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DISTRIBUTION OF TUNAS IN OCEANIC WATERS OF THE NORTHWESTERN ATLANTIC

By JAMES L. SQUIRE, JR.

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ABSTRACT

Exploration of the oceanic northwest Atlantic adjacent to the Continental Shelf of North America indicates that major populations of bluefin tuna exist along the northern edge of the central Gulf Stream axis in winter and spring. Species dominance, in the oceanic area explored, changes from bluefin tuna to yellowfin tuna during summer and early fall. Commercial concentrations of bluefin and yellowfin tunas were present offshore in addition to minor concentrations of albacore, bigeye tuna, and skipjack.

DISTRIBUTION OF TUNAS IN OCEANIC WATERS OF THE NORTHWESTERN ATLANTIC

By JAMES L. SQUIRE, Jr., *Fishery Methods and Equipment Specialist*
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The increased importance attached to commercial utilization of tunas during the past decade has increased the importance of studies of the habits and life histories of the principal tuna species and investigations of areas known or thought to be inhabited by tunas.

Seasonal tuna fisheries have been carried out for many years on the Continental Shelf between Newfoundland and Cape Hatteras by commercial and sport fishermen. But the short season and fluctuating availability of the stocks—principally bluefin and little tuna—have made commercial operations economically hazardous. Since the early 1950's the U.S. Bureau of Commercial Fisheries has worked to reduce the fluctuations in availability through introduction and development of diverse types of commercial gear. This work has culminated recently near Cape Cod in a successful commercial purse seining venture (Squire, 1959), which, in 1959, landed 750 tons of bluefin tuna in 21 days of fishing—a record for the Cape Cod area.

In addition, the Bureau and the Woods Hole Oceanographic Institution have conducted research on the life history of bluefin in attempts to understand the resource more fully, but the life history studies have been seriously hampered by the almost complete lack of knowledge of bluefin during periods when they are absent from the inshore regions. Prior to 1957, knowledge of tunas in the oceanic region of the northwest Atlantic was practically nonexistent, in sharp contrast to the extensive body of knowledge concerning tunas of inshore and oceanic regions of the Pacific that had been gained through continuing research.

Note.—The author is presently Fishery Research Biologist, Tiburon Marine Laboratory, Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service, Tiburon, Calif.

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In 1957, the Bureau's North Atlantic Fisheries Exploration and Gear Research Base began an investigation of the broad oceanic region adjacent to the Continental Shelf of northeastern North America. Primary objectives were to determine the distribution patterns of the dominant tuna species inhabiting these oceanic waters and to determine the availability of tunas to commercial gear. Eight cruises of the Bureau research vessel *Delaware* were made during the investigation, which was conducted intermittently from March 1957 through May 1960. Explorations with longline gear were made during at least some portion of all seasons. Represented in the catches were tunas of six species—bluefin (*Thunnus thynnus*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), blackfin (*Thunnus atlanticus*), and skipjack (*Euthynnus pelamis*). The first three are dominant tuna species in the region explored.

This paper firstly reviews the status of tuna knowledge in the northwestern portion of the Atlantic at the start of the investigation; secondly, describes the exploratory methods and procedures used, the physical characteristics of the area explored, the seasonal and geographic distribution of dominant tuna species of the oceanic region, and the occurrence of other tuna species in the region; and thirdly, discusses the relation between the tunas of the oceanic region and those of the Continental Shelf.

The investigation was facilitated greatly by cooperation with Boston University and the Woods Hole Oceanographic Institution. In particular, acknowledgment is made of the efforts of Robert H. Gibbs, Jr., Boston University, and Frank J. Mather III, Woods Hole Oceanographic Institution.

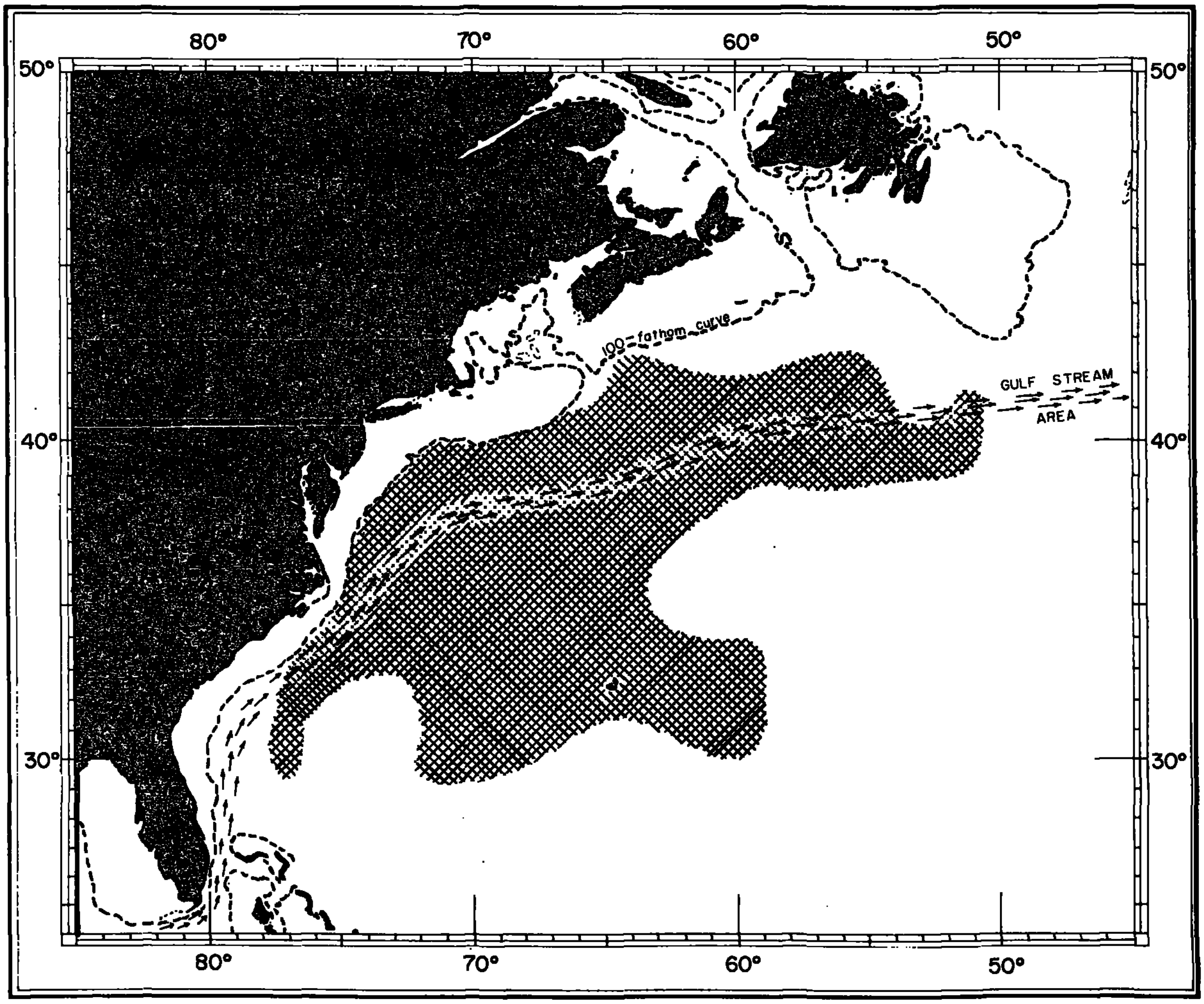

FIGURE 1.—Oceanic region of the northwestern Atlantic covered in M/V *Delaware* tuna explorations, 1957–60.

THE STATUS OF TUNA KNOWLEDGE, 1957

A review of the literature indicated that no knowledge was available of extensive tuna stocks in the oceanic region of the northwestern Atlantic and that records of tuna captures in this region were relatively few. The review showed further that whereas knowledge of tuna stocks of the Continental Shelf was more extensive, it was confined almost entirely to the period during which these stocks are available to fishermen, roughly June or July through October. Knowledge of the tunas of the shelf had been provided largely by commercial and sport fishermen and through explorations conducted by the Bureau and the Woods Hole Oceanographic Institution.

Information on the hydrography of the oceanic region also was examined and analyzed, and inquiries concerning sightings of tuna schools at the surface were made with the U.S. Coast Guard and the Woods Hole Oceanographic Institution. Answers to these inquiries and the scarcity of school sightings during a 1956 cruise of the *Delaware* were discouraging and indicated that little surface-fish life exists in the Gulf Stream area—an indication that was later substantiated.

In general the outlook was discouraging; however, there was one favorable sign. Mowbray (1956) in the Bermuda area in the mid-1950's had successfully used drifted longline gear to capture four species of tunas—bluefin, yellowfin, albacore, and little tuna. These results suggested that tunas were to be found in subsurface rather than surface waters of the oceanic region. Largely for this reason, the *Delaware* explorations were conducted with longline gear.

A brief review of the knowledge of each tuna species known to inhabit the northwestern Atlantic follows. This review portrays the status of knowledge of the tunas of Continental Shelf and the oceanic regions prior to the start of *Delaware* explorations in 1957.

