represent a true difference in the population sampled by this fishery.

3. All samples of yearling and younger mackerel, where occurring unmixed with adult mackerel, in summer and autumn catches. These are to be presented in detail in a report to be prepared on the subject of growth rates.

4. All samples from the summer purse-seine fishery; however, a summary table of length-frequences for the summer-fishery samples as a whole is given in table 24.

5. All samples prior to May 1 of each year. The mackerel catches prior to May 1 were so nearly identical in size composition with those from the first half of May that the latter serve to give the early-spring composition.

The remaining data cover the seasons, spring and fall, when evidence of migrations is given by changes in size composition. Table 20 gives a list, by date and statistical subareas, of number of fish measured; and table 21 gives the length frequencies of these measurements, by date groups and statistical subareas, for May and June of each year. The corresponding data for the fall fishery are given in tables 22 and 23. For the year 1933 a discrepancy will be noted between the numbers of fish listed in tables 22 and 23. This is due to the omission from table 23 of mackerel under 32 centimeters.

TABLE 20.—*Numbers of mackerel from purse-seine catches measured in May and June from statistical areas XXII and XXIII, by date and statistical subarea*

1926 [1]

Date	Area XXIII				Area XXII											
	C	B	B [2]	A	R	R [2]	Q	Q [2]	P	P [2]	O	G	G [2]	E	E [2]	D [2]
May 3	40															
May 4	160															
May 5	140															
May 6	80															
May 7	[3] 320	40														
May 8	[3] 180	100														
May 10	[3] 40	280														
May 11		280														
May 12		300														
May 13		40														
May 15				60												
May 17		20	200	60												
May 18		60	80													
May 19		20	80	20												
May 20			240													
May 21			120													
May 22		20	80													
May 24			180													
May 25			40													
May 28						60				20						
May 29						40										
June 1						20		120		100					80	
June 2															40	
June 3															100	
June 4															140	
June 5															79	
June 7															120	
June 8															20	
June 9															140	
June 10														80	80	
June 11										40				200	80	80
June 12						40								20	80	
June 14		20					60				20				200	20
June 15										20						40
June 16							80									
June 17							40				40				40	
June 18							120		40							
June 19					40		140		20							
June 21					80				20		100					
June 22							120		20		100				20	
June 24					40							40				
June 25					200										40	
June 26												80				
June 28												300	20		60	
June 29												240	20			
June 30					20							40			20	

[1] In addition to the numbers listed in the table for 1926, there were 620 mackerel measured from drift-gill-net catches in area XXIII during the period from May 1 to 15 that were unclassified as to date and subarea and 20 each from purse-seine catches on May 7, 8, and 10 that were unclassified as to subarea.
[2] From drift-gill-net catches.
[3] Includes 20 fish not classified by statistical subarea.

TABLE 20.—*Numbers of mackerel from purse-seine catches measured in May and June from statistical areas XXII and XXIII, by date and statistical subarea*—Continued

1927

Date	Area XXIII				Area XXII				
	D	C	B	A	S	R	Q	P	O
May 1	160	60	----	----	----	----	----	----	----
May 2	140	460	----	----	----	----	----	----	----
May 3	20	140	----	----	----	----	----	----	----
May 4	----	240	100	----	----	----	----	----	----
May 5	----	60	20	----	----	----	----	----	----
May 6	----	140	260	----	----	----	----	----	----
May 7	----	54	99	----	----	----	----	----	----
May 9	----	20	376	26	----	----	----	----	----
May 10	----	----	[4] 139	----	----	----	----	----	----
May 11	----	----	100	----	----	----	----	----	----
May 12	----	----	60	----	----	----	----	----	----
May 13	----	----	60	----	----	----	----	----	----
May 14	----	----	20	----	----	----	----	----	----
May 17	----	----	----	----	----	----	40	----	----
May 20	----	----	----	----	100	----	100	----	----
May 21	----	----	----	40	80	----	[5] 200	----	----
May 22	----	----	----	----	----	----	120	20	----
May 23	----	----	----	----	80	----	250	20	20
May 24	----	----	----	----	----	----	80	----	----
May 25	----	----	----	----	20	----	60	----	----
May 26	----	----	----	----	----	----	60	----	----
May 27	----	----	----	----	----	----	140	----	----
May 28	----	----	----	----	----	----	250	----	----
May 31	----	----	----	----	----	----	160	20	40

Date	Area XXIII				Area XXII				
	D	C	B	A	S	R	Q	P	O
June 1	----	----	----	----	----	20	100	20	40
June 2	----	----	----	----	----	20	420	----	20
June 3	----	----	----	----	----	----	220	----	40
June 4	----	----	----	----	----	----	300	----	20
June 5	----	----	----	----	----	----	20	----	----
June 6	----	----	----	----	----	----	180	----	----
June 7	----	----	----	----	----	----	120	----	----
June 8	----	----	----	----	----	----	160	----	80
June 9	----	----	----	20	20	----	200	40	120
June 10	----	----	----	----	60	----	160	----	60
June 11	----	----	----	----	100	----	240	----	40
June 12	----	----	----	----	----	----	20	----	----
June 13	----	----	----	120	----	20	280	----	160
June 14	----	----	----	----	140	----	200	----	100
June 15	----	----	----	----	----	----	100	----	440
June 18	----	----	----	----	----	----	40	100	360
June 22	----	----	----	----	----	----	80	----	----
June 23	----	----	----	----	----	60	60	----	[6] 20
June 24	----	----	----	----	----	40	160	----	----
June 25	----	----	----	----	60	20	[5] 180	----	----
June 27	----	----	----	----	40	----	200	----	----
June 28	----	----	----	----	40	----	[7] 160	40	----
June 29	----	----	----	----	----	----	180	20	[6] 20
June 30	----	----	----	----	60	----	180	20	----

[4] Includes 39 not classified by subarea.
[5] Includes 20 not classified by subarea.
[6] From XXII D.
[7] Includes 40 not classified by subarea.

1928

Date	Area XXIII			Area XXII			
	C	B	A	R	Q	P	O
May 7	20	20	----	----	----	----	----
May 8	----	140	----	----	----	----	----
May 10	----	40	----	----	----	----	----
May 11	----	80	----	----	----	----	----
May 14	----	238	20	----	----	----	----
May 15	----	240	----	----	----	----	----
May 16	----	160	40	----	----	----	----
May 17	----	296	100	----	----	----	----
May 18	----	240	180	----	----	----	----
May 19	----	180	20	----	----	----	----
May 21	----	100	80	----	----	----	----
May 22	----	20	140	----	----	----	----
May 23	----	----	120	----	----	----	----
May 24	----	20	186	----	20	----	----
May 25	----	----	140	----	20	----	----
May 26	----	----	----	40	80	----	----
May 28	----	----	----	120	60	----	----
May 29	----	----	----	109	----	----	----
May 31	----	----	----	20	100	60	----
June 1	----	----	----	----	140	----	----

Date	Area XXIII			Area XXII			
	C	B	A	R	Q	P	O
June 2	----	----	----	----	60	20	----
June 5	----	----	----	----	120	----	----
June 6	----	----	----	----	100	60	----
June 9	----	----	----	----	200	60	----
June 11	----	----	----	----	160	40	----
June 12	----	----	----	----	260	40	----
June 13	----	----	----	20	140	60	----
June 14	----	----	----	----	143	----	----
June 15	----	----	----	----	80	100	----
June 16	----	----	----	----	100	100	----
June 18	----	----	----	----	240	100	20
June 19	----	----	----	----	260	20	20
June 20	----	----	----	----	60	20	----
June 21	----	----	----	----	180	40	----
June 25	----	----	----	----	260	40	80
June 26	----	----	----	----	180	40	----
June 27	----	----	----	----	80	40	----
June 28	----	----	----	----	120	40	----
June 29	----	----	----	----	80	160	40
June 30	----	----	----	----	140	60	20

TABLE 20.—*Numbers of mackerel from purse-seine catches measured in May and June from statistical areas XXII and XXIII, by date and statistical subarea*—Continued

1929

Date	Area XXIII			Area XXII				
	C	B	A	Q	O	H	G	E
May 1	320							
May 2	353							
May 3	75							
May 4	[8] 30							
May 6		206	20					
May 7	60	90						
May 8		72						
May 9		180	20					
May 10		140	140					
May 11		80	40					
May 13		20	100					
May 15			20					
May 24			175					
May 25			71					
May 27			65					
June 4				104				
June 5				260				
June 6				343	40			
June 7				92	40			

Date	Area XXIII			Area XXII				
	C	B	A	Q	O	H	G	E
June 10				233				
June 11				40				
June 12				201				40
June 13				80				20
June 14				153				
June 15				174				[9] 64
June 17				95				95
June 18				[10] 227	60			
June 19				113	60			20
June 20					104	25		20
June 21					108	20	45	
June 22					40		120	
June 24					40	40	63	136
June 25					40	20	126	90
June 26							[11] 175	
June 27							95	126
June 28							196	40
June 29							[12] 225	

[8] From subarea XXIII D.
[9] Includes 32 from XXII D.
[10] Includes 167 from XXII R.
[11] Includes some fish from adjacent portion of subarea O.
[12] Includes some fish from adjacent portion of subarea H.

1930

Date	Area XXIII			Area XXII					
	C	B	A	R	Q	O	H	G	E
May 1	[13] 398								
May 2	40								
May 3	36								
May 5	20								
May 6	20								
May 7	52								
May 9		96							
May 10		36							
May 12			25						
May 19			22		[14] 40				
May 20			124	25	91				
May 21					60				
May 22					80				
May 23					65				
May 24					25				
May 26					20				
May 29					50				
June 2					263				
June 3					76				
June 4					140				

Date	Area XXIII			Area XXII					
	C	B	A	R	Q	O	H	G	E
June 5					252				
June 6				20	264				
June 7					134				
June 9				36	248				
June 10					[15] 172				
June 12					257				
June 13					220				
June 14					40				
June 17					180				
June 18					285				
June 19					100				
June 20				20	40				135
June 21					184				
June 23					100	135	102		70
June 24					50	[16] 140		60	20
June 25						30		175	
June 26						[16] 76		137	20
June 27						[16] 20	45	186	
June 28						20	45	40	20
June 30						36	120	60	

[13] Includes 25 from XXIII D.
[14] Includes 20 from XXIII S.
[15] Includes 32 from XXIII S.
[16] Includes 20 from XXIII P.

TABLE 20.—*Numbers of mackerel from purse-seine catches measured in May and June from statistical areas XXII and XXIII, by date and statistical subarea*—Continued

1931

Date	Area XXIII				Area XXII			
	D	C	B	A	S	Q	O	H
May 1	100							
May 2	310							
May 4	220							
May 5	80							
May 6	120							
May 7	[17] 190	20	50					
May 8	190							
May 9	[17] 20	40						
May 11			100	40				
May 12			120	20				
May 13			140					
May 14			100	20				
May 15				147				
May 16				123				
May 17				54		37		
May 18				60				
May 19						72		
May 20				101				
May 21				43				
May 22					80			
May 23				80	22	52		
May 27						95		
May 28						57		
May 29						75		
May 31						72		
June 1						80	40	
June 2						208		
June 3					120	200		
June 4					65	80		
June 5					40	40		
June 6						276		
June 8						60		
June 13						100		
June 15						389		
June 16						15		
June 17					40	80		
June 18					[18] 30	210		
June 19						200		
June 20					[18] 20	220		
June 22					[18] 40	200		
June 23						80		
June 24						200		
June 25						140		
June 26						120		70
June 27						80	[19] 60	[20] 120
June 29								40
June 30						60	20	20

[17] Includes 20 not classified by subarea.
[18] From XXII R.
[19] Includes 20 from XXII P.
[20] Includes 60 from XXII G.

1932

Date	Area XXIII				Area XXII				
	D	C	B	A	S	Q	O	G	E
May 1	74								
May 2	80	75							
May 3		185							
May 4		177	124						
May 5		561	25						
May 6			100						
May 7		80	20						
May 9		20	330	20					
May 10			40	60					
May 12				20					
May 15				20					
May 16				155					
May 17				40					
May 18						50			
May 19				25					
May 20						[21] 40			
May 22						48			
May 24						99			
May 25							109		
May 26						73			
May 28						25			
May 29						50			
May 30						75			
May 31						180	25		
June 1							85		
June 2							235		
June 3						80	450		
June 4						30	220		
June 5					25				
June 6					140	85	90		
June 7					215	105			
June 8					75	40	30		
June 9							200		
June 11							100		
June 13							40		
June 14							320		[22] 40
June 18							140		
June 21							[23] 320		
June 22							290	[24] 20	
June 24								20	
June 27									20
June 28								20	20
June 29									180
June 30									40

[21] Includes 20 from XXII R.
[22] From XXII F.
[23] Includes 50 from XXII P.
[24] From XXII H.

TABLE 20.—*Numbers of mackerel from purse-seine catches measured in May and June from statistical areas XXII and XXIII, by date and statistical subarea*—Continued

1933

Date	Area XXIII			Area XXII				Date	Area XXIII			Area XXII			
	D	C	B	Q	O	G	E		D	C	B	Q	O	G	E
May 1		160						June 7					100		30
May 2	40	85						June 10					100		
May 3	80	80						June 14				50	170		
May 4		140						June 15				60	180		20
May 5		130						June 16				20	100		60
May 6			25					June 19					40		80
May 8			76					June 20				170	60		
May 10			25					June 21					90		70
May 15			110					June 22				60			
May 18				110				June 23							20
May 22				110				June 24					20		
May 31				40				June 26					20		120
June 1				225				June 27						30	190
June 3				50	100			June 28					50	90	80
June 5				60	383			June 29					80		30
June 6					170			June 30							40

1934

Date	Area XXIII			Area XXII					Date	Area XXIII			Area XXII				
	C	B	A	S	Q	O	G	E		C	B	A	S	Q	O	G	E
May 3	[25] 590	100							June 6					[28] 1175			
May 7	731	390	100						June 12								140
May 8	200	20							June 13					150	120		
May 9	50	600							June 14						100		
May 10		512							June 15					320			
May 11		94							June 16					80	100	40	
May 12			100						June 18					220			50
May 14		150	330						June 19					252			120
May 15		80	360						June 20					80			
May 17		100	50		150				June 21					60			
May 18				31	381				June 22					160			
May 19				[26] 80	150				June 23					100			
May 22					250				June 25					160		100	
May 23					100	101			June 26					200		120	
May 24					110	100			June 27					280		90	
May 25					350	60			June 28					80			40
May 26					300	20			June 29					40			
May 29					[27] 1370	80											

[25] Includes some from May 2 and 4.
[26] From XXII R.
[27] Includes all samples from May 28 to June 2.
[28] Includes all samples from June 4 to 9.

1935

Date	Area XXIII		Area XXII				Date	Area XXIII		Area XXII			
	B	A	S	Q	H	E		B	A	S	Q	H	E
May 1	40						May 31				151		
May 2	590						June 1				302		
May 3	539						June 3				303		
May 4	300						June 4				250		
May 6	460						June 5				154		
May 7	540						June 6				302		
May 8	490						June 7				252		
May 9	330						June 8				99		
May 10	240						June 10				351		
May 11	160						June 11				50		
May 13	200						June 12				200		
May 14		190					June 13				200		
May 20				50			June 17				350		
May 22				400			June 18				403		
May 23			100	101			June 19				202		
May 24				90			June 21						203
May 25			101	99			June 22				51	76	102
May 27	50		50	450			June 24			[29] 51			304
May 28				400			June 25					[30] 50	303
May 29				51			June 26						962

[29] From XXII R.
[30] From XXII G.