BLUEFIN TUNA

Bluefin, largest of the tunas, are common on the Continental Shelf off eastern United States and Canada from June through October. Because of their large size, bluefin are considered highly desirable game fish and have dominated tuna catches of the shelf sport fishery for many years (Westman and Neville, 1942). The species has also dominated the commercial fishery. Commercial purse seining for bluefin tuna existed in the late 1930's in the Continental Shelf area north of Cape Cod (Murray, 1952), and limited commercial bluefin productión was achieved through trapping, sporadic seining, harpooning, and hook-and-line fishing in the 1940's and early 1950's. In efforts to help the fishery, the Bureau conducted gear trails on the shelf in 1951 and 1954 with Pacific coast purse seine gear and techniques (Murray, 1952, 1955) and in 1952–53 with longlines (Murray, 1953, 1954). The Woods Hole Oceanographic Institution, Miami Marine Laboratory, and the Bureau have been engaged in studies of the life history of bluefin for several years (Mather, 1959; Rivas, 1954, 1955; Robins, 1957; Westman and Gilbert, 1941; and Westman and Neville, 1942).

Bluefin had also been reported from near Bermuda by Mowbray,[1] but no records of this species in the oceanic region adjacent to the coast of North America existed prior to the *Delaware* work.

Migratory routes taken by bluefin on their way to and from their summer habitat in the inshore areas and the location of their winter habitat have long been subjects of considerable speculation among fishermen and fishery biologists. The most popular view has been that in the fall when the fish head south or southeast into the oceanic region, toward unknown spawning grounds, probably in the Caribbean Sea. Bullis and Mather (1956), through examinations of bluefin ovaries, have partially substantiated the supposition that the spawning grounds, for at least part of the bluefin population, lie in the Caribbean. The migration route may lead directly to the spawning grounds or may be circuitous. Other workers proposed that bluefin could perhaps winter in deeper waters along the Continental Slope off the Middle Atlantic States (Bigelow and Schroeder, 1953).

The return migration has been linked with an observed northward migration of large tuna in mid-May and June along the western edge of the Straits of Florida. Rivas (1951, 1954) proposed that these migrants comprise the stock of large fish that enter the New England and Nova Scotia fisheries in late June. Rivas later (1955) stated that the fish taking part in this migration ranged from 300 to 700 pounds and averaged 400 to 500 pounds. Linking these fish with those of the northern inshore fishery would, if confirmed, account for the large individuals, but this would still leave unexplained the many small bluefin common to the northern fishery.

YELLOWFIN TUNA

Yellowfin tuna are not common inhabitants of the Continental Shelf areas and are less well-known in the northwestern Atlantic than bluefin. One yellowfin was taken on a trolling line from the Bureau research vessel *Theodore N. Gill* in February 1953 (Anderson, Gehringer, and Cohen, 1956), north of the Bahamas. In the true oceanic region between the Continental Slope of North America and Bermuda, five additional records exist—all from trolling line captures. One of these refers to a fish taken in 1949 by the Woods Hole Oceanographic Institution research vessel *Caryn* and two to yellowfin taken in 1953 by the WHOI research vessel *Atlantis* (Mather and Gibbs, 1957); and two to fish taken in 1954 by the *Atlantis* (Mather, 1954). Yellowfin also were reported from the Bermuda area by Mowbray (1956).

ALBACORE

Albacore have been reported by Goode and Bean (1879) off Woods Hole and near Banquereau Bank off Nova Scotia. One specimen was reportedly taken by a halibut trawl off Devil's Island

[1] Mowbray, Louis S. The gamefishes of Bermuda. Paper presented at the International Gamefish Conference, International Oceanographic Foundation, Nassau, 1956, 8 p.

near Halifax harbor in 1922 (Vladykov, 1935), and one was captured by the Woods Hole Oceanographic Institution research vessel *Bear* at latitude 39°45′ N., longitude 73°00′ W. in September 1956 (Mather and Gibbs, 1957). In addition, albacore have been taken on longline gear around the island of Bermuda by Mowbray (1956). Other reports of albacore captures exist but are unconfirmed.

BIGEYE TUNA

Captures of bigeye tuna have been reported from sport fishery catches on the Continental Shelf off North Carolina and Maryland, and Mowbray (1956) has recorded the capture of bigeye off Bermuda. The species was unrecorded from the oceanic region off the United States and Canada prior to the Bureau's exploratory studies.

OTHER TUNA SPECIES

Blackfin tuna are recorded from the Bermuda area by Mowbray (1956) and from oceanic waters of the northwestern Atlantic by Mather and Day (1954). One of the two specimens constituting the latter record was taken near latitude 32°21′ N. and longitude 64°37′ W. by the *Atlantis* in June 1948. The other specimen was taken 300 miles east of Cape Hatteras by the same vessel in August 1953. A number of specimens has been taken in inshore areas, and Mather (Mather and Day, 1954) believes that the species does not normally range far beyond the 100-fathom curve. The northernmost record of the species is the capture of one blackfin about 75 miles south of Martha's Vineyard (latitude 40°04′ N., longitude 70°42′ W.) by the *Caryn* in October 1948 (Mather and Schuck, 1952).

Little tuna are common inhabitants of inshore areas, especially from New York south, and have been reported from the Gulf of Maine by Schuck (1951). Little tuna do not, apparently, range into deep waters. Sporadic attempts have been made, along the Middle Atlantic coastline, to utilize little tuna commercially.

EXPLORATORY GEAR AND PROCEDURES

The Bureau research vessel *Delaware* traveled over 17,900 nautical miles during the explorations in the northwestern Atlantic (fig. 2).

FISHING GEAR

The longline fishing gear used in the explorations (fig. 3) is identical in basic design and construction to that used by the Bureau research vessel *Oregon* in exploring the tuna resources of the Gulf of Mexico (Captiva, 1955) and Caribbean. The method of longlining used by the *Delaware* was essentially the same as that used by the Japanese for tuna fishing operations in the Pacific, Indian, and Atlantic Oceans.

FISHING PROCEDURE

On station, the fishing gear and bait were prepared for setting at about 0630 hours. A set of 60 tubs of longline gear (600 hooks) was selected, following initial operations, as the unit that would give a reasonable representation of fish in the area, but this set would still be convenient to handle when large numbers of large fish were caught. Atlantic herring, *Clupea harengus harengus* Linnaeus, were used as bait. The gear was allowed to drift for about 2 hours after the last tub had been set, and hauling was then begun with the aid of a Japanese longline hauler. The vessel was moved slowly ahead as the gear was being retrieved so that the line was kept on the starboard quarter. When a fish was brought to the side of the vessel, the branchline bearing the fish was removed from the mainline, another branchline was tied on, and hauling was continued. The fish, on its separate branchline, was then gaffed and hauled aboard or tagged and released. Tagging was carried out in cooperation with the Woods Hole Oceanographic Institution. Setting the gear required four to five men; retrieving it required six to seven.

TEMPERATURE DETERMINATIONS

Several workers (Murphy and Shomura, 1955; Bullis, 1955; and Wathne, 1959) have stated that longline sections do not function with uniform efficiency or at uniform depth, owing to the many variables to which the gear is subjected. These variables include lengths of mainline, branchlines, and buoylines, as well as the amount of tension applied to the mainline when the gear is set, the force and direction of the wind, and the strength and direction of the current.