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*

[All are from catches by purse seines except those noted for 1926 which are by drift gill nets. For region number see table 19]

Length, centimeters	May 1926					June 1926												
	1–15	16–20	21–25	26–30		1–5				6–10	11–15				16–20	21–25	26–30	
	(1)	B	B	P	R	E	P	Q	R	E	D	E	P	R	E	E	E	G
29.0	1																	
34.5																	1	
35.0		1															1	
35.5	4		3									1						
36.0	12	4	5					3	1								4	
36.5	35	16	11			1		7		3		1					5	1
37.0	38	39	34			1		5	1	6	4	7				4	2	2
37.5	94	72	46		1	3		6	1	10	2	11		1	2	4	8	6
38.0	119	106	68		1	9	3	16		13	5	12		1	2	9	15	6
38.5	97	93	56	1	2	14	4	14	2	12	4	19	2		4	10	15	7
39.0	77	79	47		4	15	5	6	1	17	4	22	2		4	6	6	7
39.5	38	44	33	2		23	5	4	1	20	9	29	3	1		3	5	3
40.0	24	26	7	1	1	47	2	6	1	26	11	28			5	7	5	1
40.5	22	7	10		3	49	3	1	1	36	19	45	1	1	1	3	3	4
41.0	4	4	7	1	4	50	4	7	2	28	14	47		4	3	2	3	1
41.5	6	5	3	2	3	37	2	1		40	17	34	1	1	5	4	1	
42.0	5	2	3		2	38				26	11	27		2	1		3	
42.5	1	4	2	1	3	16	1	1		24	7	13	1		2	1		1
43.0	2	6	5			7	2	1		13	5	9	1	1	2			
43.5	1	6	6	2	3	8				7	1	6	2		1			
44.0	11	4	7	1	4	10	2	3		3	3	9	3		2		1	
44.5	1	7	5		5	12	3	2	2	12	2	7	1	1		1		
45.0	7	10	5		6	10	10	6		13	5	9	4	2	2	1		1
45.5	2	19	9	3	10	21	9	6	1	10	5	6	2	3	2	1		
46.0	10	10	15	1	10	15	8	4	2	12	4	5	8	4		1		
46.5	6	9	10		15	18	7	7	2	10	4	6	9	6	1			
47.0	2	8	8	2	5	9	12	4		10		5	8	4		3		
47.5		3	8	2	8	8	2	2		5	1		4	2				
48.0		9	6		4	9	7	4		1	3	1	2	5				
48.5	1	5	1		1	2	6	1		2			2					
49.0		1			1	7	3	1	1	1			3	1			2	
49.5				1	1			1	1									
50.0					2										1			
50.5								1				1	1					
51.5		1			1													
Total	620	600	420	20	100	439	100	120	20	360	140	360	60	40	40	60	80	40

Length, centimeters	May 1926					June 1926											
	1–10		11–20		20–31	1–10	11–15				16–20				21–30		
	B	C [2]	A	B	B	E	B	E	O	Q	O	P	Q	R	G [3]	O [3]	R [4]
33.0																	5
33.5													3		1		3
34.0													3	1	2		4
34.5	1												2	2	4		6
35.0		1		1											6		16
35.5	2	11	3	7									6	1	2	1	13
36.0	9	39	5	26	1	1		2			3	1	21	1	10	4	22
36.5	33	97	13	48	1	1		3	1	4	1	8	46	2	18	6	34
37.0	69	160	24	111	5	4		6	3	7	3	9	58	7	53	27	72
37.5	85	198	27	148	3	6		12	3	7	8	24	81	5	135	36	78
38.0	97	178	11	130	5	5	2	19	3	6	7	7	87	7	156	36	71
38.5	56	139	16	103	3	4		21	3	7	7	8	29	4	125	32	58
39.0	26	53	10	57	1	6	2	13		4	1	2	16	5	93	16	37
39.5	16	21	2	28		5	5	17	1	7	3	1	7	3	30	10	15
40.0	6	8	2	8		8	3	18	1		1		4		17	4	5
40.5	1	7	2	4	1	12	4	24		3	2		3		12	4	2
41.0	1	1	1	6		7	2	22	1	2			2		4	3	1
41.5		1	2	4		7		18		1	1		2		2	3	1
42.0		5	1	2		5		8		2			1		2	3	1
42.5	2	3	1			3		8								1	1
43.0		6				1	2	3					2		1	2	
43.5				2		1		4									2
44.0	1	2		3				1	1							2	
44.5	1	4	1	3				4						1	6	3	
45.0	2	3	5	1		1		5							4	6	1
45.5	3	4	2	6				2					1		5	9	2
46.0	1	4	3	4		1		3	1	2			1	1	1	4	4
46.5	2	1	2	1				3		1					3	6	1
47.0	2	5	3	7		2			1	2	1		1		2	12	1
47.5	1	3	2	3				2		1			2		3	2	2
48.0	1	1		3						2	1		1			2	
48.5	1	1		1											1	2	
49.0	1	1	1	1				1	1	1	1					2	
49.5		3	1					1		1			1			1	
50.0				2											1		1
50.5																	1
51.0																1	
51.5															1		
Total	420	960	140	720	20	80	20	220	20	60	40	60	380	40	700	240	460

[1] All subareas.
[2] Includes 60 fish not classified by subarea.
[3] Includes 40 fish from subarea P.
[4] Includes 120 fish from subarea Q.

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1927												June 1927								
	1–10				11–15	16–20		21–31					1–5				6–10				
	A	B[5]	C	D	B	Q	S	A	O	P	Q[6]	S	O	P	Q	S	A	O	P	Q	S
<33.0									1												
35.0			1	1																1	
35.5			1	1																	
36.0		2	3	1														2		3	1
36.5		6	9	4	2						1	1							1	4	2
37.0	1	13	45	5	5	1	1	1			4	2		1	8	1	2	1	1	23	2
37.5		56	87	26	21	4	5	2			12	7	2		23			5	3	48	6
38.0	4	148	190	31	36	13	4	9	1		32	8		1	49	1	3	14	10	102	11
38.5	2	173	221	69	54	8	14	3	1	1	46	19	3		87	2	6	29	4	122	15
39.0	3	207	197	72	44	14	10	6	1	2	61	20	3	2	99	1	6	28	3	161	18
39.5	4	149	172	45	28	11	11	3	4	1	74	16	12		112	2	1	35	8	124	8
40.0	6	110	104	31	24	13	8		4	7	116	18	11	3	124	5	1	37	3	95	9
40.5	2	57	55	10	10	13	2	5	12	6	155	19	16	3	147	6	1	31	1	41	5
41.0		25	23	7	1	11	6	5	6	12	202	12	23	3	135	8		26		39	1
41.5	2	13	14	3	2	9	7	2	11	7	164	17	19	3	96	6		14	1	22	2
42.0		5	7	3		2	3	2	7	6	113	9	12	3	56	2		12	2	8	
42.5		1	4	4		2	2		4	7	50	6	4		37	2		6	1	7	
43.0		2	1	2	1		2		2	1	41				16			3	1		
43.5		1				4				1	22		3		9			2		3	
44.0		1	2	2	2		2				21	2	1		4			1			
44.5		1	2		1	2	1			2	16	2			6			1		1	
45.0		3	5	1	1	8	2	1	1	2	21	2			2			2		2	
45.5		5	11		1	8	2		1	1	31	4	3	1	14			2		3	
46.0		4	5			1	2				18	3	1		5	1		1	1	4	
46.5		4	3	2	2	1	4				34	3	1		7	1		5		1	
47.0		2	4		1	3	2			1	25	3	3		7			1		2	
47.5	1	1	2		3	5	4				17	4	1		6			1		1	
48.0	1	2	3			2	2	1	3	2	15	1	1		3	1				2	
48.5		1	2			3	2			1	11	1			3	1		1		1	
49.0			1			1	1				7				1						
49.5							1		1		6				1						
50.0		2				1					3				2						
50.5											2	1									
51.0															1						
51.5					1								1								
Total	26	994	1,174	320	240	140	100	40	60	60	1,320	180	120	20	1,060	40	20	260	40	820	80

Length, centimeters	June 1927										
	11–20						21–30				
	A	O	P	Q	R	S	D	P	Q[7]	R	S
<33.0									3	1	
34.5											1
35.0									4	1	
35.5								1	1	1	
36.0	1	2		2		1		1	3	1	3
36.5		8		5		2		1	7	3	3
37.0	2	18	1	24		4		5	47	4	9
37.5	13	51	2	75	1	12		7	103	12	24
38.0	19	88	8	119	7	26		15	199	11	44
38.5	29	136	9	190	2	48	3	19	234	16	47
39.0	19	170	21	199	2	41	1	13	251	27	37
39.5	15	172	22	143	3	47	5	13	193	15	14
40.0	15	147	14	57	1	23	7	2	99	18	13
40.5	3	102	7	36	1	12	5	1	33	5	2
41.0	3	47	8	13		10	4	2	11	3	2
41.5		33	2	8	2	2	4		4	1	
42.0	1	17	1	2		2	4		2		
42.5		8					2		1		
43.0		8	2	1		1	1				
43.5		7			1		1				
44.0		9	1			1	1				
44.5		6					2				
45.0		9	1	2		1					
45.5		12		2		3			1		
46.0		14				1			1	1	1
46.5		13									
47.0		8		1		1			1		
47.5		3		1					1		
48.0		3									
48.5		7							1		
49.0		1									
49.5						1					
50.0						1					
51.0		1	1								
Total	120	1,100	100	880	20	240	40	80	1,200	120	200

[5] Includes 39 fish for which the subarea was not reported.
[6] Includes 20 fish for which the subarea was not reported.
[7] Includes 60 fish for which the subarea was not reported.

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1928									June 1928										
	1–10		11–20		21–31					1–2		5–10		11–20				21–30		
	B	C	A	B	A	B	P	Q	R	P	Q	P	Q	O	P	Q	R	O	P	Q
20.5				1																
21.5				2																
22.0				5												1				
22.5				5												2				
23.0				9												4				
23.5				5												7				
24.0				4												11				
24.5				1												6				
25.0				2												5				
25.5				1												3				
26.0				1												3				
27.0				2												1				
36.0																				1
36.5			1																	
37.0					2	1							2		1	2	1			
37.5			2	2	2	1			1						1	5			5	5
38.0	6	1	2	15	8	3		2			1	4	5		10	34			9	17
38.5	9	1	17	60	21	8		10	2	2	7	5	20	4	34	76		7	19	58
39.0	25	2	37	166	37	20	2	13	15		8	11	51	4	61	200	8	16	47	148
39.5	39	3	46	193	99	20	3	18	18	2	21	32	89	12	106	285	3	22	81	232
40.0	43	3	64	276	112	26	3	25	27	4	17	17	82	12	100	325	3	39	97	224
40.5	32	4	67	250	109	21	5	36	33	3	27	21	78	6	72	233	2	30	77	177
41.0	21	2	47	167	82	20	11	36	37	1	22	9	51	2	63	116	1	14	41	103
41.5	12	2	26	99	64	11	5	44	31		31	9	21		19	70	2	6	30	53
42.0	1		11	52	28	3	9	26	16	3	22	5	7		8	26		3	11	13
42.5	3		7	20	20	2	11	13	17	2	16	3	7		3	13			1	2
43.0	1	1	4	10	15	1	2	20	7		13	3	2		1	5				1
43.5	1		3	4	11		3	6	13		5	1	1			1		1		2
44.0		1	1	5	4	2	1	4	7	1	1					3		1	2	
44.5	2			3	5		1	2	3	2	3					2				
45.0			3	5	7			5	6							1				
45.5	1		2	10	6			3	5											
46.0	2		3	5	4			3	5				2							1
46.5	1		5	9	5	1	1	4	9				1		1	1				1
47.0	1		1	16	5		2	3	8		1		1			2				
47.5			1	15	3			1	9		2									
48.0			3	4	4			3	1		2									1
48.5			4	3	2				8											
49.0			1	3	3		1		7		1									1
49.5			1	1	2				1											
50.0				1				1	1											
50.5			1					1	1											
51.0								1	1											
51.5				1																
52.0				1														1		
Total	200	20	360	1,434	660	140	60	280	289	20	200	120	420	40	480	1,443	20	140	420	1,040

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1929							June 1929														
	1–10				11–20		21–31	1–10		11–15			16–20						21–30			
	A	B	C	D	A	B	A	O	Q	D	E	Q	E[8]	E[9]	H	O	Q	R	E	G[10]	H	O
19.5		5																				
20.0		6																1				
20.5		8																1				
21.0		3																				
21.5		3																3		1		
22.0		1																7				
22.5																		12		6		
23.0																		22		2		
23.5																		35		6		1
24.0																		40		9		2
24.5																		22		26		1
25.0			1															9		36		1
25.5			4															5		26		2
26.0			9															2		25		3
26.5			17				2											2		5		1
27.0			22	1			3													3		
27.5			18	3			2											2		4		
28.0			7	2			3													3		
28.5			6															1		7		1
29.0																		2		18		2
29.5			1				1											1		29		7
30.0																				46		5
30.5																				25		2
31.0																				18		
31.5																				4		
32.0																1						
32.5								1												2		
33.0									1											2		
33.5			3	1					1			1							1			
34.0			7						2			5								2		
34.5			9				1		4			4								1		
35.0			13	2			2		3			5				1	6		2	6		1
35.5			7						15			13		2		1	2		3	6		1
36.0		1	5					1	11			17	1	1		2	1		1	14	1	4
36.5			3				1		12			15		2		1	1		2	10	1	
37.0								1	8			9				1	3		2	11	1	1
37.5									7			6				1	1		1	4		1
38.0			1						3			6		1						10		
38.5			2				1		2											3		
39.0	1	3	4				1		4			5	1			3	2			3	1	2
39.5	4	5	18		1	5	5		13			14				2	6		5	8		6
40.0	6	25	74	1	4	5	9		31	2	4	38	1	1		13	13		13	20	2	10
40.5	14	64	93	1	8	10	27	2	101		2	68	4	1	1	21	22		32	65	9	20
41.0	32	101	130	3	18	12	38	2	176	2	8	111	9	4	5	47	46		58	87	11	44
41.5	27	110	120	2	29	14	44	10	194	2	13	107	12	7	1	42	56		62	116	8	38
42.0	33	110	88	3	26	23	59	5	186	10	12	117	10	7	4	45	49		74	121	15	41
42.5	26	76	58	5	29	8	33	14	132	7	13	62	11	4	6	22	24		60	108	12	17
43.0	15	64	53	5	18	6	31	15	70	3	13	23	21	2		9	14		38	64	7	10
43.5	6	29	18		7	8	17	12	20	1	10	14	4	2	3	5	6		12	29	6	1
44.0	2	20	7		6	4	10	4	14	2	2	5	7	1		1	3		7	18		
44.5	2	7	1	1	5	2	4	6	3		3		3	2	1	1	1		6	5	1	2
45.0	1	4	2		2	1	5	1	5		2		1	1			2		2	5		
45.5	3	5			1		2	2	1	2	3		3			1	1		2	3	1	
46.0	1	6	2		2	1	2	1	1				2				1		2	7	1	1
46.5	1	4	1				1				1		1		2		2			2	2	
47.0	2	5			1		2	1	4		2		1	1			4		2	5	1	
47.5		7	1				2		3		1					3			1	2		
48.0	2	3	2				1		1	1	1	1			1	1	1		1	1		
48.5		5						1	2				1				1		1	2		
49.0		1			1				1			1	2						1	4		
49.5	1	4			1	1		1			2	1										
50.0	1	2			1		1												1			
50.5		1					1															
51.0			1												1							
53.0									1					1								
Total	180	688	808	30	160	100	311	80	1,032	32	92	648	95	40	25	224	268	167	392	1,045	80	228

[8] June 17.
[9] June 19 and 20.
[10] Includes some samples from adjacent positions of subareas H and O.

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1930									June 1930											
	1–10			11–20				21–26	27–31	1–10			11–20			21–30					
	B	C	D	A	Q	R	S	Q	Q	Q	R	S	E	Q	R	E	G	H	O	P	Q
23.5														1							1
24.0														5							
24.5														6							1
25.0														11							2
25.5														16							11
26.0										1				12							3
26.5										1				13				1			5
27.0														2							3
27.5														6							5
28.0										1				4							2
28.5														2							1
29.0														6							
29.5														2	1						
30.0										2				1							
30.5														1			1				
31.0										1							1	2			
31.5																	1		1		
32.0										2				2							1
32.5										6				6							1
33.0									1	21				9		1	1				2
33.5									6	52				30			5		6		7
34.0								1	4	154	5			103			16	2	16	3	23
34.5									7	218	15			169		2	31	5	34	10	34
35.0									6	248	6			223		5	53	5	52	13	52
35.5									1	190	7			185		4	88	10	69	17	60
36.0						1				76	3		1	110		5	80	10	36	12	37
36.5										35	3			61		4	34	13	27	2	23
37.0				1	1			1	1	8	1			22		2	16	5	9	2	6
37.5										6	1			9		3	10	2	6	1	7
38.0				1	1					5				2	1	3	12	1	3		3
38.5						1				3	1			4		2	5	2	4		
39.0					1									2	1		5		2		1
39.5		1						1		3			1	2	3	2	2	2	1		
40.0		3						1		8		1		1	3		7	5	1		1
40.5	1	12		4	3		1	1		11			4	3	4	4	6	8	5		2
41.0	5	32		8	3	1				17	1	3	8	8	1	6	20	10	14		4
41.5	10	62	3	21	8	1		1	2	40	6	2	11	14	2	7	25	22	20		9
42.0	23	81	3	22	8			6	1	67	2	4	21	17	1	16	54	52	25		11
42.5	18	83	4	22	8	2	4	7	2	61	1	7	22	17	2	17	61	35	18		4
43.0	21	92	5	29	8	3	3	14	3	58	3	7	16	16		12	46	48	24		5
43.5	27	73	5	17	8	4	1	34	5	58		1	16	12		8	35	44	9		3
44.0	10	45	1	15	9		4	34	4	49		3	10	4		8	18	14	7		1
44.5	5	26	3	17	9	1	2	42	2	36			10	1	1	2	9	7			
45.0	8	13		6	5	3		34	1	28			3			6	6	2	3		
45.5		5		2	7	1	1	23	3	19		1	4			1	1	1			
46.0		1		1		1	1	14	1	8		1	2	1		5	4	1			1
46.5	1	4		1	2	1		9		6			3	1			1				2
47.0	1	3		1	5	2		4		4		2	1			1	2		2		
47.5	1	2			6	1	2	9		3								1			
48.0				3	8	1		4		2			1			2	1	1			
48.5					3	1		4		2	1					1					
49.0	1				6		1	4									1	1			
49.5		1	1					2					1						2		
50.0		1			2					5						1					
50.5		1								1											
51.0										1									1		
Total	132	541	25	171	111	25	20	250	50	1,517	56	32	135	1,122	20	130	658	312	397	60	334

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1931									June 1931											
	1–10			11–20			21–31			1–10			11–20			21–30					
	B	C	D[11]	A	B	Q	A	Q	S	O	Q	S	Q	R	S	G	H	O	P	Q	R
18.0											1										
19.0											1		1								
19.5											8										
20.0											4		5								
20.5											17		6								
21.0											5		8								
21.5											11		14								
22.0											11		4								
22.5											9		1								
23.0											4		1								
23.5											1										
24.0											3										
25.5																					1
27.0																					1
27.5																					1
28.0																					3
28.5																					6
29.0																					2
29.5																					2
30.0													1								4
31.5																				1	
32.0													1								
32.5													2								
33.0													4								
33.5			3										7							1	
34.0			2										21		1					3	
34.5			3					1				1	38							4	
35.0			3					1			6	1	58			1				14	
35.5			1								8		41				1			18	
36.0			2								10	1	40				1			11	
36.5			8					1			5		23			1	3		1	8	
37.0		1	17				1	3			5	1	14				2			7	
37.5			56				1	3			14		13							4	
38.0		2	90				2	5			58	1	19				3			4	1
38.5			110	1	1			28	1		68	2	22				6			18	
39.0		2	109	6	5	3	4	21	1		77	4	25	1			6		1	29	
39.5	1	1	88	6	2	2	3	39	1		80	5	34		2	1		1		32	
40.0		1	62	6	3	1	6	30	2	1	30		24		2	1	3			26	
40.5			42	4	3	1	3	13			26	9	19	1		3	9			25	6
41.0		3	51	8	12	4	2	4			20	8	31	3	3	2	5	3		32	4
41.5	1	3	43	19	14	5	9	9	6		44	23	60	4	13	1	9	3	1	61	4
42.0	5	10	76	42	53	10	8	17	9		56	34	104	3	5	7	26	5	2	100	2
42.5	4	11	88	64	47	12	14	20	7		76	30	161	14	3	13	25	8	5	108	2
43.0	8	10	100	73	73	13	16	18	12	1	93	34	152	9	4	10	27	15	4	142	
43.5	13	5	73	92	78	9	11	22	8	2	74	29	104	7	3	8	26	12	1	102	
44.0	5	4	71	75	70	12	13	29	11	4	44	20	82	3		7	16	5	2	66	
44.5	3	2	47	55	32	12	10	25	10	6	30	10	40	4	1	3	11	4	1	41	
45.0	2	3	33	38	34	9	3	17	8	5	15	4	13		3		5	2		10	
45.5	3	1	18	19	13	3	3	16	5	5	14	4	9	1		1	5	2		3	
46.0			13	15	4	4	6	11	7	6	4		1							5	1
46.5	1		6	6	2	1	3	5	2	3	3	1	1				1			1	
47.0	1		4	6	1	3	2	2	5	3	4		2			1					
47.5		1	4	5	3	1			3		2	2	2							2	
48.0	1		2	7	3	1	1	2	2	1			2								
48.5	1		1	9	4	2	2	3	2	1	3		2								
49.0	1		3	3	1			1		1										2	
49.5			1		1			3											1		
50.0				4		1		1		1			2						1		
50.5				1	1			1				1									
51.5				1																	
Total	50	60	1, 230	565	460	109	123	351	102	40	944	225	1, 214	50	40	60	190	60	20	880	40

[11] Includes 40 fish for which subarea was not reported.

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1932									June 1932												
	1–10				11–20			21–31		1–5			6–10			11–20		21–30				
	A	B	C	D	A	Q	R	O	Q[13]	O[13]	Q[12]	S	O[13]	Q	S	F	O	E	G	H	O	P
22.5				1																		
23.0			1												1							
23.5															1							
24.0			1											1								
24.5															2							
25.0				1										2	4			3	1			1
25.5			1							1					9			4				3
26.0			2	1								2		5	15			16	3		1	4
26.5			2	3						5		1		8	14			11			3	4
27.0			6	9					1	11				6	27			15	3		14	7
27.5			12	6					5	8		3	1	13	27			18	2		14	8
28.0			25	12					14	25			2	10	42			23	4		16	6
28.5			30	13					27	27		3	5	18	54			24	2		23	4
29.0			21	21					35	63	3	7	6	22	37			26	3		37	8
29.5			37	18					36	76		1	2	8	28			22			28	2
30.0			48	15				2	44	80	3	2	5	10	27	2		29			31	2
30.5			51	14				1	51	77	5	3		12	19	8		15	1		24	
31.0			47	15				3	32	69	4	1	1	8	16	9		13			11	1
31.5			36	12				9	30	51	7	1	2	6	10	5		9			13	
32.0			27	5			2	2	11	27	6			1	5	11		6	1		11	
32.5			18	3				8	7	9	6	1	1	3	1	2		2			3	
33.0			5	3				1	5	5	3			2	1	3		4			1	
33.5			2						3	4	1											
34.0		2	1	1					2		1											
34.5									2	1								1				
35.0				1							1											
35.5			1							1								1				
36.0									1				2				1					
36.5								1	1												1	
37.0			2							2							2					
37.5		1							1	1			3								2	
38.0		1	1				1	2	3	1			1	1	1		2				2	
38.5			3		1		2	2	7	3	1		4		1		5					
39.0			7			1	3	9	9	6	2		10	1	1		8		1		2	
39.5	1	3	12		4		3	12	23	16	1		8				16		2	1	5	
40.0	2	9	22		2	1	3	12	23	14	1		14	2	1		24	2		1	9	
40.5	3	14	18		4	3	1	13	20	11	2		7	1	2		44	1		1	11	
41.0	1	16	21		7	1	1	13	5	16	2		10	3	2		30	2			11	
41.5	4	19	31		6	2		3	7	13			15	4	4		26	2	2		20	
42.0	6	46	63		18	2		2	3	26	2		12	7	11		46	1	1	2	23	
42.5	9	63	104		28	2		2	5	28	8		20	7	9		63	1	1	2	46	
43.0	11	98	134		38	2	1	2	8	29	13		21	21	15		81		4	4	45	
43.5	15	112	99		38	5	1	4	15	51	15		28	16	11		86	3	3	3	49	
44.0	14	100	87		35	10		6	17	50	21		24	13	15		68			3	45	
44.5	7	69	62		28	8	1	7	14	59	10		19	8	5		43	1	4	2	23	
45.0	3	46	28		22	10		7	16	48	3		14	6	6		26	2		1	22	
45.5	2	16	17		12	7		3	13	48	2		5	2	3		16				6	
46.0	1	10	5		9	5	1	1	10	27	3		4	2			7		1		2	
46.5		2	2		2	4		1	8	25	3		3				2				2	
47.0	1	4	3		1	3		1	1	10	3		4		1		1	1			1	
47.5			1		2	2			2	6	1		1				2	1			1	
48.0		4	1		1	1		1	2	5	1				1							
48.5		2	1			1		2	4	5	1						1	1	1			
49.0		1							1	6											2	
49.5		1			1			1	1	2					1							
50.0					1			1		3				1								
50.5										4			1									
Total	80	639	1,098	154	260	70	20	134	525	1,055	135	25	255	230	430	40	600	260	40	20	560	50

[12] 1 sample of 25 large fish taken on May 31 is omitted from the May 21–31 column and included in the June 1–10 column.
[13] 2 samples of 65 large fish taken on June 6 are included with the June 1–5 and excluded from June 6–10 column.

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1933							June 1933										
	1-10			11-15	16-20	21-25	26-31	1-10			11-20			21-30			
	B	C	D	B	Q	Q	Q	E	O	Q	E	O	Q	E	G	O	Q
29.0	1																
29.5	1	2	1								1						
30.0	1	2	3						2	2							
30.5		4	6					1	10	5	3	3	5				
31.0	1	12	8			1	1		27	9	1	6	4	1	1		
31.5	2	13	14			1	8	1	60	27	5	15	14	17	1	5	1
32.0	7	17	14			4	5	1	62	36	11	32	39	25	9	10	3
32.5	3	26	11			2	6	1	101	34	27	26	39	48	10	9	5
33.0	5	34	19		1	11	4	6	74	23	24	17	45	63	26	9	2
33.5	9	28	14		3	6	4	3	62	22	12	13	22	64	20	5	2
34.0	3	35	11	1	1	10	2	1	51	12	13	8	10	56	13	4	2
34.5	5	26	5	3	2	3	4	1	40	15	11	6	6	41	7	2	2
35.0	3	28	5	2	5	9	2	1	13	2	6	3	4	22	5	4	1
35.5	1	14	3		4	8	3		8	1	3	3		13	4	1	1
36.0	3	13	4	1	2		1		8	4	3	1	1	4	4	1	1
36.5		11	1	1	3	5		1	2	1				4		1	
37.0		4	1		1	1		3	2								
37.5				1	2			2	2		1			2			
38.0		1				1			5	1	1		2	2			
38.5	1				3				2			1		1			
39.0	2	5							3	1	2	1		4	1	1	1
39.5	1	3		1	1	1			3	3	2	3	2	1		1	1
40.0	4	4		2	3				10	1		3	2	3		4	
40.5	4	7		5	3				6	3	1	12	3		2	7	2
41.0	10	15		1	3	2			8	3	1	8	6	5	1	9	1
41.5	7	13		2	5	3		2	21	10	1	29	7	12		8	1
42.0	7	26		7	2	1			26	15	2	25	7	14		15	3
42.5	6	26		5	2	3		1	49	24	6	48	7	30	4	20	4
43.0	10	40		17	5	3			39	15	6	72	23	35	3	36	5
43.5	6	48		14	8	2		2	54	23	3	64	12	25	3	35	9
44.0	6	36		14	5	5		1	29	13	4	53	18	19	1	33	7
44.5	4	40		10	4	3		1	30	14	3	43	11	16	5	17	4
45.0	4	26		12	12	4			19	7	4	28	9	10		15	1
45.5	2	18		5	11	9			9	1	2	14		5		3	
46.0	2	6		3	12	4			6	5		7	1	3		1	
46.5	3	3			3	4			2	2		2		1		1	
47.0		1		2	1	2		1	3					3		1	
47.5	1	1			2				1			2				1	
48.0		3				1			3			2					
48.5	1	1								1	1			1		1	1
49.0		2			1	1							1				
49.5		1		1					1								
Total	126	595	120	110	110	110	40	30	853	335	160	550	300	550	120	260	60

TABLE 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1934												May 27–June 2		June 1934									
	1–5		6–12			13–19					20–26				3–9	10–16				17–23		24–30		
	B	C	A	B	C	A	B	Q	R	S	O	Q	O	Q	Q	E	G	O	Q[14]	E	Q	E	G	Q
25.5																	1		1		1			
26.0																	1							
26.5																					1			
27.5																		1						
28.5					1																			
29.0																			1					
29.5					1										1		1							
30.0					2										1		1	3	2		1			
30.5					3										2		2	1	9					
31.0					1			1							7		3	3	8		1		1	
31.5					5							1		2	12		4	13	16	1	3		1	2
32.0		1			6									3	23	1	6	11	38	3	5		3	5
32.5		1		1	2								1	4	40		8	16	34	2	7		4	4
33.0					3							1		7	18		4	9	28	1	12		9	5
33.5		3			3			1						5	16	1	6	6	35	1	9		8	6
34.0		14		7	12	3	3	2	1				1	9	15	3		8	19	1	10		5	8
34.5		23		32	30	12	8	5		1		5		20	8			4	11	1	15	1	8	7
35.0		45	2	51	70	17	14	11	1	2	5	12	4	52	40	2		10	31	4	33		10	26
35.5		59	5	91	124	26	16	29	4	3	10	26	5	99	86	6	1	16	62	12	60		30	49
36.0		76	7	100	141	46	23	42	9	1	17	51	8	155	115	10		28	54	14	83	6	32	92
36.5	1	71	4	99	136	42	7	31	1	5	19	106	10	160	149	9		27	78	16	75	4	46	80
37.0		42	1	54	108	49	15	34	2	5	27	95	8	138	119	12	1	18	43	8	52	3	41	67
37.5		21	3	30	38	30	9	20	4	3	10	63	8	82	61	14		22	20	9	25	4	22	35
38.0		10	2	15	23	14	6	9	3		10	49	2	55	58	13	1	8	6	6	12	2	9	15
38.5		6		6	7	11	1	9			3	26	1	19	13	4		3	3	4	4	1	4	10
39.0		1		11	10	4	2	5		2	8	16	2	15	4	6		3		3	4			3
39.5		4	1	9	5	3	3	12		1	2	6	1	6	6	1		3	1	3	2			1
40.0	4	11	1	14	12	6	5	7	1		8	13	1	13	1	3		1		2	2		1	2
40.5	1	10	6	19	20	18	2	12	2	2	8	19	1	18	6	4		2		1	4	1	1	2
41.0	2	14	11	26	32	19	8	12	2		13	26	1	16	11	3				2	5	1	3	11
41.5	6	16	11	54	32	22	6	17	1		18	50	2	18	10	2		6	2	6	16	1	2	7
42.0	7	15	10	67	19	25	10	19	3		11	21	1	23	19	3		4	3	2	25	1	3	24
42.5	11	23	17	94	13	38	14	18	6		10	22	2	29	26	7		8	4	4	49		11	35
43.0	7	21	18	145	15	48	26	42	2	1	5	18	1	39	33	5		12	7	11	60	6	12	55
43.5	9	36	23	153	27	58	33	31	4		4	51	2	52	62	5		14	11	12	86	2	10	56
44.0	10	28	26	177	23	51	40	54	7	2	8	71	6	63	58	8		17	11	16	74	2	13	55
44.5	10	14	22	145	19	52	24	65	5		11	65	3	62	56	7		17	3	4	72	2	8	46
45.0	21	12	16	106	19	56	22	56	6	1	20	60	3	58	40	4		12	4	5	36	2	2	34
45.5	6	10	9	56	5	37	13	48	5	1	18	73	2	56	26	2		8	3	11	17	1	6	12
46.0	2	2	4	24	3	24	8	30	5	1	10	50	3	25	16	1		2	1	2	10		2	6
46.5	1			14	7	14	4	30	3		12	45	1	26	6	1		2		2	2		1	
47.0	2			10	3	8	8	9	2		6	31		12	5	3		1		1				
47.5		1		1		2		10			3	11		13	3									
48.0			1			2		6			3	11		7	1			1					1	
48.5								1				5		4										
49.0				2		1		2				6												
49.5				3					1		2	3		4									1	
50.0												2		1	2									
50.5						1		1																
51.0					1	1																		
Total	100	590	200	1, 616	981	740	330	681	80	31	281	1, 110	80	1, 370	1, 175	140	40	320	550	170	872	40	310	760

[14] 1 special, nonmarketed, sample of 30 small fish from area Q on June 13 not included.

Table 21.—*Length frequency of mackerel in May and June 1926 to 1935, inclusive, by time periods and by statistical subareas*—Continued

Length, centimeters	May 1935							June 1935						
	1–10	11–20			21–31			1–10	11–20	21–30				
	B	A	B	Q	B	Q[15]	S	Q[16]	Q	E[17]	G	H	Q	R
25.0									1					
25.5									1					
26.0										1				
26.5													1	
27.0								2		2				
27.5								1	2	1				
28.0								1					2	
28.5									1	1				
29.0										1				
31.0								9	2	1			1	
31.5								20	7	3				
32.0								54	46	21	1	2	2	2
32.5						3	3	98	76	49		1	11	3
33.0						2	1	132	132	115	3	5	11	4
33.5						8	2	109	154	120	3	4	11	12
34.0						7		108	148	143	1	6	4	6
34.5						8	2	65	82	115	4	7	2	8
35.0						8	3	28	48	82	1	5	2	4
35.5	2			1		9		23	13	30	3			1
36.0	2					27	1	41	14	17			3	
36.5	15		1	1	1	68	3	68	17	18	1			
37.0	51	4			5	152	12	123	34	25	2	2		1
37.5	138	7	11	2	6	201	13	179	54	46	4	6		
38.0	288	11	19	1	7	268	18	229	95	92	3	6		
38.5	382	10	21	5	4	229	25	214	102	104	5	6		4
39.0	407	16	20	6	2	143	22	147	102	148	2	5		
39.5	274	7	24	6	4	97	20	91	60	101	1	4		4
40.0	171	4	20	3	3	50	3	51	27	76	1	4		
40.5	86	4	9	1	1	24	4	18	12	32		1		
41.0	47	1	9	3	1	28	6	13	2	36		2		
41.5	51	8	5	1		27	5	6		25	2			
42.0	89	9	7	3		32	8	11	13	27		1		
42.5	100	5	11	2	1	26	10	10	7	33		1		
43.0	181	10	13	2		26	10	19	29	50	2			
43.5	208	14	22	1	6	42	13	37	23	63	3		1	
44.0	257	22	42	2	3	37	12	29	29	80	3	2		1
44.5	246	24	37	2	1	43	15	18	29	61	3	1		
45.0	214	12	32	1	3	44	16	17	23	49		1		1
45.5	153	10	25	1	1	54	7	15	12	57	2	3		
46.0	97	8	15			30	5	14	7	28		1		
46.5	43	2	10	4		22	6	5		11				
47.0	19	1	2		1	9	4	5		5				
47.5	4	1	2	1		5	1			2				
48.0	1		3			7				1				
48.5	2			1		5		1						
49.0						1			1	1				
49.5	1							2		1				
50.0							1							
Total	3,529	190	360	50	50	1,742	251	2,013	1,405	1,874	50	76	51	51

[15] Includes 90 fish for which the subarea was not reported.
[16] Excludes 66 small (less than 26 centimeters) fish taken June 6 and 7.
[17] Includes some fish from area G.