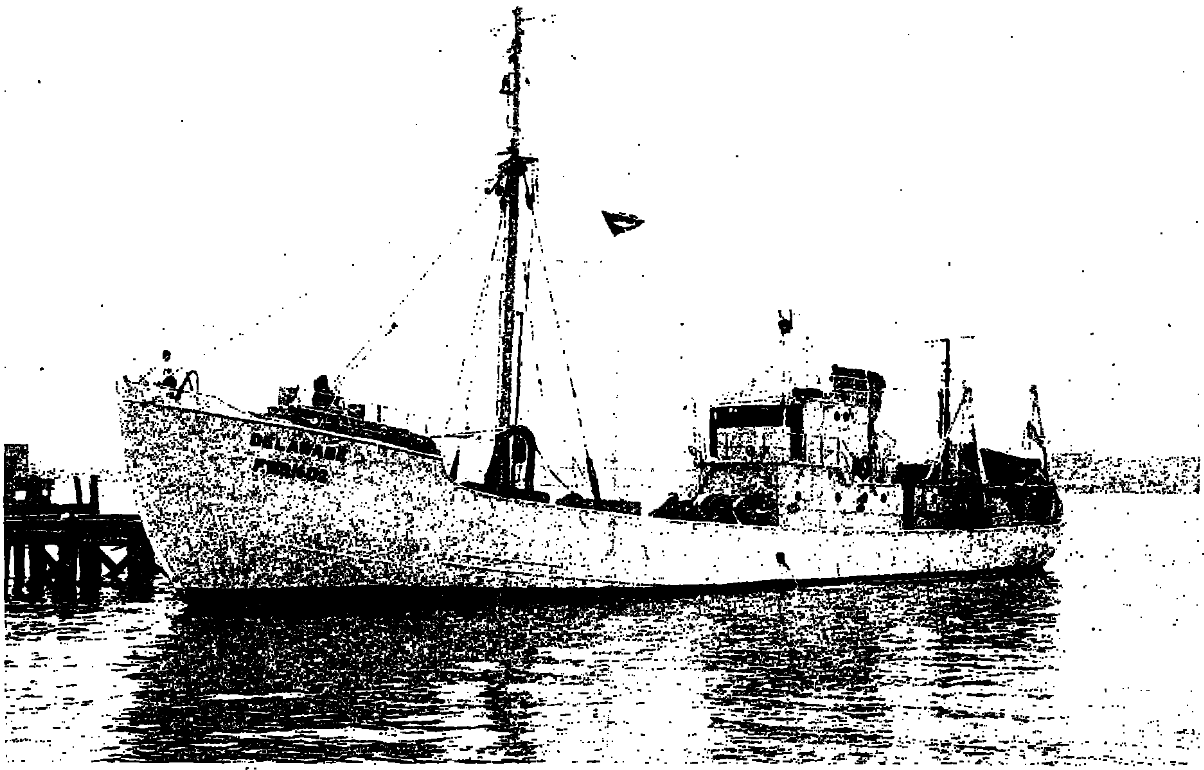

FIGURE 2.—The M/V *Delaware*, 148-foot exploratory research vessel, owned and operated by the Bureau of Commercial Fisheries.

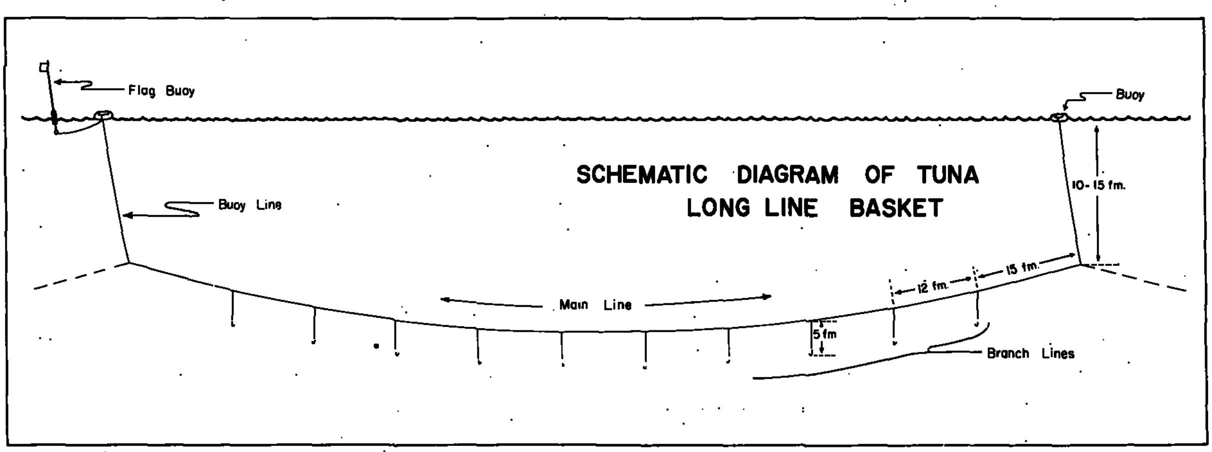

FIGURE 3.—Schematic diagram of the tuna longline gear used in *Delaware* explorations.

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Since there are so many variables operating on a longline, determination of the depth at which the hooks were situated (estimated average fishing depth) is based on calculations taken from echograph observations of similar gear by Bullis (1955) and Wathne (1959). These calculations showed that, with the gear used, the average hook was placed at a depth of about 173 feet.

At all fishing stations a bathythermograph cast was made to a minimum depth of 450 feet. Water temperatures at the surface and at the 173-foot estimated fishing depth were obtained from these casts, and within the limits of the data, temperature ranges and average water temperatures were determined for tuna of each species.

DISTRIBUTION OF EXPLORATORY EFFORT

Explorations were carried out as one phase of the overall program of the North Atlantic Fisheries Exploration and Gear Research Base. Fishing effort was distributed through all seasons, but it was necessarily intermittent. In all, eight cruises were devoted to tuna exploration and 111 stations were fished with longline gear. Of the 111 stations, 9.9 percent were fished in winter (January and February), 37.8 percent were fished in spring (March, April, and May), 14 percent in early summer (June), 18.5 percent in middle and late summer (July and August), and 19.8 percent in fall (September and October). No stations were fished in November or December.

The first cruise in the oceanic region was designed to cover the entire region. The vessel route ran south from the 1,000-fathom curve off New England to the approximate latitude of Cape Hatteras, then east past Bermuda, and north to the point of origin. The cruise took place in the early spring, for the cruise objective was to intercept, and record the distribution of bluefin tuna during a portion of the spring migration. The seven cruises that followed were carried out to cover areas where tuna had been concentrated on previous cruises or where the possibility of tuna concentrations had been indicated by hydrographic data or theories on migration routes, and to cover systematically the Gulf Stream area with a series of longline sets, 95 to 120 miles apart.

PHYSICAL CHARACTERISTICS OF THE REGION EXPLORED

The oceanic region explored by the *Delaware* extends south and east of the edge of the Continental Shelf of northeastern North America to about latitude 30° N. and longitude 50° W. The region is characterized by the presence of that portion of the Gulf Stream system known as the Gulf Stream proper. Since the region is influenced greatly by the Gulf Stream system, an understanding of the physical nature of the system is a necessary preliminary to an understanding of the distribution of that region's fauna.

The Gulf Stream system is composed of three principal parts: the Florida Current from the Tortugas to Cape Hatteras; the Gulf Stream proper from Cape Hatteras to the Grand Banks; and the North Atlantic Current from the Grand Banks eastward. As the principal current system of the western North Atlantic, the Gulf Stream system is analogous to the Kuroshio Current of the western North Pacific. It has been studied in detail by the Woods Hole Oceanographic Institution, and as a result, considerable information is available that relates directly to a study of the environmental conditions that may affect the distribution of the tunas.

The Gulf Stream system is described by Stommel (1960) as:

> . . . a narrow, intense, northeastward-flowing current which returns to the north again the southward-driven Sargasso Sea water that has passed through the Caribbean and has turned through the Florida Straits. The Gulf Stream flows along the western boundary of the warm Sargasso Sea surface water. As the Stream turns toward the east, off the Grand Banks, it acts as a kind of dynamic barrier, or dam, which, by virtue of coriolis forces, restrains the warm Sargasso Sea water from overflowing the colder northern water of the North Atlantic. The water in the Stream is not significantly different in temperature from the large mass of warm water which lies to the right of its direction of motion.

Studies have shown that variations occur within the Gulf Stream system in the form of wavelike perturbations that can be likened to the meanders of a geologically old river or stream, and other physical complications occur along the edge of the Stream in the form of cyclonic eddies (Iselin, 1960). Then too, the water masses of the Gulf

Stream frontal area, which occur between the Gulf Stream axis and the cooler waters to the north, are not stable. They have been described by von Arx, Bumpus, and Richardson (1955) as having ". . . a structure which, as far as one can tell, is best interpreted as a succession of short, overlapping segments which may be described as 'shingles'." The "shingle effect" is of left-hand orientation as one looks down the axis of the Gulf Stream system.

Bathythermograph recordings indicate that relatively large variations in temperature occur within short distances in the oceanic region lying on either side of the Gulf Stream. On several cruises, bathythermograph casts were made at each end of the longline set, and even in this relatively short distance, marked variations in temperature were observed.

The Gulf Stream, south of New England, effectively divides the region investigated into a cool-water northern area and a warm-water southern area.

DISTRIBUTION OF DOMINANT TUNA SPECIES

EXPLORATORY RESULTS AND OBSERVATIONS

Catch rates, for the entire investigation and for all species of tuna, ranged from no tuna at several stations to a high figure of 20.8 tuna per 100 hooks. Catch rates and catch composition varied widely with season and geographical area fished (figs. 4–8), as did the weights of individual fish (table 1).

Bluefin Tuna

The single exploratory cruise conducted in winter indicated that bluefin tuna are common in the portion of the oceanic region lying east of the Continental Shelf, from Cape Hatteras to south of New England (fig. 4A). The extent of the bluefin population to the north and east toward the Grand Banks during winter and late fall is unknown. The greatest number of bluefin in winter were caught along the northern edge of the Gulf Stream (fig. 4A) where, at one station, the catch rate was 5.7 bluefin per 100 hooks. The fish caught at this station averaged nearly 300 pounds each, although large fish apparently are not common in winter, in the area investigated.

The distribution pattern assumed by bluefin in spring (fig. 5A) is similar to that in winter, at least in the portion of the region explored in both seasons; and exploratory catches indicate that commercial longline fishing might be feasible in the vicinity of the Gulf Stream in spring, and possibly in winter. Bluefin were taken in spring at the easternmost stations occupied, south of Grand Banks and east of Bermuda. Highest catch rates were achieved farther south and west of these stations, however, in the general area of the Gulf Stream (fig. 5A). At one station, south of Cape Cod on the inshore side of the Gulf Stream, the catch rate was 16.3 bluefin per 100 hooks. Almost directly east of that station, on the northern edge of the Stream, the maximum catch rate for the entire series of cruises was attained—20.8 bluefin per 100 hooks.