TABLE 22.—*Numbers of individuals measured in samples of catches in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*

1926

Date	By purse seines				By drift-gill-nets
	D	E	G	P	E
Sept. 1			80		
Sept. 2		60	40		
Sept. 3		300	80		
Sept. 7		80	140		
Sept. 8		60	80		
Sept. 9			60		
Sept. 10			100		
Sept. 11		80	40		
Sept. 13		20	180		
Sept. 15		80			
Sept. 16		60			
Sept. 17		140	20		
Sept. 23			80		
Sept. 24	20		60		
Sept. 25			20		
Sept. 27		40			
Sept. 28	20	160	140		
Sept. 29		280	40		
Sept. 30		80	260		
Oct. 1			300		
Oct. 2			100		
Oct. 4			40		
Oct. 5			420		
Oct. 6			140	20	
Oct. 9			140		
Oct. 11			20		
Oct. 13					
Oct. 14			40		
Oct. 15		140	40	40	
Oct. 28		180	20		
Oct. 29		60			
Oct. 30		40	40		
Nov. 1		80			
Nov. 2		80			
Nov. 3		40			
Nov. 4		40			
Nov. 5		40			
Nov. 6		40	40		
Nov. 8		40	240		
Nov. 9			160		
Nov. 11			80		
Nov. 15			240		
Nov. 29			100		
Nov. 30			120		60
Dec. 1					80
Dec. 11					193

1927

Date	By purse seines					By drift-gill-nets
	E	G	H	O	P	E
Sept. 1		100				
Sept. 2		220				
Sept. 6	100	80	20			
Sept. 7		200	40			
Sept. 8		120		20		
Sept. 14	40	120			40	
Sept. 15	20	60				
Sept. 17		100				
Sept. 19		100	20		20	
Sept. 20			100			
Sept. 22	160	100				
Sept. 23			160			
Sept. 24		40	40			
Sept. 26			140			
Sept. 27			80			
Sept. 28			90			
Sept. 29			200			
Oct. 4			260			
Oct. 5			140			
Oct. 8			100			
Oct. 17						100
Oct. 18	180					
Oct. 27	80					100
Oct. 28	120	100				
Nov. 3		100				

TABLE 22.—*Numbers of individuals measured in samples of catches in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued.

1927

Date	By purse seines					By drift-gill-nets
	E	G	H	O	P	E
Dec. 12						180
Dec. 13						40
Dec. 14						140
Dec. 15						80
Dec. 16						120
Dec. 17						160
Dec. 19						80
Dec. 22						180
Dec. 23						260
Dec. 24						20

1928

Date	By purse seines					By drift-gill-nets
	E	G	H	P	Q	E
Sept. 4			100			
Sept. 6	20		40			
Sept. 7			140			
Sept. 10	40		140			
Sept. 14			40			
Sept. 20			100			
Sept. 22		285				
Sept. 24		40		80		
Sept. 25			40	180		
Oct. 5					90	
Oct. 10					80	
Oct. 22						60
Nov. 9						190
Nov. 14						80
Nov. 15						620
Nov. 16						460
Nov. 19						160
Nov. 22						360
Nov. 23						130
Nov. 26						60
Nov. 30						120
Dec. 3						20
Dec. 4						200
Dec. 5						80

1929

Date	By purse seines				By drift-gill-nets
	D	E	G	H	E
Aug. 23			105	60	
Aug. 24			20		
Aug. 26			239		
Aug. 27			210		
Aug. 28			141		
Aug. 30			140		
Sept. 16	40		39		
Sept. 18		20			
Sept. 19		30			
Sept. 23					60
Sept. 27		15			
Sept. 30		11			
Oct. 7		29			
Oct. 21					100
Oct. 22					110
Nov. 4					30
Nov. 5					215
Nov. 6					162
Nov. 7					220
Nov. 8					160
Nov. 13					210
Nov. 14					223

TABLE 22.—*Numbers of individuals measured in samples of catches in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued.

1930

Date	By purse seines								By drift-gill-nets
	C	D	E	G	H	O	P	Q	E
Aug. 11		245		90					
Aug. 12		100					40		
Aug. 14				30			100		
Aug. 15				20		70	126		
Aug. 16				20		20	60		
Aug. 18			80	80			45		
Aug. 19			20			40	20	100	
Aug. 20						48	56		
Aug. 21							40		
Aug. 29							60		
Aug. 30							20		
Sept. 2				40					
Sept. 3			40	20		20			
Sept. 8		210							
Sept. 12			25						
Sept. 15			40						
Sept. 16					45				
Sept. 17			65						
Sept. 20				80					
Sept. 22				20					
Sept. 23				60					
Sept. 24				200					
Sept. 26				20			40		20
Sept. 29							100		
Sept. 30							40		
Oct. 1							294		
Oct. 13									30
Oct. 16									20
Oct. 24			126						58
Oct. 29									60
Oct. 31									103
Nov. 3									140
Nov. 4									140
Nov. 5									120
Nov. 10									150
Nov. 11									80
Nov. 12									40
Nov. 14									214
Nov. 20									40
Nov. 21									390
Nov. 22									195
Nov. 24									153
Nov. 28									60
Nov. 29									80
Dec. 1									210
Dec. 3									80
Dec. 4									140

1931

Date	By purse seines				By drift-gill-nets
	C	D	E	G	E
Aug. 11	60	20			
Aug. 12	60				
Aug. 13	100				
Aug. 15	40				
Aug. 17	105	120			
Aug. 18	140	40			
Aug. 19	100	20			
Aug. 22	140				
Aug. 24	220				
Aug. 25	230				
Aug. 26	20	100			
Aug. 27	140				
Aug. 28	20	80			
Aug. 29	40				
Aug. 31	40				
Sept. 1	75				
Sept. 4	20				
Sept. 8	130				
Sept. 9	160				
Sept. 10	180				
Sept. 11	250		40		
Sept. 21	190	40			
Sept. 22	80				
Sept. 23			200		
Sept. 24			140		
Sept. 28			80		

TABLE 22.—*Numbers of individuals measured in samples of catches in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued.

1931

Date	By purse seines				By drift-gill-nets
	G	D	E	G	E
Oct. 6			120		
Oct. 13		60	40	62	
Oct. 17				180	
Oct. 22			30		40
Oct. 23					160
Oct. 27					20
Nov. 10					50
Nov. 12					70
Nov. 15					120
Nov. 16					455
Nov. 17					70
Nov. 18					90
Nov. 22					20
Nov. 23					110
Nov. 24					240
Nov. 25					60
Nov. 28					20
Nov. 29					40
Nov. 30					170
Dec. 1					90
Dec. 3					100
Dec. 4					40
Dec. 7					120

1932

Date	By purse seine			By drift-gill-nets
	C	D	E	E
Aug. 11	20			
Aug. 12	20	20		
Aug. 13	240			
Aug. 15	140			
Aug. 16	60	40		
Aug. 17		20		
Aug. 18	20			
Aug. 20		40		
Aug. 22	83			
Aug. 23		146		
Aug. 24		40		
Aug. 25		94		
Aug. 26		51	56	
Aug. 27		47		
Aug. 30		70		
Aug. 31		100		
Sept. 1		60		
Sept. 8			140	
Sept. 9		40		
Sept. 12			40	
Sept. 19		20	20	
Sept. 20		20		
Sept. 21			20	
Sept. 27				22
Sept. 28		17		
Sept. 30		47		20
Oct. 1		20		
Nov. 7				110
Nov. 12				20
Nov. 14				55
Nov. 15				80
Nov. 16				250
Nov. 17				160
Nov. 18				120
Nov. 21				200
Nov. 22				120
Nov. 23				80
Nov 25				160
Nov. 26				120
Nov. 29				105
Nov. 30				60
Dec. 2				280
Dec. 5				70
Dec. 6				140
Dec. 7				100
Dec. 8				50
Dec. 9				140
Dec. 10				30
Dec. 14				43

TABLE 22.—*Numbers of individuals measured in samples of catches in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued.

1933

Date	Purse seines	By drift-gill-nets	Date	Purse seines	By drift-gill-nets
	E	E		E	E
Aug. 28	220		Oct. 19	120	
Aug. 29	218		Oct. 20	80	
Aug. 30	140		Oct. 21	40	
Aug. 31	180		Oct. 22	140	
Sept. 1	65		Oct. 24	180	
Sept. 5	160		Oct. 27	270	
Sept. 6	336		Oct. 28	120	
Sept. 7	90		Oct. 30	110	
Sept. 8	100		Oct. 31	210	40
Sept. 9	120		Nov. 1	40	
Sept. 11	60		Nov. 2	70	90
Sept. 12	20		Nov. 4		60
Sept. 13	160		Nov. 6		40
Sept. 14	180		Nov. 7		120
Sept. 15	30		Nov. 10		20
Sept. 20	100		Nov. 17		100
Sept. 21	290		Nov. 18		80
Sept. 22	220		Nov. 20		235
Sept. 23	160		Nov. 21		160
Sept. 25	120		Nov. 22		440
Sept. 26	140		Nov. 23		150
Sept. 27	100		Nov. 24		40
Sept. 28	230		Nov. 25		20
Sept. 29	110		Nov. 27		100
Sept. 30	160		Nov. 28		60
Oct. 2	180		Nov. 29		340
Oct. 3	160		Dec. 1		260
Oct. 4	220		Dec. 2		35
Oct. 9	180		Dec. 4		26
Oct. 10	280		Dec. 5		235
Oct. 11	380		Dec. 6		189
Oct. 12	170		Dec. 7		70
Oct. 13	40		Dec. 8		190
Oct. 14	100		Dec. 9		40
Oct. 16	280		Dec. 11		35
Oct. 18	140		Dec. 14		40

1934

Date	By purse seines				By drift-gill-nets
	D	E	G	H	E
Sept. 21	100	50			
Sept. 22		140			
Sept. 24		20	80		
Sept. 25			261		
Sept. 26		210			
Sept. 27		100			
Sept. 28			223		
Sept. 29		40	40		
Oct. 1		141			
Oct. 5			108	100	
Oct. 6		40			
Oct. 8		40			
Oct. 11		200			
Oct. 13		40			
Oct. 15	20				
Oct. 17		240			
Oct. 18		145			

TABLE 22.—*Numbers of individuals measured in samples of catches in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued.

1934

Date	By purse seines				By drift-gill-nets
	D	E	G	H	E
Nov. 13					190
Nov. 18					97
Nov. 19					273
Nov. 20					100
Nov. 21					135
Nov. 26					167
Nov. 28					126
Nov. 30					60
Dec. 5					61

1935

Date	By purse seines				By drift-gill-nets
	E	O	Q	R	E
Sept. 3	229		105		
Sept. 4	100		217		
Sept. 5	116				
Sept. 9	87		50		
Sept. 10	60				
Sept. 11	74				
Sept. 12	127				
Sept. 13	35				
Sept. 18	348				
Sept. 19	68				
Sept. 20	116	70			
Sept. 23	73	63			
Sept. 24		177			
Sept. 25	267	241			
Sept. 26		543			
Sept. 28	75				
Sept. 30			149		
Oct. 1	393				
Oct. 2	83		50		
Oct. 3	332		195		
Oct. 4			319		
Oct. 5	331				
Oct. 7	246				
Oct. 17	180				
Oct. 19	364				
Oct. 21			458		
Oct. 22			194		
Oct. 24			910		
Oct. 26			375		
Oct. 28			378		
Oct. 29			760	158	
Oct. 30			751	59	
Oct. 31				146	
Nov. 4			588		58
Nov. 9			455		
Nov. 12					163
Nov. 20					119
Nov. 22					240
Nov. 26–29					1, 292
Dec. 2–4					796
Dec. 11–13					668
Dec. 16–17					266

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*

1926

Length, centimeters	Purse seines																		Drift-gill-nets	
	September—							October—							November—				Nov. 30 to Dec. 1	Dec. 11
	1–10		11–20		21–30			1–10		11–20			21–31		1–10		11–20	21–30		
	E	G	E	G	D	E	G	G	P	E	G	P	E	G	E	G	G	G	E	E
31.0			1																	
31.5		1																		
32.0			2			1	1													
32.5	1		2	1		2	1													
33.0	4		1			4	1	3												
33.5			1	1		4	3	2												
34.0	1			1		5	2	1												
34.5		1	3	1		4		1	1						1					
35.0	9	3	4	1		7	1	3			1									
35.5	10	5	6	5		20	4	16		1										
36.0	28	14	13	11	1	25	14	22	2	2	1									
36.5	29	30	31	11	4	39	30	69		3	6		1							
37.0	39	69	40	24	2	61	57	120	4	3	6	4					1			
37.5	53	115	42	55	6	89	99	210	3	7	14	9	8	1	2	2	1			
38.0	74	109	65	59	8	98	125	256	5	16	23	7	11	2		5	2			
38.5	74	103	72	32	9	84	122	202	2	24	14	10	15	4	15	13	9	1		
39.0	73	72	44	28	7	73	76	127	2	17	18	6	31	8	30	29	6	5	2	1
39.5	39	34	27	6		21	26	50		15	8	2	45	9	23	53	33	9	7	2
40.0	31	14	13	1	2	13	16	24		14	3	2	53	9	58	71	38	19	6	9
40.5	14	5	3	1		5	9	7		14	2		35	9	70	81	55	26	19	9
41.0	4	1	3			1	6			7	2		29	11	62	73	65	34	17	16
41.5	4	1	4	2		1	1	3	1	3			29	1	49	50	39	31	30	9
42.0	3	1	1			1	1	2		6	1		8	3	21	29	29	25	19	5
42.5						1	1	2		1			7	3	8	10	12	8	7	7
43.0							1	1		3			3		7	9	4	4	5	8
43.5							1	1		2			1		4	5	2	4	3	3
44.0	1							1		1					1	1	1	5	2	7
44.5	1							2							3		2	2	3	13
45.0	2							2					1		2	2	5	7	3	13
45.5	1		1					2								1	3	8	6	15
46.0					1		1	2		1					2	2	5	13	2	20
46.5	1							1					1		1	1	2	8	5	23
47.0	1												1		1		3	4	1	14
47.5		1				1		1					1			3	2	3	1	7
48.0	2						1	1										2	1	3
48.5								5									1	1		3
49.0	1																			4
49.5		1						1			1								1	
50.0			1																	2
51.0																		1		
Total	500	580	380	240	40	560	600	1,140	20	140	100	40	280	60	360	440	320	220	140	193

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued

1927

Length, centimeters	Purse seines																Drift-gill-nets			
	September—											October—				Nov. 1–10	October—		December—	
	1–10			11–20					21–30			1–10	11–20	21–31			11–20	21–31	11–20	21–31
	E	G	H	O	E	G	H	P	E	G	H	H	E	E	G	G	E	E	E	E
32.0	2																			
32.5	1					1														
33.0	5	1				1			1											
33.5									1											
34.0	2																1			
34.5	1																			
35.0						1			1											
35.5		1							2											
36.0	1	1				1					1									
36.5	5	4			1	2			1	3	4									
37.0	2	17	3	1	1	7		3	4	3	6	6	1							
37.5	8	33	2		1	18	5	4	6	10	21	22								1
38.0	11	73	2	2	6	33	15	6	9	16	75	47	4	2	2	1	1			
38.5	16	93	9	5	7	62	16	6	11	20	121	71	2	2	6	1	4	2		
39.0	11	127	18	1	11	65	26	9	18	26	174	113	12	9	3	2	4	2	2	5
39.5	12	122	15	4	7	67	28	11	20	24	133	93	16	17	5	4	8	4	3	2
40.0	9	92	4	6	4	60	17	5	20	17	80	75	16	24	12	6	10	5	12	15
40.5	7	65	2	1	11	31	8	5	26	7	57	37	20	31	13	10	7	11	26	32
41.0	2	34	1		2	10	4		6	4	19	14	26	25	10	15	17	14	67	49
41.5	2	15	1		2	9		3	6	2	9	6	26	26	15	18	16	19	98	63
42.0	2	9	1		2	4	1	1	8	2	3	6	21	34	15	18	9	17	110	64
42.5		5			1	1		1	3		1	1	11	17	5	10	10	10	99	46
43.0		5	1		1	3		2	5	2		1	17	5	6	5	5	5	75	31
43.5		5			1				3	2	1		4	2		6	5	4	48	16
44.0	1	2							2		3	3	2	3	2	2	2	3	38	9
44.5		4			2				2				1	1	1	1	1	2	22	12
45.0		3				1		1	1	1		1		1	1				20	6
45.5		1				1			3						2				23	20
46.0		2						1			1	1			1			1	28	24
46.5		2				1													37	22
47.0		1						1	1			2							36	21
47.5						1					1	1	1					1	23	7
48.0		2								1									14	2
48.5								1											8	4
49.0			1												1				4	1
49.5		1												1		1			1	4
50.0																				2
50.5																			5	
51.0																			1	1
52.0																				1
Total	100	720	60	20	60	380	120	60	160	140	710	500	180	200	100	100	100	100	800	460

1928

Length, centimeters	Purse seines							Drift-gill-nets				
	September—						Oct. 1–10	Oct. 21–31	November—			Dec. 1–10
	1–10		11–20	21–30					1–10	11–20	21–30	
	E	H	H	G	H	P	Q	E	E	E	E	E
37.0				1			1					
38.0				3		2	1					
38.5		1		5	1	4	4					
39.0	1	8	2	15		9	6					
39.5	2	19	8	32	4	27	23		1	2		
40.0	6	72	23	53	6	50	26		2	5	4	
40.5	1	94	27	52	10	39	31	1	2	24	6	1
41.0	8	66	27	44	9	37	44	5	8	45	14	4
41.5	4	73	16	35	4	31	11	6	5	85	32	5
42.0	6	47	18	28	3	21	7	6	23	116	66	15
42.5	8	16	8	16		12	6	8	31	184	96	31
43.0	4	8	6	12	1	2	4	9	34	201	107	43
43.5	2	3		5		1		7	31	209	84	33
44.0	2			2	1	2	2	6	20	166	81	42
44.5	5	3		4		4	1	4	13	98	58	25
45.0	2	1	1	2	1	3	1	4	8	60	28	23
45.5	3	1		4		2		3	4	22	22	9
46.0		2	1	2		2	1		1	25	13	11
46.5			1	1		2	1			18	14	6
47.0	1	1	1	4		2			3	14	10	12
47.5	1	1		2		3			2	21	16	12
48.0	2	2						1		8	5	11
48.5		1	1	2					1	7	8	7
49.0	1	1		1		1			1	5	5	3
49.5	1					1				1	1	4
50.0						2				2		
51.0										2		2
51.5												1
54.0						1						
Total	60	420	140	325	40	260	170	60	190	1,320	670	300