TABLE 1.—*Estimated weights of tunas, by seasons*

Season [1]	Major species [2]								
	Bluefin			Yellowfin			Albacore		
	Number	Total weight	Average weight	Number	Total weight	Average weight	Number	Total weight	Average weight
		Pounds	*Pounds*		*Pounds*	*Pounds*		*Pounds*	*Pounds*
Winter	100	19,901	199	18	589	33	17	554	33
Spring	687	107,287	156	213	18,546	87	31	1,242	40
Early summer	82	28,270	345	50	5,321	[3] 106	8	268	34
Summer	6	1,428	238	109	10,733	98	15	750	50
Fall	2	650	325	329	17,325	53	42	1,990	47
Totals	877	157,536		719	52,514		113	4,804	
Averages			253			75			41

[1] Seasons are defined as follows: Winter=January, February; spring=March, April, May; early summer=June; summer=July, August; fall=September, October. No explorations were conducted in November or December.

[2] Average weights of species of minor importance are: Bigeye, 137 pounds; skipjack, 18 pounds; blackfin, 13 pounds.

[3] Reflects a large catch of fish made at one station.

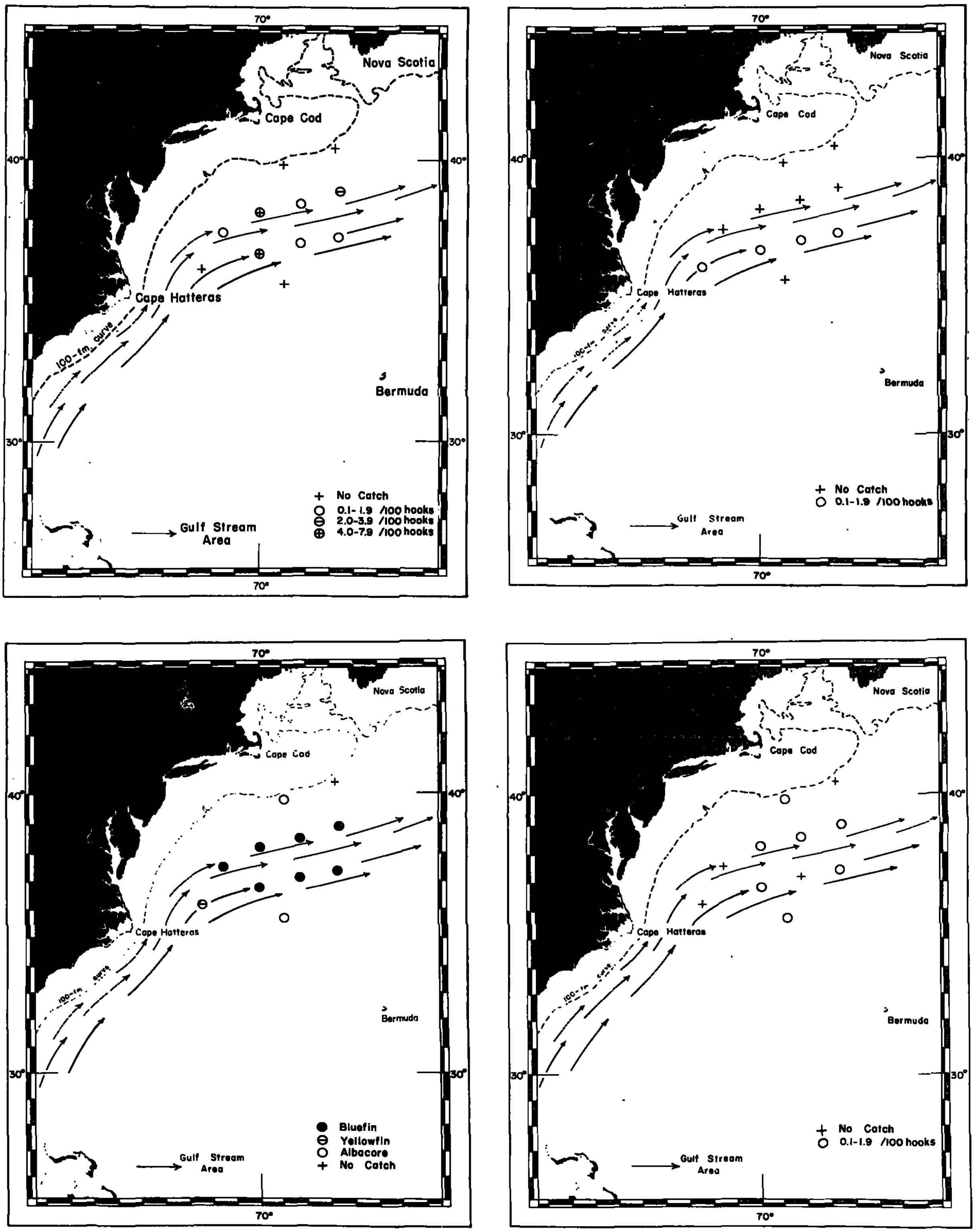

FIGURE 4.—Observed distribution of dominant tuna species in winter (January and February), based on *Delaware* cruise 59–1.

Upper left—Bluefin. Upper right—Yellowfin. Lower left—All dominant species. Lower right—Albacore.

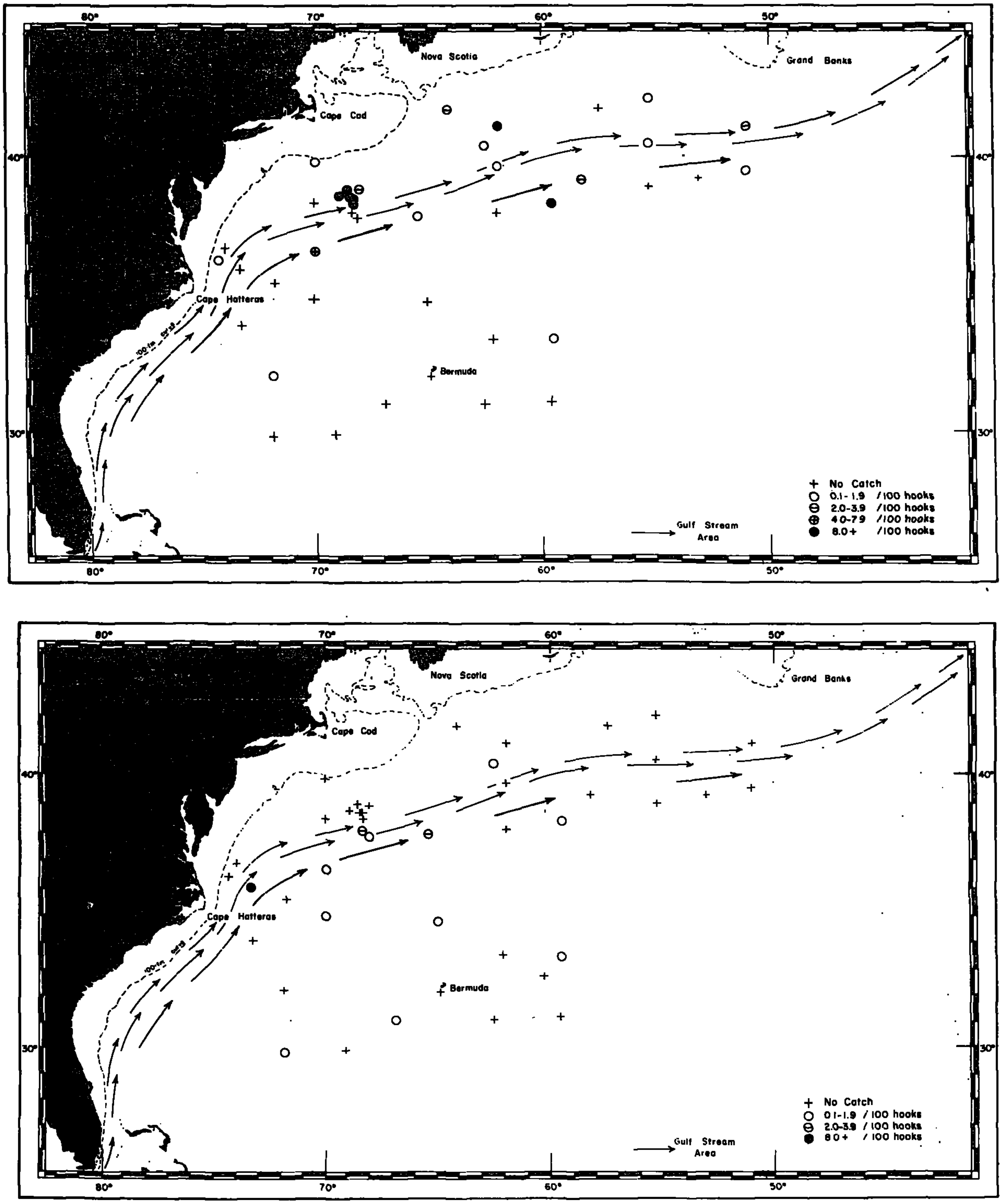

FIGURE 5.—Observed distribution of dominant tuna species in spring (March, April, and May), based on *Delaware* cruise, 57–3, 58–2, 59–6, 60–6.

Upper—Bluefin. Lower—Yellowfin.

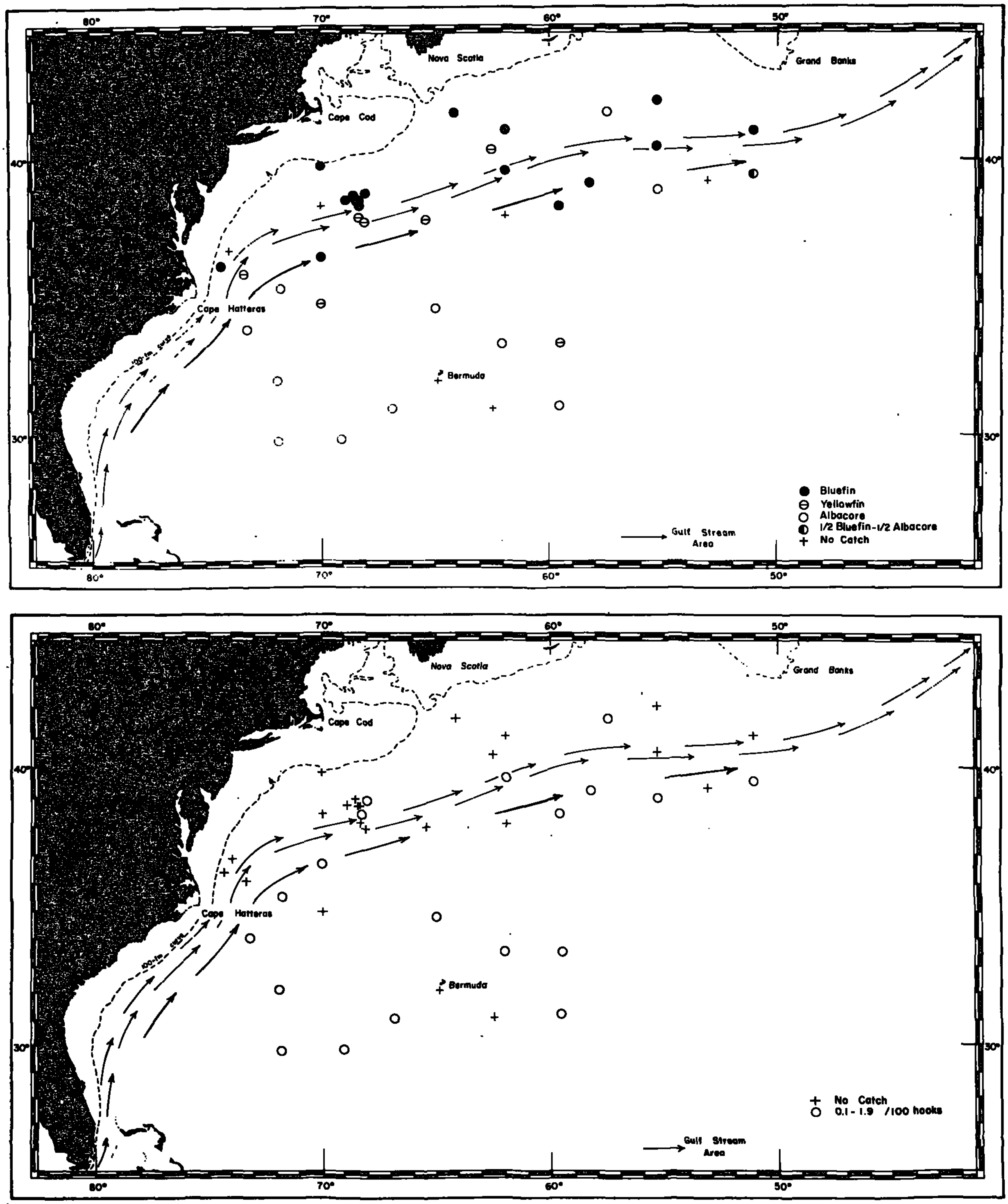

Figure 5.—Observed distribution of dominant tuna species in spring (March, April, and May), based on *Delaware* cruise, 57–3, 58–2, 59–6, 60–6.

Upper—All dominant species. Lower—Albacore.

Although bluefin caught during the spring were mostly small, several weighed over 300 pounds and one, caught east of Bermuda, was estimated to weigh between 350 and 400 pounds.

By late spring or early summer (fig. 6A), bluefin begin to disappear from the oceanic region, and by midsummer (fig. 7A) are uncommon. They apparently remain scarce in oceanic waters through early fall (fig. 8A).

The range of water temperatures in which bluefin were taken during the explorations and the average water temperature for all stations at which bluefin were taken are shown in figure 9. The mean temperatures were obtained by using the following formula:

$$\bar{x}=\frac{(f\times t)}{N}$$

where f=the number of fish in a sample; t= water temperature in degrees F.; and N=the total number of fish of each species for which data were available.

Yellowfin Tuna

Yellowfin tuna apparently do not occur in large numbers anywhere in the oceanic region of the northwestern Atlantic in winter, and none were taken north of the Gulf Stream during that season (fig. 4B).

In the spring the fish are widely distributed over the southern portion of the region, but explorations indicate that they are not generally present in large concentrations. However, at one station, east of Cape Hatteras near the Gulf Stream axis, yellowfin were caught at the rate of 14.1 fish per 100 hooks (fig. 5B).

In summer and fall (figs. 6B–8B), the fish were found in greater general concentration, especially in the vicinity of the Gulf Stream. The highest catch rate achieved during explorations in the summer was 5.0 yellowfin per 100 hooks, and the highest catch rate in the fall was 8.5 yellowfin per 100 hooks. A wide variation in weight was noted among yellowfin caught at stations fished in different areas and seasons. For instance, at a station fished in July in the area north of the Gulf Stream the fish averaged only 30 pounds, whereas in April at a station farther south the fish averaged 92 pounds.

The observed range of water temperature and the average temperature of the water inhabited by yellowfin taken during the explorations are shown in figure 9.

Albacore

Albacore appear to be widely distributed, but thinly scattered, in the oceanic region in all seasons (figs. 4D–8D), and no specific patterns were discerned, either of migration or distribution. The maximum albacore yield, from a longline set, was at the rate of 2.0 fish per 100 hooks. Many of the albacore taken were large, and the average weight for all albacore taken at all stations was 41 pounds. Observed temperature limits and averages for albacore are shown in figure 9.

Other Tuna Species

In addition to the dominant species for which the distribution has been described, several other species, of lesser importance, were taken. These included skipjack and bigeye. Individuals of these species, however, were taken so rarely and in such small numbers that little can be said concerning their patterns of distribution on the basis of the *Delaware* explorations. Some of the stations at which bigeye were caught are shown in figure 7C and represent the northernmost records of the species for the western North Atlantic (Mather and Gibbs, 1958). The temperature range of waters in which bigeye were caught is shown in figure 9.

DISCUSSION

Although the exploratory coverage was not complete, owing to the intermittent scheduling necessitated to carry out several other program phases during the period of investigation, the outline of distribution of bluefin and yellowfin tunas that emerges does provide a substantial basis for future work and a more complete understanding than was formerly available.

Workers in Japan (Nakamura, 1951; Nakamura, Yabuta, and Mimura, 1956; Uda, 1953) and the United States (Sette, 1955) have established that concentrations of tuna are generally associated with oceanic, convergent, tropical, and subtropical water masses—particularly those of major circulatory systems. Extensive work in the Pacific has resulted in the discovery of definite correlations between tuna abundance and the major circulatory systems of the Kuroshio or North Pacific Current, the North and South Equatorial Currents, and the counter currents to these.