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued

1929

Length, centimeters	Purse seines							Drift-gill-nets			
	August—		September—				Oct. 1–10	Sept. 21–30	Oct. 21–31	November—	
	21–31		11–20			21–30				1–10	11–20
	G	H	D	E	G	E	F	E	E	E	E
30.0										1	
32.5	1										
33.0	5										
33.5	2										
34.0	6										
34.5	4										
35.0	6										
35.5	1					1					
36.0	10					1				1	
36.5	29		1			1			1		
37.0	48	1			1	1					
37.5	73	1				1					1
38.0	70	1	3		1	2	5	1	2	3	
38.5	46	1	2		1		1	2	1	5	
39.0	33		3	6	1	2	2		1	9	
39.5	23		3	3	1		2	1	5	13	2
40.0	37	2	1	2	3			5	3	10	2
40.5	74	3	1	1	2		3	1	2	7	1
41.0	73	10	6		3	1			1	8	4
41.5	90	5	3	1	4		1	4	7	15	6
42.0	81	7	6	10	9	3	3	5	8	36	23
42.5	42	5	6	2	3	2		8	16	57	37
43.0	28	4	2	3	2	2	4	8	28	95	51
43.5	25	4	1	4	2	4	1	4	28	120	65
44.0	7			5		1	2	3	28	125	71
44.5	5	3	1	2	1	1	1	2	25	99	61
45.0	6					1	2	5	15	91	48
45.5	1	2		5		2	1	3	19	40	32
46.0	4	1		2	1			2	6	20	11
46.5	5			3	1		1	1	8	12	6
47.0	3	2	1	1	1			3	3	8	3
47.5	3	2			1			1	2	6	6
48.0	3	1							1	3	3
48.5	4	3			1						
49.0	5							1		2	
49.5		2									
51.0	1										
52.0	1									1	
Total	855	60	40	50	39	26	29	60	210	787	433

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued

1930—BY PURSE SEINES

Length, centimeters	August—							September—										October—	
	11-20						21-31	1-10				11-20			21-30		1-10	21-30
	D	E	G	O	P	Q	P	D	E	G	O	E	G	H	G	P	P	E
30.0																	1	
30.5			1		2												3	
31.0																	2	
31.5			1		1							1					2	
32.0		1	2		2							1					2	
32.5			2		3					1		3					6	
33.0			4		4							7			1		4	
33.5			2		5							7					4	
34.0			3		5		1			2		9			4	1	5	
34.5			7	2	5					1		6	1			1	2	
35.0		2	4	1	18			1		2	1	3	1		2	1	6	1
35.5	1	2	20	9	45	4	7	1	1	3		2	1		3	2	6	
36.0	2	4	37	22	66	13	18	5		6	1	6	4	3	5	10	18	1
36.5	12	5	42	36	101	20	21	8		14	4	6	8	3	10	18	35	2
37.0	11	21	46	43	93	26	32	20	2	14	2	4	18	5	25	39	61	6
37.5	13	19	24	27	54	20	25	33	3	6	5	12	13	8	28	41	52	5
38.0	9	13	12	15	20	12	9	33	10	7	3	12	11	11	29	25	36	7
38.5	5	8	9	11	13	3	5	25	8	3	2	5	15	8	33	17	26	19
39.0	3	8	4	3	4	1		17	6		1	9	6	5	27	9	12	9
39.5	1	1	3		1			3	4		1	6		2	17	4	2	4
40.0	2	2	2	1	1			4	2			1			10	1	2	7
40.5	7	1	1					1				2			1	1	3	1
41.0	8		3	2	1			1				1			8	2	2	1
41.5	11	1	6	1	1				1	1		3			5	4	2	3
42.0	24	2	1	2			1	3	1			1	1		11	2		4
42.5	32	1			1							1			14	1		7
43.0	26	3	1	1				2	1			4			10			10
43.5	41					1	1	7				3	1		12			11
44.0	33	3	1	1				3				3			9			10
44.5	25	1	1		1			5	1			4			7			5
45.0	21	1		1				9				4			5	1		4
45.5	9							4							5			3
46.0	19							5				1			3			3
46.5	4							8							4			1
47.0	9	1						2							4			
47.5	6							2				1			1			1
48.0	2							5							5			1
48.5	4											1			2			
49.0	3							1										
49.5												1						
50.0			1					1										
50.5								1										
51.0	1																	
51.5	1																	
Total	345	100	240	178	447	100	120	210	40	60	20	130	80	45	300	180	294	126

1930—BY DRIFT-GILL-NETS (SUBAREA E)

Length, centimeters	Sept. 21-30	October—		November—			Dec. 1-10	Length, centimeters	Sept. 21-30	October—		November—			Dec. 1-10
		11-20	21-31	1-10	11-19	20-30				11-20	21-31	1-10	11-19	20-30	
34.0	1			1				44.0		2	14	40	21	92	45
34.5					1			44.5	1	2	19	31	9	98	68
35.0			2					45.0	1	2	20	34	9	109	56
35.5			1					45.5	7	1	9	16	6	84	30
36.0			2			2		46.0		1	10	15	5	51	20
36.5		2	2	4	4	4		46.5			1	7	7	26	15
37.0		6	11	17	18	10	3	47.0		1	4		3	19	15
37.5	1	1	11	24	34	31	7	47.5			1	2		21	4
38.0	2	5	22	62	41	33	9	48.0				1	1	10	5
38.5	1	5	18	76	45	54	15	48.5				1		3	5
39.0		4	11	48	49	47	10	49.0						5	2
39.5	1	4	4	21	19	18	9	49.5				1		2	
40.0		2	3	12	5	19	3	50.0				1		1	2
40.5		1		8	7	9	2	50.5							2
41.0		1	3	5	8	9		51.0							2
41.5			2	6	4	10	3	51.5						1	2
42.0	2	1	9	31	9	23	8	52.0							1
42.5	1	5	13	22	11	30	10	52.5							1
43.0	2	3	11	29	9	33	29								
43.5		1	18	35	9	64	47	Total	20	50	221	550	334	918	430

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued

1931

Length, centimeters	Purse seines															Drift-gill-nets			
	August—				September—						October—					Oct. 21–30	November—		Dec. 1–10
	11–20		21–31		1–10	11–20		21–30			1–10	11–20			21–30		10–20	21–30	
	C	D	C	D	C	C	E	C	D	E	E	D	E	G	G	E	E	E	E
30.5																	1		
32.5														1		1			
33.0								1		1									
33.5															1				
34.0							1								1				
34.5											1			1	1				
35.0	1		1	1				1			2								
35.5	2	1	3					1			1			2					
36.0	3		3	2	1									2	2				
36.5	4	1	13	2	5	1		2		1	4		1	2	1				
37.0	7	2	17	1	11	2		2	1	4	3	2	1	1	1			2	
37.5	6	5	17	2	7	4		5		1	2	1			1		4		1
38.0	21	4	26	10	17	4		4	2	8	5	2	1	6		2	8	2	2
38.5	29	9	38	16	33	12	2	17		16	10	4		22		1	14	9	3
39.0	54	21	100	19	59	24	3	36	7	48	12	1	2	33		2	34	11	4
39.5	60	30	109	26	85	38	8	33	8	54	16	11	3	33	4	8	45	22	10
40.0	66	23	112	21	96	35	8	41	3	65	14	10	6	50	8	5	84	33	24
40.5	47	25	78	23	49	23	2	29	6	60	9	7	9	31	2	11	65	33	19
41.0	21	6	36	12	33	15	2	26	3	44	10	1	3	12	2	5	56	22	8
41.5	12	9	24	2	19	9	4	6	1	20	4		3	6		4	29	13	4
42.0	22	9	21	4	10	7	1	5	1	17	3	2	3	6		16	10	14	3
42.5	27	7	26	4	22	12		5	2	10	4			4		29	17	11	2
43.0	39	10	32	8	17	9	1	8		11	5	4		3	1	26	23	24	8
43.5	41	14	46	5	23	9	1	4	1	17	1	2	3	5	2	29	48	23	13
44.0	42	4	44	7	23	13	2	9	1	10	5	1		5		31	69	38	28
44.5	26	6	34	3	15	8	2	4	2	9	4	5	1	5		13	75	62	41
45.0	29	4	29	5	12	7		11	1	5	2	3	3	4		16	74	99	42
45.5	16	2	16	1	11	4	1	10		5		2		6		10	87	90	39
46.0	14	4	18	1	5	8		3		3	1		1	2	1	2	38	52	39
46.5	5		1	3	4	2	1	3	1	7	1	1				1	37	38	28
47.0	2	1	3	1	1	2		1		3	1	1			1	3	18	27	9
47.5	3	1	2		2	1		1		1					1		5	20	11
48.0	3	2	1	1		2										3	9	4	4
48.5	1			1												1	4	4	1
49.0	2				1	1	1	1								1	1	3	3
49.5																		2	
50.0																		2	3
50.5					1														1
51.0								1											
52.0					1														
Total	605	200	850	180	565	250	40	270	40	420	120	60	40	242	30	220	855	660	350

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued

1932

Length, centimeters	Purse seines											Drift-gill-nets					
	August—					September—						Sept. 21-30	November—			December—	
	11-20		21-31			1-10		11-20		21-30[1]			1-10	11-20	21-30	1-10	11-20
	C	D	C	D	E	D	E	D	E	D	E	E	E	E	E	E	E
33.0				1													
34.0																1	
34.5															1		
35.0		1		1	1									3	1		1
35.5				1		1									2	1	
36.0				1										1			
36.5	1	1		1											2		
37.0				2									1	1		1	
37.5				2													1
38.0	1			1					2		1			3	1		
38.5	2	2		5		1	1		2	1			2		2		
39.0	10	4	1	11	1	1		3	2	3			3	5	8		
39.5	9	7	1	21	3	2	1	4	4	3		2	5	12	17	5	
40.0	22	8	1	32	2	7	5	1	7	8	1	2	12	38	34	14	1
40.5	33	11	6	38	8	7	9	5	6	11		3	15	59	63	25	2
41.0	43	14	6	52	3	5	14	3	6	5	1		12	50	68	21	1
41.5	27	8	6	40	4	7	7	1	2	1	4	4	10	48	46	28	
42.0	25	9	8	35	2	11	8	1	2	5	4	1	6	36	36	20	3
42.5	39	3	8	47	5	4	11	7	4	1		3	4	24	23	20	1
43.0	40	13	7	55	8	11	23	3	3	11	3	1	5	37	24	26	1
43.5	61	8	11	40	2	9	14	4	9	11	1	4	7	30	33	34	2
44.0	54	14	11	56	9	10	15	4	1	8	3	4	6	39	62	60	6
44.5	43	6	8	49	4	5	15	1	4	5	1	5	7	61	80	99	3
45.0	32	5	3	24	1	11	5	2	2	1	1	7	7	49	94	104	4
45.5	27	2	3	15		2	6		2	6		1	3	53	92	97	7
46.0	16	3	1	11	1	2	1	1	1	4		3	3	50	59	84	3
46.5	5		1	3	1	2	2						2	36	37	65	3
47.0	4	1	1	2			1		1			1		15	24	38	2
47.5	4			1	1	1						1		9	15	22	
48.0						1	2							6	13	13	2
48.5	1			1										7	4	10	
49.0														7	3	6	
49.5	1													2	1	10	
50.0														1		3	
50.5														1		2	
51.0														1			
51.5														1		1	
Total	500	120	83	548	56	100	140	40	60	84	20	42	110	685	845	810	43

[1] Includes 1 sample of 20 mackerel landed Oct. 1 from subarea D.

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive, by gear, by time periods, and by statistical subareas of area XXII*—Continued

1933

Length, centimeters	Purse seines										Drift-gill-nets							
	Aug. 27 to Sept. 2	September—				October—				Oct. 29 to Nov. 4	Oct. 29 to Nov. 4	November—				December—		
		3–9	10–16	17–23	24–30	1–7	8–14	15–21	22–28			5–11	12–20	21–25	26–30	1–5	6–10	11–14
32.0	1	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
32.5	3	5	----	----	----	----	3	----	2	1	----	----	----	----	----	----	----	----
33.0	11	14	2	4	5	3	6	7	16	2	----	----	----	----	----	----	----	----
33.5	30	31	14	8	20	8	21	22	22	6	----	1	----	----	----	----	----	----
34.0	69	55	30	30	45	32	67	62	57	11	6	6	1	1	----	----	----	----
34.5	99	94	58	68	70	53	119	99	98	13	5	4	----	2	----	----	----	----
35.0	126	111	70	128	162	96	192	137	126	24	11	10	5	10	----	----	1	----
35.5	102	108	69	144	192	122	256	116	129	19	18	13	10	11	1	----	1	----
36.0	67	65	64	117	134	106	183	95	81	12	16	9	13	12	2	----	2	----
36.5	42	54	32	107	115	75	136	56	52	7	25	12	13	22	6	1	2	1
37.0	19	16	19	64	57	30	65	24	38	6	25	15	18	8	8	3	9	----
37.5	11	3	6	23	25	22	29	10	9	4	11	9	9	17	6	8	16	----
38.0	3	2	4	8	9	4	10	10	7	----	9	8	9	16	5	4	12	----
38.5	3	2	4	9	3	4	4	1	1	----	6	4	6	4	8	6	6	----
39.0	4	1	1	1	----	----	3	----	1	1	7	2	1	7	5	6	5	----
39.5	1	3	2	1	1	----	----	----	1	----	1	2	6	15	----	2	5	----
40.0	1	6	2	1	1	----	2	----	----	----	1	4	18	20	4	4	11	----
40.5	6	2	1	1	1	----	3	----	----	----	3	3	23	46	9	10	11	----
41.0	12	17	3	1	1	----	----	----	----	----	6	9	32	53	12	15	12	1
41.5	12	18	6	3	1	----	1	----	----	----	11	3	38	72	20	17	22	1
42.0	24	27	10	3	1	----	6	----	----	----	3	7	26	56	18	25	26	5
42.5	35	21	13	6	----	----	2	----	----	----	2	6	24	52	18	29	24	4
43.0	38	30	8	6	3	----	4	----	1	----	3	12	21	47	17	21	18	4
43.5	34	27	5	7	2	----	7	----	----	----	7	6	19	41	24	44	36	4
44.0	26	33	9	13	----	----	4	----	----	----	2	6	22	54	37	48	38	13
44.5	24	24	3	6	3	----	5	----	----	----	4	5	30	52	49	59	40	11
45.0	10	19	7	5	4	----	4	----	----	----	2	6	24	61	64	64	61	9
45.5	3	6	4	2	2	----	3	----	----	----	1	1	17	43	52	67	41	5
46.0	3	5	2	1	----	----	----	----	----	----	----	2	13	38	34	31	21	6
46.5	----	1	----	1	----	----	1	----	----	----	----	5	9	21	42	32	26	1
47.0	----	1	----	----	1	----	----	----	----	----	----	----	3	11	28	25	13	4
47.5	----	2	----	2	----	----	----	----	----	----	----	1	4	4	10	17	11	3
48.0	----	----	----	----	----	----	----	----	----	----	----	----	1	6	5	7	2	----
48.5	1	1	----	----	----	----	----	----	----	----	----	----	----	----	4	5	5	3
49.0	----	----	----	----	----	----	----	----	----	----	----	----	----	2	6	2	5	----
49.5	----	----	----	----	----	----	----	----	----	----	----	----	----	1	3	3	6	----
50.0	----	----	----	----	----	----	----	----	----	----	----	----	----	1	1	1	----	----
50.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	1	----
51.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----	----	----
Total	820	804	449	770	858	555	1,136	639	641	106	185	171	415	806	500	556	489	75

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive by gear, by time periods, and by statistical subareas of area XXII*—Continued