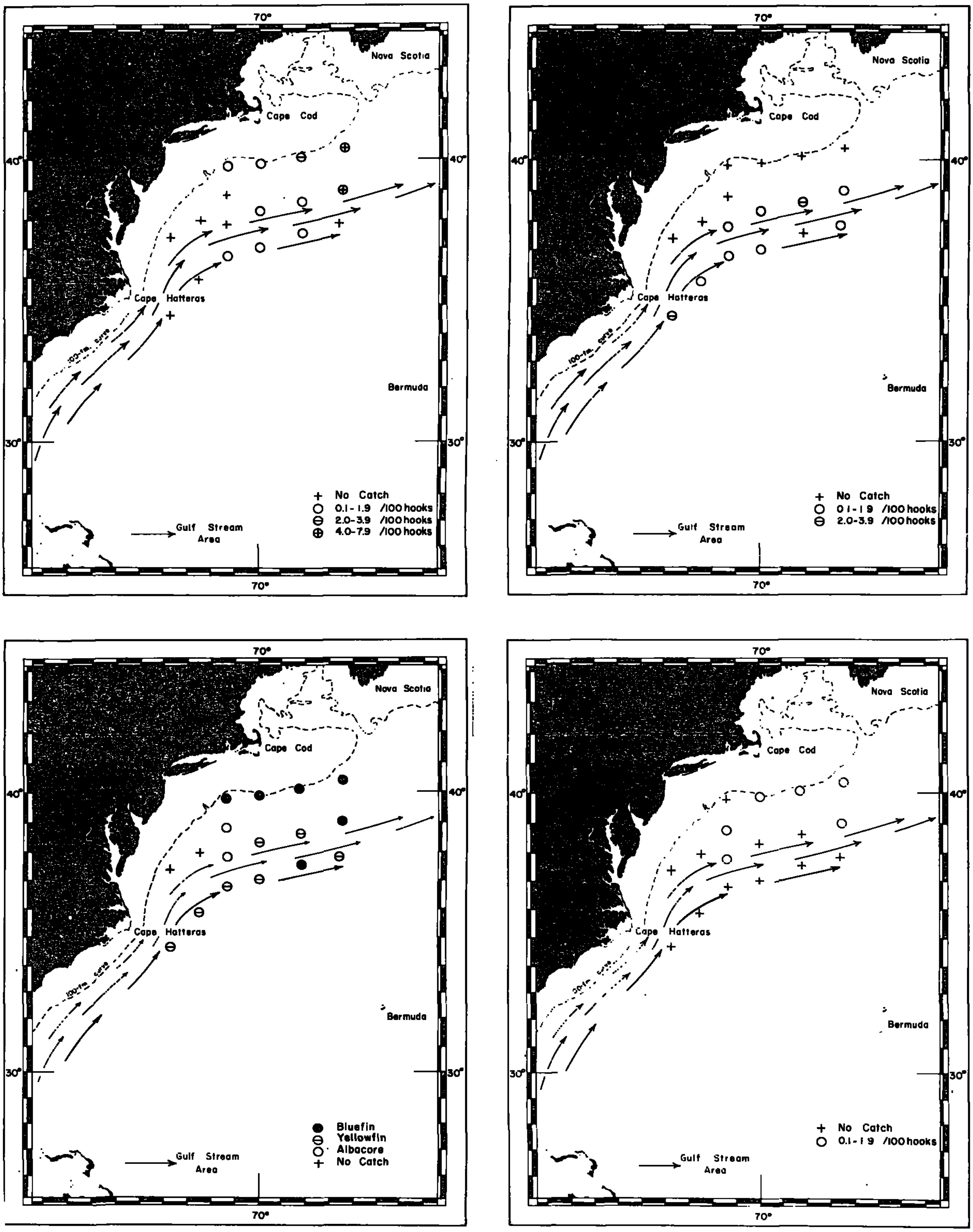

FIGURE 6.—Observed distribution of dominant tuna species in early summer (June), based on *Delaware* cruise 57–5.

Upper left—Bluefin. Upper right—Yellowfin. Lower left—All dominant species. Lower right—Albacore.

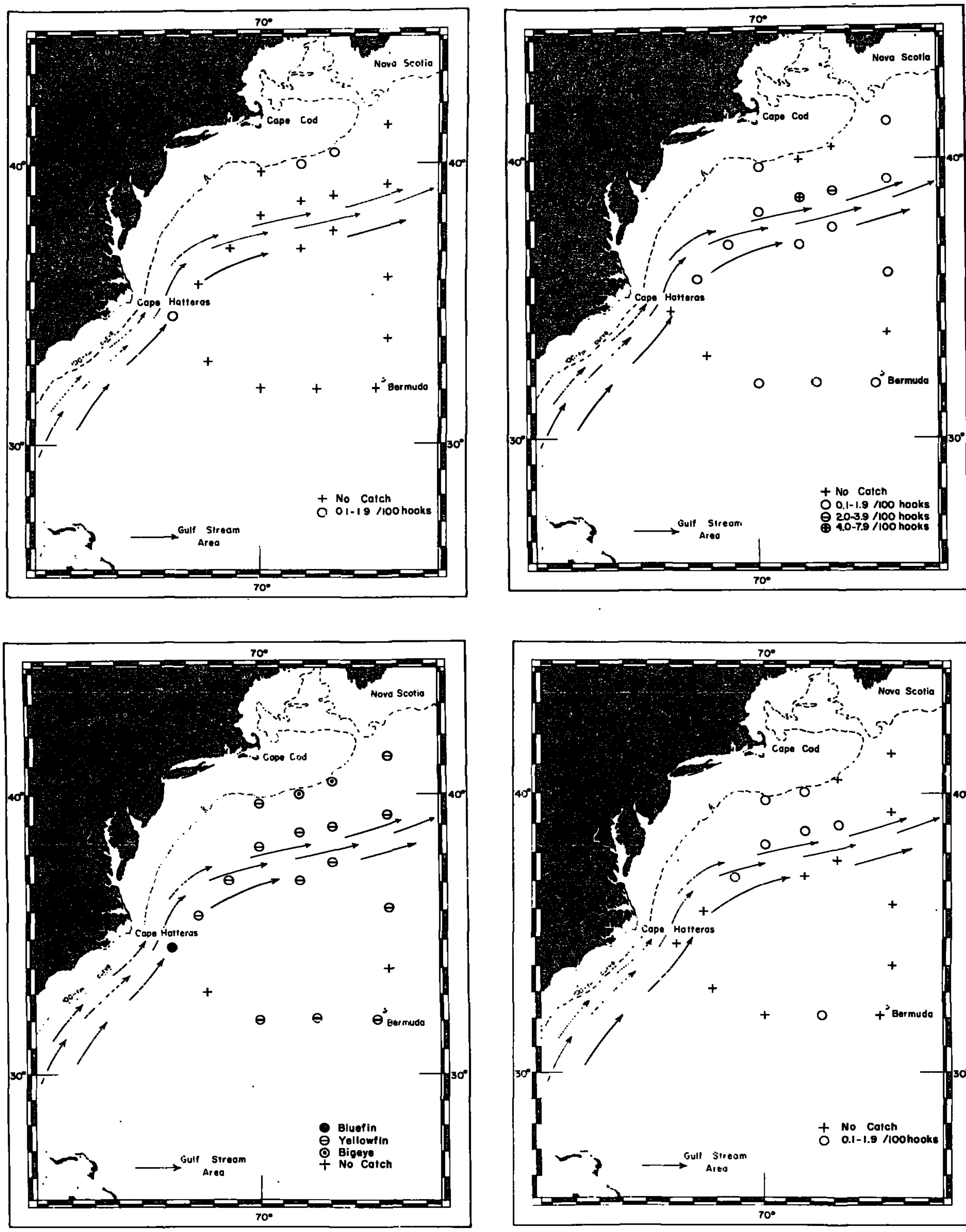

FIGURE 7.—Observed distribution of dominant tuna species in middle and late summer (July and August), based on *Delaware* cruise 57-5, 58-3.

Upper left—Bluefin. Upper right—Yellowfin. Lower left—All dominant species. Lower right—Albacore.