1934

Length, centimeters	Purse seines								Drift-gill-nets		
	September—			October—					November—		Dec. 5
	21–30			1–10			11–20		13–21	26–30	
	D	E	G	E	G	H	D	E	E	E	E
29.0			1								
29.5									1		
30.5									2	2	
31.0								2	7	1	
31.5									7	5	
32.0					1	1		2	19	3	
32.5	1			2		1		3	4	2	
33.0			1	4				4	8	1	
33.5		3	1					8	2	1	
34.0			5	4		2	1	10	4	1	
34.5		14	1	7	1	1	2	38	3	1	
35.0	5	16	13	6	5	4	3	67	9	1	
35.5	5	41	24	25	9	10	2	115	9	2	3
36.0	5	46	19	28	13	10	5	91	27	4	1
36.5	7	62	52	24	15	13	3	81	35	7	4
37.0	10	71	60	23	18	16	2	61	47	13	7
37.5	12	68	41	24	14	11		36	75	23	6
38.0	17	59	68	18	13	11	1	29	107	41	4
38.5	7	35	43	21	7	4	1	27	90	30	5
39.0	9	38	38	8	4	5		27	65	25	
39.5	5	19	31	12		2		5	38	11	3
40.0	1	12	17	2	2	1		4	26	2	4
40.5	2	8	13	6	1	1		2	21	16	3
41.0	2	3	12	1		1			17	15	4
41.5	1	14	17	1		1		3	23	24	
42.0	1	8	18	1				1	29	27	1
42.5	1	9	18		1	1			32	18	
43.0	1	3	25			2		1	23	14	2
43.5	2	3	24		2			2	14	8	2
44.0	1	6	14	1					14	10	3
44.5	2	9	14	2				3	11	6	1
45.0	2	7	16	1					9	11	4
45.5	1	4	9		1	2			4	13	
46.0		2	5					2	5	6	1
46.5					1			1	3	5	2
47.0			2						1	1	1
47.5									2	2	
48.0									1		
48.5			2								
49.0									1		
49.5										1	
Total	100	560	604	221	108	100	20	625	795	353	61

TABLE 23.—*Length frequencies of mackerel in the fall, 1926 to 1935 inclusive by gear, by time periods, and by statistical subareas of area XXII*—Continued

1935

Length, centimeters	Purse seines													Drift-gill-nets				
	September—							October—					Nov. 1-10	November—			December—	
	1-10		11-20		21-30			1-10		11-20	21-31			1-10	11-20	21-30	1-10	11-20
	E	Q	E	O	E	O	Q	E	Q	E	Q	R	Q	E	E	E	E	E
23.0										1								
25.0											1							
26.0											1							
27.0						1												
27.5						5					1							
28.0					2	11		1		1	1							
28.5					6	26	4	1	4	1	11		2			1		
29.0					19	38	12	1	8	3	33		1					
29.5					37	55	16	14	11	10	77		5					
30.0	1			1	41	57	28	11	10	19	209		20					
30.5	2				47	62	26	25	9	45	300	3	30					
31.0		4	6		67	50	17	38	16	58	374	6	37					
31.5	7	3	7		39	43	17	38	12	75	346	5	40					
32.0	7	6	24	2	33	31	9	45	8	70	238	2	43					
32.5	9	9	30	2	14	14	5	35	8	53	139	5	21					
33.0	18	6	24		9	11	1	27	6	22	101	3	15					
33.5	17	14	26		2	23	1	16	10	9	63	5	11					
34.0	43	43	43	1	3	37	1	30	33	12	102	10	20					
34.5	91	66	69	9	8	58	2	35	81	12	211	20	57					
35.0	113	72	131	15	23	126	3	95	88	11	305	47	92					
35.5	105	72	132	18	12	110	3	119	91	23	393	70	114			2		
36.0	71	39	91	11	18	113	3	153	80	36	302	70	112		2	1		
36.5	38	21	79	5	12	86	1	135	40	22	189	34	86	2		4	2	1
37.0	26	2	40	2	3	32		100	21	10	107	14	40	1	3	36	6	6
37.5	5	5	13		3	12		53	4	6	42	8	25	2	11	73	11	11
38.0	3	1	11	1	1	5		52	6	4	50	7	33	5	19	112	38	25
38.5	5	2	7	1	1	3		53	1	5	41	11	41	7	33	242	81	51
39.0	2	2	8	2	6	4		68	3	8	59	11	42	6	45	290	116	112
39.5	4	2	10		2	3		49	3	5	31	12	20	9	43	257	104	93
40.0	2		6		1	1		38	2	4	18	4	19	3	39	180	73	100
40.5	1		1		1	1		27		1	7	1	17	4	15	95	46	62
41.0	2		2			1		15		4	4	1	4	3	8	38	27	47
41.5								11	1		5		5	3	9	39	31	59
42.0	1		1			1		6		1	8	1	4	2	7	28	42	51
42.5		1	3		1	1		14		2	3	2	6	2	5	24	56	59
43.0	2		2					10	2	2	8	3	15	1	7	29	36	45
43.5	1		2					9		3	10		19	1	14	16	31	51
44.0	5	1						15	4	3	8	4	13	2	6	16	18	30
44.5	5					3		9	1		10	1	12	1	2	15	14	29
45.0	4							6			9		12	1	5	7	22	28
45.5	2	1			1			15		2	7	1	3	2		11	12	20
46.0								8		1	2		4	1	5	6	14	28
46.5					1			7				2	3		4	2	8	9
47.0					1			1								3	4	10
47.5																5	2	5
48.0																	1	1
48.5																	1	
49.0					1													1
52.0									1									
Total	592	372	768	70	415	1,024	149	1,385	564	544	3,826	363	1,043	58	282	1,532	796	934

TABLE 24.—*Length composition of mackerel during the "summer" period, 1926 to 1935*

Length, centimeters	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
	July 1–Aug. 31	July 1–Aug. 31	July 1–Aug. 31	July 1–Aug. 20	July 1–Aug. 10	July 1–Aug. 10	July 1–Aug. 10	June 25–Aug. 26	July 1–Aug. 20	July 1–Aug. 31
30.5							393			
31.0							472	3		
31.5							392	23		
32.0							423	50		129
32.5							293	153	123	146
33.0	2						219	337	163	317
33.5	18				9		137	605	268	700
34.0	32				32	2	101	974	347	1,170
34.5	45	2		4	60	7	45	1,055	410	1,438
35.0	74	3		10	169	13	38	998	575	1,416
35.5	115	6	1	8	342	29	12	763	653	971
36.0	186	21	3	12	572	52	7	537	816	528
36.5	431	76	5	27	680	72	10	248	958	260
37.0	759	233	13	49	612	89	15	150	1,142	135
37.5	1,325	541	27	43	375	77	14	67	888	158
38.0	1,642	1,146	67	41	222	81	4	26	770	238
38.5	1,477	1,843	223	24	129	69	13	23	484	302
39.0	860	2,124	571	20	85	107	10	27	379	324
39.5	394	1,717	1,089	56	40	135	16	19	175	255
40.0	183	1,118	1,791	203	46	146	31	23	125	174
40.5	64	495	1,832	482	109	158	60	23	110	110
41.0	33	227	1,470	841	205	119	58	30	70	57
41.5	20	87	961	1,003	367	182	53	43	97	38
42.0	15	31	505	1,023	674	319	67	66	120	49
42.5	10	18	207	669	684	448	79	100	161	101
43.0	3	13	91	386	614	485	92	118	221	115
43.5	4	9	53	157	457	422	101	119	259	154
44.0	2	8	18	74	263	319	109	104	279	183
44.5	6	12	25	33	103	175	74	91	214	156
45.0	7	11	12	23	45	82	38	69	163	141
45.5	1	7	13	18	28	36	19	23	73	93
46.0	6	8	16	24	14	24	11	20	43	68
46.5	3	9	12	16	8	11	2	7	22	22
47.0	3	7	15	16	24	9	5	6	10	9
47.5	1	4	19	12	12	3	2	2	9	3
48.0	3	5	15	9	23	8		3	5	1
48.5	1	4	6	4	12	2		4	3	1
49.0		2	6	3	10	4		2	1	1
49.5	4		2	3	4	1	1	1	1	2
50.0			3		8	2		1	1	
50.5			1		2		2			1
51.0				1	1					
51.5				1	2					
52.0	1				2	1				
Total	7,730	9,787	9,072	5,295	7,044	3,689	3,418	6,913	10,183	9,966

APPENDIX B.—MARKING EXPERIMENTS

In this section the data on experiments in marking mackerel will be given and their results discussed with special reference to the technique of the method.

Field experiments, begun prior to the inception of the comprehensive mackerel investigations,[1] soon revealed the difficulties in marking a species so active and so delicate as the mackerel, and subsequent endeavors sought to discover methods of marking that would be suited to the species. For convenience in reference, the experiments will be serially numbered and taken in approximately chronological order.

FIELD EXPERIMENTS

Experiment No. 1

In the spring and late fall of 1925 in the vicinity of Woods Hole, Mass., 696 mackerel were marked. The fish were caught in commercially operated pound nets, transferred to a live car, marked and released at the place they were caught. The tag used was a celluloid band commonly used in marking poultry. It consisted of a flat strip of celluloid molded in the form of a flat spiral of two complete turns forming a ring that was unwound, placed around the caudal peduncle and when released, resumed its original ring-shape surrounding the peduncle. The mackerel were measured to the nearest half inch before release. Returns from this experiment are given in table 25. Since the subsequent returns from individuals below and above 15¼ inches of length differed significantly, these sizes have been separated in the table. The individuals released August 24 to September 1 were all between 11 and 14 inches in length.

[1] These marking experiments took place under the auspices of the North American Council of Fishery Investigations in the United States and Canada. In the United States they began in June 1925, under the direction of Henry B. Bigelow and the immediate supervision of William C. Schroeder. Late in that season supervision was transferred to O. E. Sette.

Table 25.—*Returns from 696 mackerel released in Buzzards Bay and Vineyard Sound, near Woods Hole, Mass., in 1925*

(EXPERIMENT NO. 1)

Time of recapture	June 8–17, under 15¼ inches long (142 released)	June 8–17, over 15¼ inches long (415 released)	Aug. 24–Sept. 1 (139 released)
Local (area XXII S):			
0–4 days after release	1	2	3
5–9 days after release	1	1	---
10–14 days after release	---	1	---
14–19 days after release	---	---	1
20–24 days after release	1	1	---
25–29 days after release	1	---	---
30–39 days after release	---	1	---
Total	4	6	4
Massachusetts Bay (area XXII E):			
July 11–20, 1925	---	3	---
Sept. 12, 1925	1	---	---
Oct. 7, 1925	1	---	---
Total	2	3	---
Lightship Grounds (area XXII O):			
July 13–20, 1925	---	2	---
Rhode Island Shore (area XXII S):			
June 21–23, 1925	2	1	---
July 2, 1925	1	---	---
June 19, 1926	---	1	1
Oct. 19, 1926	---	---	1
Total	3	2	2
Western Long Island (area XXIII B):			
July 7, 1925	1	---	---
Central Nova Scotia (area XXI M)	---	1	---
Grand total	10	14	6

Experiment No. 2

During the summer and fall of 1925, at pound nets and weirs in the vicinity of Provincetown, Mass., 3,939 mackerel were marked. Procedure was the same as in experiment No. 1 except that the mackerel were transferred to a pocket of netting instead of a live car. The tag was identical to that used in experiment No. 1. The returns are given in table 26. Since relatively few (4 percent) of the Provincetown mackerel were above 15¼ inches in length, the sizes have not been separated in the table. However, there was a significant difference in the percentage returns of the various sizes in this experiment. (See p. 350.)

Table 26.—*Returns from 3,939 mackerel released at Provincetown, Mass., during the summer and autumn of 1925*

(EXPERIMENT NO. 2)

Time and location of recapture	June 23–July 3 (949 released)	July 9–July 22 (1,294 released)	July 29–Aug. 5 (996 released)	Oct. 2–7 (700 released)	Total (3,939 released)
Southern Maine, area XXII D:					
Nov. 21, 1925	------	1	------	------	1
Massachusetts Bay, area XXII E:					
0–4 days after release	28	57	55	29	169
5–9 days after release	16	4	3	------	23
10–14 days after release	9	2	1	------	12
15–19 days after release	2	1	------	------	3
20–24 days after release	2	------	------	------	2
25–29 days after release	2	------	------	------	2
30–59 days after release	3	------	1	------	4
60–89 days after release	2	1	------	------	3
90–120 days after release	2	------	------	------	2
During first season, date uncertain	8	11	11	1	31
During second season—					
Aug. 2, 1926	------	------	1	------	1
Aug. 28, 1926	------	1	------	------	1
Sept. 8, 1926	------	------	------	1	1
Total	74	77	72	31	254
Western side of South Channel, area XXII G: July 29 to Aug. 7, 1925	3	2	------	------	5
Southern Massachusetts, Area XXII R:					
June 8, 1925	1	------	------	------	1
October 1926	1	------	------	------	1
Total	2	------	------	------	2
Rhode Island, Area XXII S:					
June 9, 1926	------	------	1	------	1
Aug. 14, 1926	------	1	1	------	2
Total	------	1	2	------	3
Grand total	79	81	74	31	265

Experiment No. 3

In Casco Bay, Maine, 930 individuals were tagged August 4 to 25, 1925. Of these, 249 were caught in floating traps, and the procedure was the same as in experiment No. 2. The remaining 35 were caught by purse seine, 10 miles southeast of Seguin Island, and presumably were tagged immediately upon being brailed to the deck of the vessel. Otherwise, procedure, as well as the tag used, was the same as in previous experiments. Only four returns resulted from the trap-caught mackerel: One was caught locally, August 6, 1925; another, 10 miles southeast of Block Island, October 19, 1925; the third, 3 miles southeast of Fire Island, N. Y., June 7, 1926; and the fourth, off Point Judith, Newport, R. I., August 6, 1926. Of the purse-seine-caught mackerel one was recaptured 15 miles southeast of Eastern Point Light, Gloucester, Mass., August 2, 1926.

Experiment No. 4

To test the metal-strap tag of the type illustrated by Schroeder (1930, fig. 3), 90 individuals were tagged at Woods Hole, Mass. In this experiment the pound net was partially hauled to concentrate the mackerel which were dipped from the net, one at a time, tagged, and immediately returned to the water. The tag was the small size designated as No. 3 by its manufacturer, and it was attached at the base of the dorsal lobe of the caudal fin. Several tags were seen to have dropped off as the mackerel were returned to the water, and doubtless most of them did so later, for no returns resulted from this experiment, whereas other taggings of this size of mackerel at this season and at this place have yielded 13 percent returns. (If the stock at Woods Hole is such as to provide 13 percent returns with a suitable tag from a release of 90 individuals, there would be less than one chance in a thousand that no tags would be returned due to random causes alone.)

Experiment No. 5

To see whether the mackerel approaching the coast in early spring in the southerly end of the range were on their way to more northerly waters, 400 were marked (with the same style of tag as used in experiment No. 1) in the offing of Delaware Bay (lat. 37°35′ W.; long. 74°35′–40′ N.) April 10, 11, and 15, 1926. The fish were caught by commercial purse-seine fishermen and were tagged immediately after the fish were brailed to the deck of the fishing vessel. Of course, only the liveliest of the mackerel were selected for tagging, but even with severe selection the fish suffered more injury from this method of fishing and handling than those that were caught in pound nets and handled differently. At least this appears to be the most reasonable explanation of the paucity of returns from this experiment from which only two were recovered. One was from the same grounds on the day following tagging, the other was taken off Chatham, Mass. (area XXII G) the following August.

Experiment No. 6

To see whether better results might be obtained with an extremely light celluloid tag a special lot of tags was made of thin stock (0.025 inch thick) and with only one and a half turns. Thinking also that the bright cerise and yellow colors of the bands previously used were likely to render their bearers more vulnerable to predators, the special bands were colored green. They were attached to 967 mackerel from pound nets in the vicinity of Woods Hole, Mass., July 15–27, 1927, using the procedure of experiment No. 2. A number of these mackerel were recaptured and released again shortly after the original tagging, so that the effective number released was 1,000. The releases and returns are given by sizes and by time-of-recapture groups in table 27. Returns from this experiment were so similar to those of experiment No. 2 that no substantial advantage of the modifications in the tag was indicated.

TABLE 27.—*Returns from mackerel tagged July 15–27, 1927, in the vicinity of Woods Hole, Mass.*

(EXPERIMENT No. 6)

Length when tagged, centimeters	Number tagged	Returns classified according to the number of days elapsed between release and recapture													
		0–4	5–9	10–14	15–19	20–24	25–29	30–34	55–59	60–69	70–79	80–89	90–99	Over 100	Sum
		Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
25.5	1														
26.5	3														
27.0	7														
27.5	6														
28.0	24	4													4
28.5	63	1	1		1								1		4
29.0	88	7	3	2		1									13
29.5	106	5	1	1								1			8
30.0	158	5	7	4		1				1			1	[1] 1	20
30.5	138	8	3	2	3	2	1		1	1	1				22
31.0	117	10	6	4	1							1			22
31.5	81	8	1	2										[2] 1	12
32.0	67	4	3						1						8
32.5	36	3	3		1										7
33.0	19	2													2
33.5	13		1					1							2
34.0	2														
34.5	1														
35.0	1		1												1
35.5	1														
36.0	7	2													2
36.5	8														
37.0	10														
37.5	12														
38.0	9														
38.5	2														
39.0	6	1													1
39.5	1														
40.0	3														
41.0	2														
44.5	1														
45.0	1														
45.5	1														
47.5	1														
49.5	2														
50.0	1														
Not measured	1				1										1
Total	1,000	60	30	15	7	4	1	1	2	2	1	2	2	2	129

[1] 101 days. [2] 359 days.

EXPERIMENT No. 7

Thinking that the attachment of tags to the rapidly moving caudal region of the mackerel was less desirable than to the less active forward parts, a modification of the strap tag was devised for attaching to the operculum. Higgins had found (unpublished notes) that No. 3 strap tags on the operculum of the mullet, *Mugil cephalus*, caused enlargement of the perforation made by the clinching point, presumably by rotation of the tag around its point of attachment. He suspected that the enlargement proceeded until it reached the margin of the operculum thus allowing the tag to drop off. This modified tag was three times as broad as the standard tag and had two clinching points to prevent rotation. In September 1926, tags of this type were attached to 396 individuals caught by purse seines with the same procedure as in experiment 5. No returns resulted and although this might have been owing to the rough treatment inevitable with purse-seine-caught mackerel, it is more likely that the lack of returns was due to loss of tags from the operculum, for 20 bull's-eye mackerel, *Pneumatophorus grex*, marked with this style of tag and held in a livecar at Woods Hole lost their tags within 14 days. The loss appeared due to necrosis of the tissue.

INFLUENCE OF TAGGING ON THE MORTALITY OF MACKEREL

The diminution in returns of the mackerel released in experiments 2 and 6 during the first month after release is of interest in providing field evidence on the merits of the methods used in tagging mackerel in 1925 and 1927. In experiment 2 (table 26) the returns from mackerel released during June 23 to July 3 diminished at an average rate of 54 percent per 5 days during the first three successive 5-day periods. The returns from those released during subsequent periods in the same experiment diminished at an even higher rate.[2] In experiment 6 (table 27) the returns declined at a nearly uniform rate of 50 percent in the first four successive 5-day periods. Such declines might be due to (1) the early loss of tags from the fish; (2) rapid dispersal of the fish from the point of release to areas in which less fishing was done; (3) early mortality of the fish tagged.

[2] This higher rate may reflect the care with which the mackerel were handled. Those tagged during June 23 to July 3 were under the immediate supervision of a trained biologist. Subsequent to that date the tagging was done by an untrained crew, without immediate supervision.

That some tags were lost from the mackerel is probable. In tables 28 and 29 are given the returns of fish by size groups, demonstrating that the maximum returns of the mackerel tagged in 1925 were of the 14- to 15-inch size groups, and of those tagged in 1927, the best returns were of the 30.5 to 32.0 centimeters (12 to 12½ inches). In each case the tags were chosen of a size to fit the prevailing size of mackerel and it is seen that the maximum returns in each case were close to modal length of the mackerel released. Below these sizes the returns were appreciably poorer, and we consider it probable that a portion of the tags placed on the smaller mackerel slipped off over the caudal fin. If the percentage returns from the groups of maximum return are indicative of the returns to be expected when there is no loss of tags, the loss of tags from mackerel 8 to 12 inches may be estimated at 60 percent, and the loss from mackerel 12½ to 13½ inches, at 36 percent in

TABLE 28.—*Relation between size of mackerel tagged and percentage of returns in 3 groups of mackerel tagged at Provincetown, Mass., 1925*

Length, inches[1]	June 23–July 3			July 9–22[2]			July 29–Aug. 5			Total		
	Released	Recaptured		Released	Recaptured		Released	Recaptured		Released	Recaptured	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
8	1									1		
8½				1						1		
9	4			4						8		
9½	5			22			1			28		
10	4			108	3		12			124	3	
10½	3			114	5		37	3		154	8	
11	4			112	6		45	1		161	7	
11½	14	1		40	2		51	2		105	5	
12	21	1		35	4		37	2		93	7	
Total	56	2	3.6	436	20	4.6	183	8	4.4	675	30	4.4
12½	15			39			47	4		101	4	
13	56	2		49	5		67	4		172	11	
13½	197	15		96	11		175	9		468	35	
Total	268	17	6.4	184	16	8.7	289	17	5.9	741	50	6.7
14	378	31	8.2	199	24	12.1	303	24	7.9	880	79	9.0
14½	138	21		98	10		186	21		422	52	
15	39	6		49	3		24	3		112	12	
Total	177	27	15.2	147	13	8.8	210	24	11.4	534	64	12.0
15½	8			19	2		6	1		33	3	
16	14			23	3		3			40	3	
16½	11			2			1			14		
17	8			11	2					19	2	
17½	8	2		1			1			10	2	
18	8			6						14		
18½	3			3						6		
19	5			3						8		
19½	3									3		
20	1			2						3		
21	1									1		
Total	70	2	2.9	70	7	10.0	11	1	9.1	151	10	6.6
Grand total	949	79	8.3	1,036	80	7.7	996	74	7.4	2,981	233	7.8

[1] Measurements were made to the nearest quarter-inch, but there was such marked bias in favor of the whole-inch and half-inch intervals that the quarter-inch measurements were grouped with the preceding whole-inch group and the three-quarter-inch mark with the preceding half-inch group, so that the mid points of the class intervals in this column are 8⅛, 8⅝, 9⅛, 9⅝, etc.

[2] Exclusive of the last 258 mackerel tagged on July 22, omitted because suspected of being in exceedingly poor condition when released.

TABLE 29.—*Relation between size and percentage of returns from 1,000 mackerel tagged and released at Woods Hole, July 15–27, 1927*

(EXPERIMENT NO. 6)

Length, centimeters	Number tagged	Number returned	Percent
25.5–28.5	104	8	7.7
29.0–29.5	194	21	10.8
30.0	158	20	12.7
30.5	138	22	15.9
31.0	117	22	18.8
31.5–32.0	148	20	13.5
32.5–34.5	72	11	15.3
35.0–50.0	69	4	5.8
Total	1,000	128	12.8

experiment 2. Similarly, in experiment 7, the loss of tags from the group 25.5 to 28.5 centimeters long, may be estimated at 51 percent and the loss from the group 29.0 to 30.0 centimeters at 27 percent. If only the size groups of maximum return be considered, the rate of diminution in both the 1925 and 1927 experiments is still about 50 percent per 5-day period during the first 15 or 20 days, indicating that the loss of tags, although affecting total returns of small mackerel, was distributed uniformly during the three or four 5-day periods immediately after release, and hence was not responsible for the rate of diminution of returns.

It is probable also that the rapid diminution of returns from these experiments in part was due to the dispersal of mackerel from the point of release to areas less intensely fished. In both experiments tagging was done at pound nets, and even slight travel of the tagged fish in an offshore direction would take them out of reach of the gear alongshore. However, it would also bring them into the range of the purse-seine fishery. This is particularly true of those released in Provincetown. So also, movement along the shore would take them into the range of pound nets elsewhere. Inasmuch as the returns from distant points were negligible, it does not seem that the rapid diminution was due to dispersal. On the contrary, it appears more likely that the population of tagged fish of these particular experiments stayed more or less in the vicinity of their release during the remainder of the summer. By contrast, a tagging experiment done at Woods Hole, Mass., June 8–17, 1925 (table 25), affords an example of the results obtained when there is rapid dispersal. Of the returns during the first month after release, 50 percent, rather than a negligible number, came from distant points.[3] All things considered it would appear that only a part of the diminution of the early returns in experiments 2 and 7 was due to scatter of the fish, the remainder, perhaps the major portion, resulted from other causes.

Principal among the other causes is quite plainly the mortality of the mackerel during the first 2 weeks after tagging. Experiments on holding mackerel in confinement have shown that they are subject to high initial mortality as the result of catching and handling. In two experiments the loss was 36 and 70 percent and this is thought to have taken place during the first 2 weeks after catching. A 50-percent mortality per 5-day period would be the equivalent of 75 percent in 15 days. So it appears that the rate of decline in number of returns from field releases was not far different from the mortality in holding experiments. The number of holding experiments was too few to establish a reliable average-mortality expectancy, but perhaps adequate to demonstrate that the bulk of the decline in returns must have been due to mortality and only a minor part to dispersal of mackerel from tagging points.

TESTS OF THE SUITABILITY OF VARIOUS TAGS FOR MARKING MACKEREL

Thus, the foregoing experiments yielded returns that either were scanty, or fell sharply during the first few days, owing to loss of tags and to mortality of the tagged fish. It was also observed that (1) the caudal peduncles of some of the banded mackerel that were recaptured were sore; (2) some of the specimens were in an emaciated condition; and (3) a dead, banded mackerel was found stranded on the beach in the vicinity of its release 3 days after tagging. Therefore, field operations in tagging were suspended pending improvement of tagging technique.

Up to this time no means had been found to keep mackerel alive in confinement for more than a few days. In 1929, Hall (1930) in the course of studying respiration of the mackerel was led to the conclusion that this species could be held in confinement if provided sufficient space to swim about more freely

[3] This rapid scatter to other points should have caused a rate of diminution in local returns even greater than those of experiments 2 and 7. Unfortunately, the local returns were too few to be significant. There were three, two, and one returned locally in the first, second, and third successive 5-day periods after tagging, respectively. Presumably these low returns were due to the rapid departure of the mackerel from the region.

than in the relatively small aquaria customarily used for other marine species. The outdoor pool at the United States Fisheries Biological Station at Woods Hole, Mass., provided the space needed. Its dimensions, 24 feet wide, 89 feet long, and 3 to 7½ feet deep, and its tidal circulation through four openings totaling 29 square feet (providing an exchange of one-sixth to three-quarters of the water at minimum and maximum tides, respectively) proved adequate for holding mackerel alive and in good condition during the summer and autumn months.

About 70 tinker mackerel were brought from a local pound net in the live well of a small boat and placed in this pool on June 26. During the subsequent week many of these showed effects of injuries probably received while being handled and transported, for they developed conspicuous white patches, usually on the snout, tail, and sometimes on the sides of the body. After a week or 10 days, these evidences of injury disappeared, in part through healing, and in part through death of the injured individuals. From this time on, the mackerel ate eagerly of the ground fish and squid provided daily.

On July 22, 26 days after the mackerel had been placed in the pool, the 45 survivors were marked with 2 styles of ring tags.

On July 24 and 26, 184 additional mackerel, brought from local pound nets by means of a live car, were placed in the pool with the tagged individuals. Within 3 days the newly added individuals developed sores principally on the sides of the body, and during the first week 28 dead or dying mackerel were removed from the pool. Additional carcasses were noted on the bottom. In the meantime, the tagged mackerel continued to feed as formerly and appeared not to be injured by the tagging operation. By July 31, evidences of sores had disappeared from the mackerel of the new stock and they were feeding as readily as the original stock.

On August 22, when all mackerel were removed from the pool, there were 31 survivors of the tagged fish and 55 survivors of the stock that had been added on July 24 and 26. Those with tags were returned to the pool. Of those without tags, most were marked with additional styles of tags and returned, and a few were returned without tagging, to serve as controls.

On October 24, the experiment was ended by seining out the survivors. Only 18 were found. If none eluded the seining operation, this shows a mortality of 84 percent.

Since the mortality was not due to the tags (for controls suffered mortality equal to that of the tagged fish), to lack of nourishment (the survivors were fat and plump at the end of the experiment), or to unfavorable temperatures (varying between 68° and 72° F. between July and the first half of September, temperature declined gradually to 59° F. by October 23, hence was well within the range known to be tolerated by unconfined mackerel), I am inclined to ascribe it to the effects of the heavy rains of September 17 which flooded the harbor with muddy water which persisted for 3 days and must have lowered the salinity appreciably. The turbidity of the water precluded direct observation of the condition of the fish, but a sharp reduction at this time in the readiness with which food was accepted, indicated a significant change in the condition of the fish.

Despite the few survivors at the end of the experiment, certain of the results appear significant when growth rate and mortality of the individuals marked with the different styles of tags are compared with controls.

The various styles of tags with the names used to designate them are illustrated in figure 21. The dimensions were as follows:

Celluloid band: Made of celluloid strips 0.025 inch thick, 5/16 inch wide and 2 inches long (0.635 by 8 by 50 millimeters) molded to form a circle 7/16 inch (11.1 millimeters) in inside diameter, with an overlap of about ⅓ the circumference.

Celluloid ring: Made of rods of celluloid 3/32 inch (2.5 millimeters) in diameter and 1½ inches (38 millimeters) long, cut obliquely at the ends to fit together when molded to a circle of ⅜ inch (9.5 millimeters) inside diameter.

Rubber band: Drainage tubing ⅜ inch (9.5 millimeters) in diameter with walls 0.013 inch (0.33 millimeter) thick, cut into sections to provide bands ⅜ inch (9.5 millimeters) wide.

Internal tag: Strip of celluloid 0.025 by 5/16 by 1¼ inches (0.635 by 8 by 32 millimeters) rounded at the ends.

Each of these was chosen for particular reasons. The celluloid band was included to test our conclusions as to the earlier taggings with the celluloid poultry band. It was similar to the latter, except that it was of thinner stock and of a smaller size appropriate to the smaller mackerel on which it was to be placed.[4] The celluloid rings were included, at the suggestion of Henry B. Bigelow, to see whether the smoothly rounded form would be less injurious than the sharp-cornered bands. The rubber bands were selected to see whether a soft material would be less harmful than the hard celluloid, and the internal tags were tried because of their superiority over external tags demonstrated on other species by Nesbit (1933).

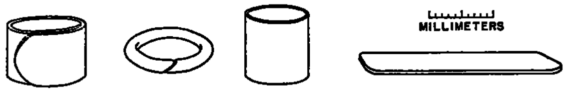

FIGURE 21.—Diagrams of tags tested in holding experiments.

In the marking of July 22 when two styles, celluloid bands and celluloid rings, were applied to the mackerel, the mackerel were tagged alternately with the bands and rings in the order that they were dipped up from the net pocket. In the marking of August 22, the mackerel were again handled in the order dipped from the pocket. Those already tagged the month before were measured and released, while the ones not bearing tags were treated in three different ways. All 27 centimeters long were tagged with rubber bands; all 27.5 centimeters long were released as controls; and the remaining sizes were marked by the insertion of internal tags. The selection of a particular size for rubber bands and controls was necessitated by their lack of individual identifying marks which required that the fish of each lot be of the same size at the time of release if their subsequent growth was to be determined.

All measurements were made to the nearest half centimeter on the measuring board described in appendix A. In table 30 the lengths are given in half centimeters just as they were originally entered in the records, but elsewhere they are given in centimeters, or decimal fractions thereof.

In table 30 are given the records of those fish that bore numbered or lettered marks. The records on the mackerel not bearing numbered marks are as follows: Of the 15 mackerel, each 27.0 centimeters long when marked with rubber bands on August 22, only 1 was found on October 24. It measured 27.5 centimeters, a gain of 0.5 centimeter since tagging. Of the 16 controls, each 27.5 centimeters long at

[4] The even-numbered tags of this style had the interior corners beveled, the odd-numbered ones had "square" corners. Since we could discern no significant differences in the results with the beveled and unbeveled rings (table 29) they have not been treated separately.

TABLE 30.—*Records of experiments with celluloid bands, celluloid rings, and internal tags*

[Lengths and increments are given in half centimeters. To convert to centimeters divide by 2]

Celluloid rings						Celluloid bands				Internal tags			
Serial letter	Length			Increment		Serial No.	Length		Increment	Serial No.	Length		Increment
	July 22[1]	Aug. 22	Oct. 24	July 22–Aug. 22	Aug. 22–Oct. 24		July 22[1]	Aug. 22	July 22–Aug. 22		Aug. 22[1]	Oct. 24	Aug. 22–Oct. 24
A	48	51	---	3	---	69	47	---	---	43	56	---	---
B	54	57	61	3	4	70	49	---	---	44	56	---	---
C	52	56	61	4	5	71	49	52	3	46	53	62	9
D	52	57	64	5	7	72	51	53	2	47	52	---	---
E	52	55	---	3	---	73	49	([2])	---	48	53	---	---
F	52	---	---	---	---	74	50	---	---	49	57	64	7
G	50	---	---	---	---	75	50	---	---	50	56	---	---
H	51	53	59	2	6	76	52	54	2	52	53	---	---
I	51	55	60	4	5	77	51	---	---	53	51	---	---
J	48	51	55	3	---	78	47	50	3	54	56	---	---
K	52	56	62	4	6	79	50	54	4	55	56	---	---
L	51	54	---	3	---	80	52	53	1	56	57	---	---
M	52	55	---	3	---	81	49	---	---	57	52	61	9
N	51	57	---	6	---	82	51	52	1	58	53	60	7
O	47	48	---	1	---	83	49	51	2	59	53	---	---
P	50	53	---	3	---	84	51	---	---	60	57	---	---
Q	51	54	---	3	---	85	47	---	---	61	56	---	---
R	50	55	---	5	---	86	48	51	3	62	51	---	---
S	51	54	62	3	8	87	49	---	---	63	52	---	---
T	53	55	---	2	---	88	49	---	---	64	52	---	---
U	44	47	---	3	---	89	49	50	1	65	53	---	---
V	54	56	---	2	---	90	52	---	---	66	53	---	---
W	50	53	---	3	---	---	---	---	---	67	51	---	---
										68	53	58	5

[1] Tags were applied on this date.
[2] Tag was found in skiff from which tagging was done Aug. 22, evidently having slipped from the mackerel unobserved.

the time of release, August 22, four survived the experiment and were 30, 31.5, 31.5, and 32 centimeters long, respectively, an average growth increment of 3.75 centimeters during the period August 22 to October 24.

Examination of the relation of size to mortality and growth increments gave very little evidence that the size of the mackerel was correlated with its subsequent fate except in the case of the 22 mackerel marked with celluloid rings. The survivors (to October 24) of this lot were all from the upper half of the range of sizes at time of tagging. However, the numbers involved were so few that the significance of this is questionable.