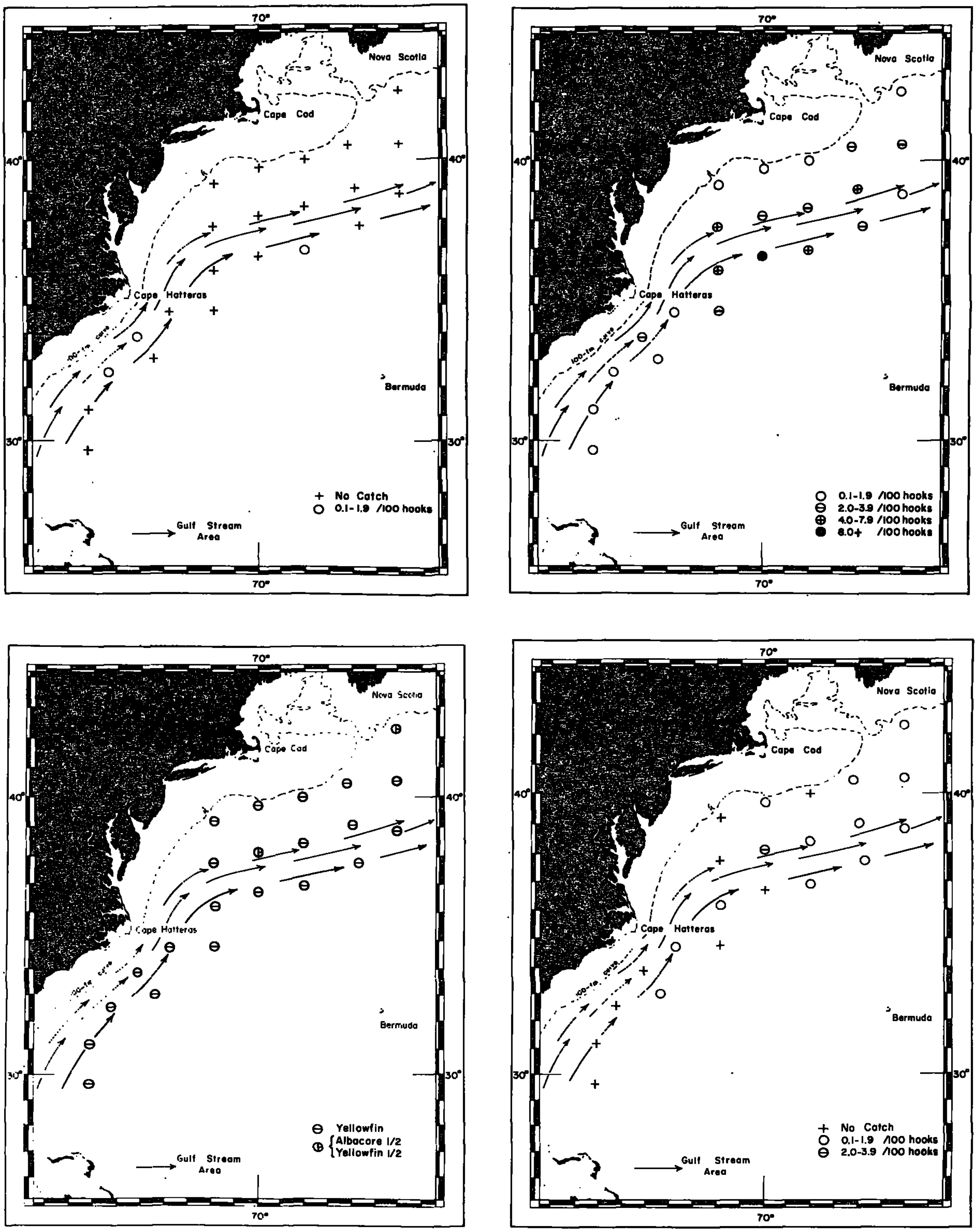

Figure 8.—Observed distribution of dominant tuna species in fall (September, October, and November), based on *Delaware* cruise 57–8.

Upper left—Bluefin. Upper right—Yellowfin. Lower left—All dominant species. Lower right—Albacore.

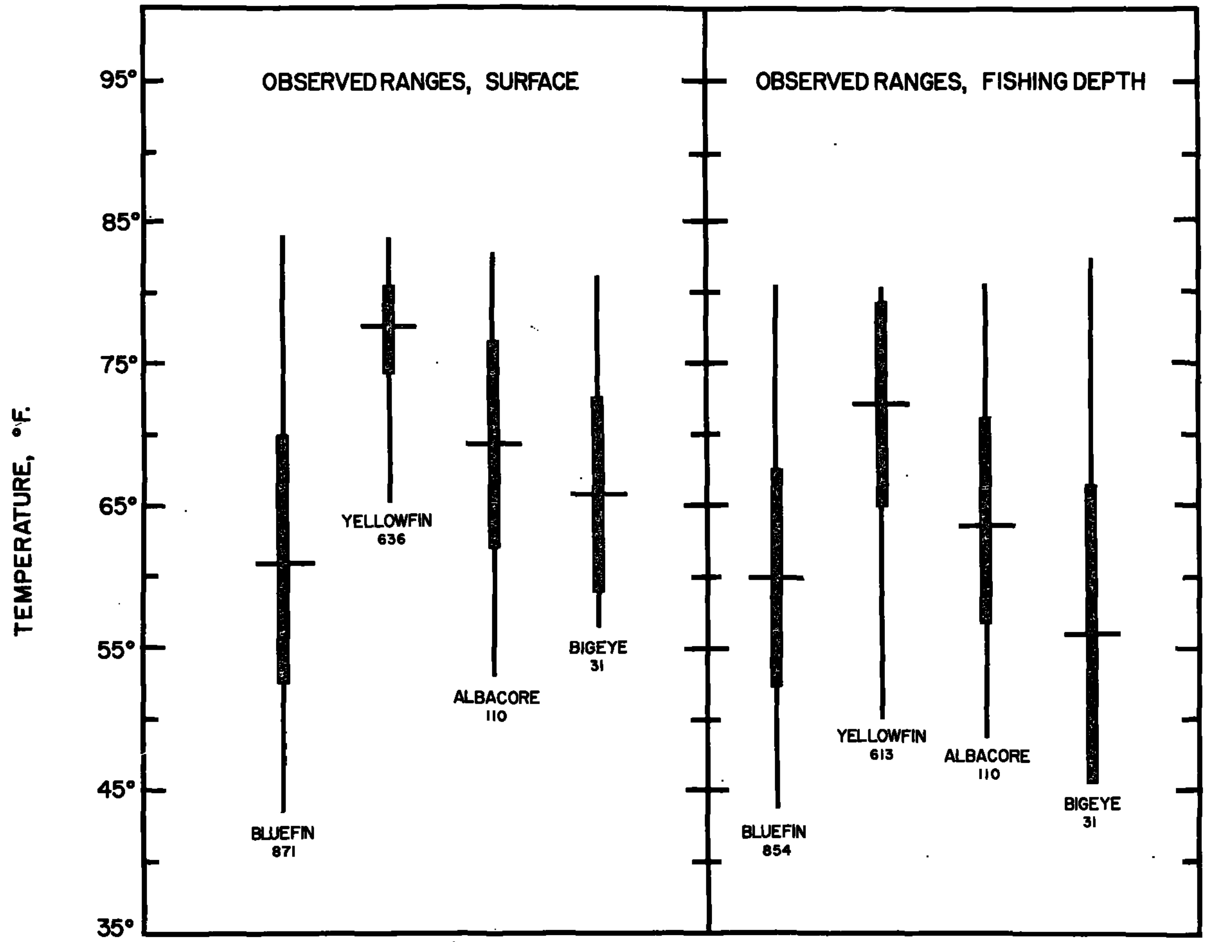

FIGURE 9.—Temperature ranges and mean temperatures for four species of tunas. Data based on temperatures recorded at stations where tunas were captured. The thin line represents the total recorded temperature range; the thick line represents 1 standard deviation on either side of the mean; and the cross bar represents the mean. The number of tunas used in the calculations are recorded below the species names.

Further, the areas yielding the greatest abundance of tuna have generally been found near the boundaries of these systems. In many cases the abrupt temperature gradients present at the edges of frontal zones of the current systems serve to separate the environments on either side of the gradients to such an extent that tuna of two or more species (for instance bluefin and yellowfin) may exist within a short distance of one another and yet be distinctly separated.

Delaware explorations indicate that temperature is an important environmental key to species distribution in the north frontal area of the Gulf Stream. To illustrate the close geographical proximity of tuna of one species to those of another in the presence of a temperature gradient, two series of isotherms were plotted from temperature recordings made at tuna stations in and near the Gulf Stream frontal area (fig. 10). The resulting plots represent conditions over a period of several days. Despite the rapidity with which individual points in the frontal area may change temperature, the general temperature structure represented should remain essentially the same, and the way in which two species—with differing ecological requirements—can exist as dominants in close proximity is indicated. Fishing results at the same points show clearly the definite change in species composition, from bluefin in the cooler waters on the edge of the Gulf Stream to yellowfin in the warmer waters in the Gulf Stream. This change in species composition with change in tem-

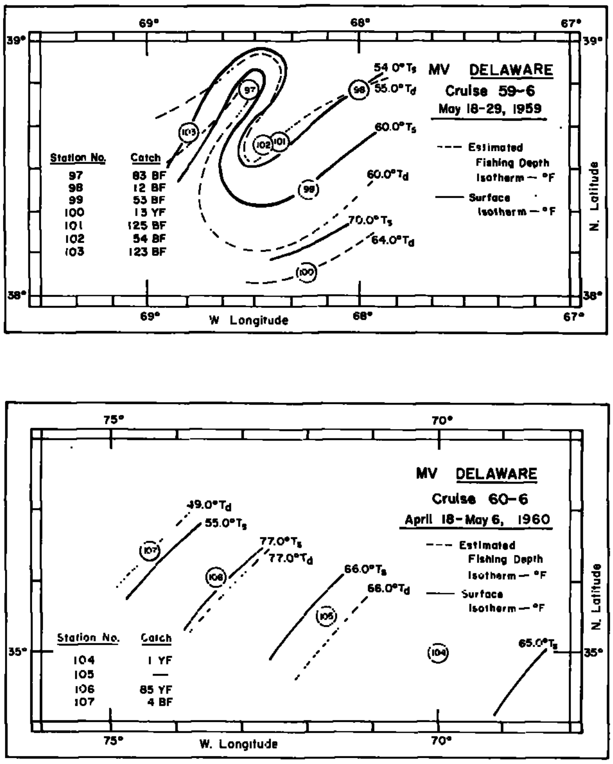

FIGURE 10.—Effect of a temperature gradient in allowing the presence of two ecologically dissimilar tuna species, bluefin (BF) and yellowfin (YF), in close proximity. Lines represent isotherms; numbered circles on lines represent the position of fishing stations with respect to the temperature. Station 100 (upper figure) was fished directly in the axis of the Gulf Stream.

perature was indicated throughout the investigation.