Considering, first, the period of August 22 to October 24 for which there are available comparisons between all four styles of marks and the controls, it is evident that there were large differences in the rates of survival and of growth of the mackerel in various experiments (table 30). The mackerel with internal tags compare most favorably with the controls, having an average growth rate practically identical with that of the controls, and a survival rate that was not significantly different from that of the controls. The celluloid rings appeared not to have affected the survival of the mackerel but to have caused a definitely lower growth rate, their average increment of 3.0 centimeters being 21 percent less than the increment of 3.7 centimeters registered by the controls. The celluloid bands and rubber bands appear to have had markedly adverse effects on the mackerel, causing almost complete mortality and, judging by the lone survivor bearing a rubber band, this style of mark caused a 60 percent lower growth rate than was experienced by the controls. The lack of survivors among the celluloid-banded mackerel during the period August 22 to October 24 precludes comparing growth with that of the controls; but the mackerel marked with celluloid bands and celluloid rings during the period of July 22 to August 22 had an average growth of 1.0 centimeter and 1.6 centimeters respectively. If we may assume that the last-named increment (1.6 centimeters) was 20 percent less than would have been registered by untagged fish, then the growth of the celluloid-banded fish was reduced by about 50 percent, a figure not unlike that of the rubber-banded mackerel. Thus it appears that bands, either of celluloid or of rubber, caused almost complete mortality of tinker mackerel within a few months; that celluloid rings did not greatly affect the survival of mackerel, at least during a 3-month period, but caused some slackening of growth; and that internal tags produced no discernible effect, either on growth or on mortality.

In the case of the celluloid bands, it is evident that the mortality data cannot be taken at their face value due to loss of tags from the fish. Although designed to fit loosely so as not to exert pressure on tissues, yet closely enough to be held in place by the flaring lobes of the tail fin, some of these tags must have been slightly too large, for one was seen to slip off over the tail fin shortly after tagging; another was seen to slip off 5 days later while the mackerel were being fed; and a third came off while the mackerel were reexamined August 22, for it was found in the bottom of the skiff shortly after conclusion of the work on that day. Hence, it would appear that the 45.5 percent so-called "survival" during the period July 22 to August 22 must be a minimum, for it is known that at least three tags were lost in this period and it is probable that additional ones were lost unobserved. It is possible that almost the entire diminution in number of banded mackerel may have been due to loss of tags rather than to mortality.

TABLE 31.—*Survival and growth of mackerel marked by various means during summer of 1933*

Marks used	July 22	Aug. 22	Survived from July 22 to Aug. 22 [1]	Average growth of survivors July 22 to Aug. 22	Oct. 24	Survived from Aug. 22 to Oct. 24	Average growth of survivors Aug. 22 to Oct. 24
	Number	*Number*	*Percent*	*Centimeter*	*Number*	*Percent*	*Centimeter*
Celluloid bands	[2] 22	10	45.5	1.1	([3])	----------	----------
Celluloid rings	[2] 23	21	91.4	1.6	7	33.3	3.0
Rubber bands	----------	[2] 15	----------	----------	1	6.7	1.5
Internal tags	----------	[2] 24	----------	----------	5	20.8	3.7
Controls	----------	[4] 16	----------	----------	4	25.0	3.8

[1] The numbers in this column includes only those survivors that retained the marks. It is known that at least some of those marked with celluloid bands lost the band soon after tagging, but they could not be distinguished from the unmarked mackerel that were present in the pool on the date of reexamination.

[2] Tagged this date.

[3] None survived except 1 doubtfully identified with this experiment by means of scar around caudal peduncle.

[4] Released this date.

On the other hand, there are three reasons for believing that the subsequent losses (i. e., after August 22) of celluloid-banded mackerel must have been due mainly to mortality: (1) All that were loose fitting enough to come off had opportunity to do so during the first month; (2) all that stayed on during the first month would be far less likely to be lost later, for the mackerel, by that time, had grown so that bands would fit more closely; (3) during the first month the bands caused sufficient soreness of the tissues to leave scars that could be detected at the last examination. Only one such scarred mackerel was found, so there cannot have been other survivors; and the final mortality in this experiment may be taken as 90 percent or 100 percent depending on whether this scarred individual should be counted. Since the loss of the tag presumably increased its chances of survival, this individual hardly can be regarded as evidence of survival of mackerel marked in this manner, and it may be concluded that this style of tag caused an unknown, but perhaps substantial, mortality during the first month after tagging, and complete mortality during the next 2 months.

The rubber bands gave similarly poor results. Of the 15 mackerel tagged on August 22 only 1 survived to October 24. In this case it is certain that the loss was due to death rather than to the loss of tags, for the rubber bands were too tight rather than too loose. Although the mackerel, by actual measurement, had caudal peduncles ⅝-inch in diameter at the slenderest point, and the diameter of the band also was ⅝-inch, the width of the band was such as to cause it to extend anteriorly and posteriorly of the slenderest part of the caudal peduncle, thereby causing slight pressure at the anterior and posterior edges of the band. This evidently was sufficient to cause necrosis of the underlying tissue, for both the survior mentioned above, and another that died 5 days after tagging, lacked skin on the area underneath the band which seemed to have "eaten" down the tissue in a sharply defined band around the caudal peduncle.

It is doubtful whether an improvement might be gained by using more loosely fitting rubber bands, for only a slight enlargement of the band would allow it to slip over the tail fin. Rubber bands are flexible enough to conform to the cross-sectional shape of the tail fin and thus slip off more easily than the stiffer celluloid band of the same diameter. Hence, it appears that rubber bands are unsuitable. Furthermore, the mere fact, established by these experiments, that bands must fit the caudal peduncle neither too loosely nor too tightly, renders this style of tag impractical for general use in field experiments where the variation in size of fish would require an extensive range of sizes of bands and an accurate judgment of size to apply.

The celluloid rings were intermediate between the bands and the internal tags in their effects on the mackerel. They apparently did not cause mortality but did retard the growth rate. It cannot be assumed, however, that the mortality of mackerel bearing the rings would remain unaffected over longer periods of time. At the end of the 93-day period, all mackerel marked with rings had sores encircling the caudal peduncle where the rings, although loose, came into contact with the peduncle during the lateral vibrations of the caudal region while swimming. These sores appeared as intense as the ones found August 22 on the mackerel that had carried celluloid bands during the previous month; that is, the skin was in most cases entirely absent from the sore region, leaving the flesh and sinews exposed. Though there was no active bleeding, the sores were decidedly reddish. The only generally apparent difference between the sores caused by the rings and those caused by the bands was the greater area involved and the deeper notching of the caudal lobes by the bands. That the rings as well as the bands caused soreness was surprising, for it was anticipated that their smoothly rounded surfaces could not chafe the skin as readily as the sharp corners of the bands. This makes it seem that soreness is caused by contact or impact as well as by chafing. If it may be assumed that the disturbance of internal salt-balance is one of the important effects of sore areas on the protective tissues of the fish, it is not surprising that the celluloid rings should have affected mackerel less than the celluloid bands, for the area of soreness was much smaller in the case of rings than of bands.

Inasmuch as the soreness caused by celluloid rings persisted throughout the experiment, showing no evidence of healing, considerable doubt is cast on the retention of the tags or the survival of the fish much beyond the length of time demonstrated by the experiment. Enlargement of the caudal peduncle through growth and the resultant increased pressure can be expected to lead to eventual impairment of the caudal fin as an organ of propulsion and ultimate destruction of the fish, either through impairment of feeding or inability to escape from predators. Hence, this tag can be considered of use during only a few months when applied to young, rapidly growing fish and possibly as much as several seasons on old and slowly growing ones.

In marked contrast to the results obtained with the bands and rings, the internal tags appeared to have had no adverse effects. Not only do the records of mortality and growth rate (table 31) indicate this, but examination of the mackerel at the close of the experiment revealed no harmful effects. In all cases the incision through which the celluloid strips had been inserted, had healed, leaving only a faint scar. In all cases save one, the tag lay alongside the internal organs or partly hidden by them. No adhesions or inflamed areas were evident. In the one exception, the tag had not entered the body cavity but had lodged under the peritoneal lining of the body wall. In this position it had caused no apparent soreness of tissues with which it came into contact. Evidently this method of marking is ideal in its lack of effects on the mackerel and there is no reason to doubt its permanence.

An important objection to the internal tag is that usually it will not be found by the person who can furnish information as to the date and locality of capture, for mackerel pass from fishermen to wholesaler to retail dealer without being gutted, except for a small fraction of the catch which is salted or canned. To some extent this difficulty may be overcome by printing on the tag instructions for ascertaining the source of tagged fish bought from dealers. Whether a percentage sufficiently high to be useful can be traced to their source remains to be demonstrated. If not, marking experiments should be of two kinds: (1) The internal tag for quantitative results; (2) an external tag for short-time, qualitative results. For external marking, the celluloid ring (or some better one yet to be devised), is indicated.

In addition to demonstrating the effects on the mackerel of the several types of tags, these tests incidentally call attention to a feature of tagging operations not previously appreciated. This is the high initial mortality attending the catching and transfering of the experimental lots to impoundment. The first lot suffered 36 percent and the second lot 70 percent mortality during the first two weeks after capture. This initial mortality might have resulted from confinement of the fish, but in view of the subsequent good condition of the impounded mackerel, we are more inclined to believe it was due to the catching operations. If this is correct, mackerel tagged and released directly after catching would be subject to a high and variable initial mortality. This would need be considered in treating results quantitatively.

LITERATURE CITED

BIGELOW, HENRY BRYANT.

1926. Plankton of the offshore waters of the Gulf of Maine. Bull. Bur. Fish., Dept. of Commerce, vol. 40, pt. 2, 509 pp., 134 figs.

1927. Physical oceanography of the Gulf of Maine. Bull. Bur. Fish., U. S. Dept. Commerce, vol. 40, pt. 2, 1027 pp., 18 tables, 207 figs.

1933. Studies of the waters on the continental shelf, Cape Cod to Chesapeake Bay. I. The cycle of temperature. Papers in Physical Oceanography and Meteorology, Mass. Inst. Tech. and Woods Hole Oceanogr. Inst., vol. 2, No. 4, 135 pp., 66 figs., Cambridge, Mass.

BIGELOW, HENRY BRYANT, and MARY SEARS.

1939. Studies of the waters of the continental shelf, Cape Cod to Chesapeake Bay. III. A volumetric study of the zooplankton. Memoirs of the Museum of Comparative Zoology, vol. 54, no. 4, pp. 184–378, 42 figs., Cambridge, Mass.

BIGELOW, HENRY BRYANT, and WILLIAM W. WELSH.

1925. Fishes of the Gulf of Maine. Bull. Bur. Fish., U. S. Dept. Commerce, vol. 40, pt. 1, 567 pp., 278 figs.

BJERKAN, PAUL.

1919. Results of the hydrographical observations made by Dr. Johan Hjort in the Canadian Atlantic waters during the year 1915. Dept. of the Naval Service. Canadian Fisheries Expedition, 1914–15, pp. 349–403, 7 figs., 5 tables, 1 map, Ottawa, Canada.

BULLEN, G. E.

1908. Plankton studies in relation to the western mackerel fishery. Jour. Mar. Biol. Assoc., New Series, vol. 8, No. 3, pp. 269–302.

CLARK, FRANCES N.

1925. The life history of *Leuresthes tenuis*, an atherine fish with tide-controlled spawning habits. Calif. Div. Fish and Game. Fish Bull., No. 10, 51 pp., 6 graphs, 3 tables, 6 pls., Sacramento.

1929. The life history of the California jack smelt, *Atherinopsis californiensis*. Calif. Div. Fish and Game. Fish Bull. No. 16; Contrib. No. 77, Calif. State Fish. Lab., pp. 1–23, 12 figs.

1934. Maturity of the California sardine (*Sardina caerulea*), determined by ova diameter measurements. Calif. Div. Fish and Game. Fish Bull., No. 42. Calif. State Fish. Lab., Contrib. No. 119, 49 pp., 19 figs., 12 tables, Sacramento.

CLARKE, GEORGE L.

1934b. Diurnal migration of plankton in the Gulf of Maine and its correlation with changes in submarine irradiation. Woods Hole Oceanogr. Inst. Collected Reprints, Contrib. No. 33, Biol. Bull., vol. 55, No. 3, pp. 402–436, figs. 1–5.

1934a. Further observations on the diurnal migration of copepods in the Gulf of Maine. Biol. Bull., vol. 67, No. 3, pp. 432–455, 6 figs., 3 tables, Dec. 1934. Contrib. No. 48, Woods Hole Oceanogr. Inst. Collected Reprints.

DANNEVIG, ALF.

1919. Canadian fish-eggs and larvae. Canadian Fisheries Expedition, 1914–15, pp. 1–74, 3 plates, Dept. of Naval Service, Ottawa, Canada.

EHRENBAUM, E.

1914. The mackerel and the mackerel fishery. Cons. Perm. Internat. pour l'explor. de la Mer, Rapp. et Proc.-Verb. XVIII.

FISH, C. J., and M. W. JOHNSON.

1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. Jour. Biol. Bd., Canada, vol. 3, No. 3, pp. 189–322, 29 tables, 44 figs. Woods Hole Oceanogr. Inst. Collected Reprints, Contrib. No. 135.

FISHER, R. A.

1932. Statistical methods for research workers. Oliver and Boyd, Edinburgh.

GARSTANG, WALTER.

1898. On the variation, races, and migrations of the mackerel, *Scomber scombrus*. Jour. Marine Biol. Assoc. vol. 5, no. 3, pp. 235–295.

GOODE, G. BROWN, JOSEPH W. COLLINS, R. E. EARLL, and A. HOWARD CLARK.

1884. Materials for a history of the mackerel fishery. U. S. Commission of Fish and Fisheries, Rept. of the Commissioner for 1881, App. B, 4, pp. 91–532.

GOODE, GEORGE BROWN, and a staff of associates.

1885. The mackerel—*Scomber scombrus*. U. S. Commission of Fish and Fisheries; Section I of the Fisheries and Fishery Industries of the United States, pp. 281–305.

HALL, F. G.

1930. The ability of the common mackerel and certain other marine fishes to remove dissolved oxygen from sea water. American Jour. of Physiology, vol. 93, No. 2, pp. 417–421, 2 tables, June 1930.

HUNTSMAN, A. G.

1922. Is winter mackerel fishery possible? Canadian Fisherman, May 1922 [See also May, 1942], 2 pp.

KENDALL, W. C.

1910. Effects of the menhaden and mackerel fisheries upon the fish supply. Proc. of the 4th Inter. Fishery Congress; Bull. U. S. Bur. Fish., vol. 28, pp. 279–293, 1908.

MOORE, J. PERCY.

1899. Report on mackerel investigations in 1897. Report Commissioner, U. S. Comm. Fish and Fisheries for 1898, (App. I) pp. 1–22.

NESBIT, ROBERT A.

1933. A new method of marking fish by means of internal tags. Trans. Amer. Fish. Soc., pp. 306–307, Sept. 1933.

NORTH AMERICAN COUNCIL ON FISHERY INVESTIGATIONS.

1932. Proceedings 1921–1930. No. 1. Ottawa, Canada.

PARR, ALBERT EIDE.

1927. A contribution to the theoretical analysis of the schooling behavior of fishes. Occasional Papers, Bingham Oceanographic Collection, No. 1, pp. 1–32, 3 figs., Dec. 1927, N. Y.

REDFIELD, ALFRED C.

1941. The effect of the circulation of water on the distribution of the calanoid community in the Gulf of Maine. Biol. Bull. vol. 80, No. 1, 12 figs., pp. 86–110, Feb. 1941. Contrib. No. 281, Woods Hole Oceanographic Inst.

Ricker, William E., and Daniel Merriman.
1945. On methods of measuring fish. Copeia 1945, No. 4, pp. 184–191.

Schroeder, W. C.
1930. Migrations and other phases in the life history of the cod off southern New England. Bull. U. S. Bureau Fish. vol. 46, pp. 1–136, 50 tables, 33 figs.

Shewart, W. A.
1931. Economic control of quality of manufactured product. Second Edition, 491 pp. D. Van Nostrand Co., N. Y.

Sette, Oscar Elton.
1931. Outlook for the mackerel fishery in 1931. Fishery Circular 4, Bur. Fish., U. S. Dept. Commerce, pp. 1–20.
1932. Outlook for the mackerel fishery in 1932. Fishery Circular 10, Bur. Fish., U. S. Dept. Commerce pp. 1–25.
1933. Outlook for the mackerel fishery in 1933. Fishery Circular 14, Bur. Fish., U. S. Dept. Commerce, pp. 1–23.
1933. Prospects for the mackerel fishery. Fishing Gazette, vol. 50, No. 5, pp. 9 and 21.
1934. Outlook for the mackerel fishery, 1934. Fishery Circular 17, Bur. Fish., U. S. Dept. Commerce, pp. 1–6.
1943. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part 1: Early life history, including the growth, drift, and mortality of the egg and larval populations. Bull. Fish and Wildlife Service, U. S. Dept. Interior, vol. 50, pp. 149–237.

Sette, Oscar Elton, and A. W. H. Needler.
1934. Statistics of the mackerel fishery off the east coast of North America, 1804 to 1930. Inv. Rept. 19, Bur of Fish., U. S. Dept. of Commerce, 1934, pp. 1–48.

Sparks, M. Irving.
1929. The spawning and development of mackerel on the outer coast of Nova Scotia. Contrib. to Canadian Biol. and Fisheries, N. S., vol. 4, No. 28, pp. 443–452.

Stansby, M. E., and J. M. Lemon.
1941. Studies on the handling of fresh mackerel (*Scomber scombrus*). Fish and Wildlife Service, U. S. Dept. Interior, Res. Rept. No. 1, 46 pp., 6 figs.

U. S. Bureau of Fisheries.
1921. Dredging and hydrographic records of the U. S. Fisheries steamer *Albatross*, 1911–1920. Appendix III, Rept. U. S. Commissioner of Fisheries, 1920 (1921) Bur. Fish., U. S. Dept. Commerce, 190 pp., Washington.

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