A comparison of the weighted average temperature of the water at stations where bluefin and yellowfin were caught (fig. 9) provides additional evidence that bluefin prefer areas of cooler water and are most abundant in cool-water areas despite the wide spread of temperatures (36° F.) included within the range observed for this species.

In early summer, when the bluefin begin to migrate from the oceanic areas, the occurrence of bluefin is reported, each year, on the Continental Shelf. This and evidence obtained from tagging tend to indicate that at least a part of the bluefin tuna of the New England and Nova Scotia summer fishery migrate to the Continental Shelf from the Gulf Stream area. One tuna, captured and tagged by the *Delaware* on May 24, 1959, 325 miles east of Ocean City, Md., was recaptured in a commercial purse seine near Cape Cod about 3 months later. But earlier evidence from tagging work accomplished by the Woods Hole Oceanographic Institution on the Continental Shelf indicates that tuna make transoceanic migrations (Mather, 1960). It is not unreasonable to suppose, therefore, that part of the tuna that winter near the Gulf Stream migrate to more distant waters than the waters of the nearby Continental Shelf. Nor is it unreasonable to suppose that at least part of the tuna found on the Continental Shelf of New England and Canada in summer months have migrated from points farther distant than the Gulf Stream area, as would be necessary if the popular theory that the large fish winter in the Caribbean were confirmed.

The available temperature data show that mean surface temperatures at the Boston light vessel ranged from 53.7° to 64.2° F. during the summer of 1957 (Day, 1959). The weighted average temperature of 59.9° F., that was calculated for oceanic stations yielding catches of bluefin tuna near the Gulf Stream (fig. 9), is within this range. Migration of bluefin into the shelf area from oceanic stations in late spring or early summer would, therefore, be accompanied by only minor temperature changes.

In contrast, Rivas (1955), in his discussion of the possible migration of bluefin from the Straits of Florida to the Gulf of Maine, stated " . . . they go in two to three weeks from temperatures of 28 to 29 degrees centigrade into waters which are 16 to 18 degrees centigrade." (From 82° to 84° F. to 61° to 64° F.) This spread of 18° to 23° represents a much greater change than would be faced by fish moving into the Gulf of Maine from the Gulf Stream area to the north, but seems to be well within the realm of possibility.

The explorations indicate that the early summer period, marking the migration of the bluefin from the oceanic area north of the Gulf Stream, also represents a period of transition in species dominance in that region. As the bluefin, which have been the dominant tuna through the winter and spring, migrate from the area, yellowfin appear and assume dominance through the summer (figs. 4C–8C).

The migratory patterns assumed by the yellowfin during this spring-summer shift and the routes taken have not been observed; but, on the basis of the evidence available, the fish are assumed to migrate from the general oceanic area south of the Gulf Stream. Yellowfin are seldom reported from inshore areas along the east coast, and confirmed records are nonexistent for the New England inshore area. However, I received an unconfirmed report of two yellowfin being taken with longline gear on Middle Bank, south of Gloucester, Mass., during the summer of 1959. Captures of the species in winter and spring have all been made in the southern areas. The yellowfin captured north of the Bahamas by the *Theodore N. Gill* in February 1953 (Anderson, Gehringer and Cohen, 1956) and the catch rate of 14.1 yellowfin per 100 hooks in the Gulf Stream east of Cape Hatteras in May provide evidence to support the assumption of migration from oceanic areas in the southern portion of the region.

Temperatures recorded at the fishing depth of the longline gear at stations in the northwestern Atlantic where yellowfin were caught compare favorably with surface water temperatures at stations in the eastern Pacific where surface-dwelling yellowfin were caught. Surface temperatures were recorded during extensive tuna-tagging operations conducted from 1952–59 by the California Department of Fish and Game, and temperature data were made available by Blunt and Messersmith (1960) for localities at which tuna were tagged that were later recovered. Using these data, a weighted average temperature of 71.4° F. was calculated for surface-caught yellowfin in the eastern Pacific. This is closely comparable to the weighted average of 72.1° F., calculated for water depths at which the subsurface yellowfin of the northwestern Atlantic were caught.

OTHER INHABITANTS OF THE OCEANIC REGION

In addition to tunas, fishes belonging to several other species were taken by the longline gear (table 2). Many of these were little-known species in the oceanic northwestern Atlantic prior to *Delaware* explorations.

Sharks were taken at a high percentage of longline stations, and their presence is important in evaluating the commercial potential of oceanic longlining in an area, because longline-caught tuna may be damaged to varying degrees by sharks. Shark damage to individual tuna may vary from minor superficial damage to complete loss. Tunas having minor damage are in most cases acceptable to the canning industry. Percents given in the following paragraphs represent only the occurrence of shark damage, not the severity of the attack. During explorations in the northwestern Atlantic, 4.2 percent of the tuna caught were reported damaged by sharks. In explorations in the Gulf of Mexico, 13.6 percent of the yellowfin tuna that were caught were damaged to varying degrees (Wathne, 1959), and the Pacific Oceanic Fishery Investigations recorded 20-percent damage for yellowfin in the Line Islands area (Iversen and Yoshida, 1956).

In the oceanic areas near the Gulf Stream where bluefin tuna were taken in relatively large quantities, very little shark damage occurred. Damage ranged from zero to a high of 12.5 percent at stations yielding large quantities of bluefin. There was no shark damage at stations fished during cruise 59–7, even though approximately 35 tons of bluefin were caught. More yellowfin have been damaged by sharks in the Gulf Stream area, however, than bluefin, and the percentage of damaged yellowfin appears to be comparable to that of other oceanic areas. Damage ranged from zero to 20.6 percent of the fish caught.

All the species of sharks responsible for tuna damage are not known. Sharks observed as they attacked tuna being hauled to a point near the surface were usually whitetips, *Carcharhinus longimanus* (Poey). Whitetip sharks are also suspected of damaging tuna in the Gulf of Mexico

TABLE 2.—*Species taken on longline gear in the oceanic northwestern Atlantic during Delaware explorations*

Family	Scientific name	Common name
Lamnidae	*Isurus oxyrinchus* Rafinesque	Mako.
	Lamna nasus (Bonnaterre)	Porbeagle.
Carcharhinidae	*Carcharhinus floridanus* Bigelow	Silky shark.
	Carcharhinus longimanus (Poey)	Whitetip shark.
	Carcharahinus obscurus (LeSueur)	Dusky shark.
	Carcharhinus falciformis (Muller and Henle).	Sickle shark.
	Prionace glauca (Linnaeus)	Blue shark.
Sphyrnidae	*Sphyrna* sp	Hammerhead shark.
Alepisauridae	*Alepisaurus fero* Lowe	Longnose lancetfish.
	Alepisaurus brevirostris Gibbs	Lancetfish.
Lamprididae	*Lampris regius* (Bonnaterre)	Opah.
Coryphaenidae	*Coryphaena hippurus* Linnaeus	Dolphin.
Bramidae	*Taractes longipinnis* (Lowe)	Bigscale pomfret.
Scombridae	*Acanthocybium solanderi* (Cuvier)	Wahoo.
	Euthynnus pelamis (Linnaeus)	Skipjack tuna.
	Thunnus alalunga (Bonnaterre)	Albacore.
	Thunnus albacares (Bonnaterre)	Yellowfin tuna.
	Thunnus atlanticus (Lesson)	Blackfin tuna.
	Thunnus obesus (Lowe)	Bigeye tuna.
	Thunnus thynnus (Linnaeus)	Bluefin tuna.
Istiophoridae	*Makaira albida* (Poey)	White marlin.
	Makaira nigricans Lacépêde	Blue marlin.
Xiphiidae	*Xiphias gladius* Linnaeus	Swordfish.

(Bullis, 1955; Backus, Springer, and Arnold, 1956). Other sharks probably also attack the line-caught tuna.

SUMMARY

From 1957–60, tuna explorations were carried out, intermittently, to determine the distribution of tunas in the oceanic portion of the northwestern Atlantic and to assess the availability of tunas to commercial gear. Major effort was expended in the Gulf Stream proper. Longline gear, fished from the Bureau vessel *Delaware* at 111 stations, caught bluefin, yellowfin, albacore, skipjack, and bigeye tunas.

Temperature studies show that the Gulf Stream system provides the environmental conditions favorable for the presence of tunas in the oceanic portion of the northwestern Atlantic. Bluefin, preferring cooler water, are the dominant tuna in the vicinity of the Gulf Stream in winter and spring. Longline catches indicate that a commercial fishery for bluefin might be profitable in those seasons. Bluefin disappear from the oceanic region in late spring or early summer, and yellowfin, preferring warmer water, are the dominant tuna in summer and fall.

A sharp temperature gradient on the edge of the Gulf Stream allows tunas of two or more species with dissimilar temperature requirements to exist within short distances and yet be distinctly separated.

Temperatures at calculated fishing depths at stations where subsurface yellowfin were taken in the northwestern Atlantic were comparable to temperatures of the surface water at positions in the Pacific where surface-dwelling yellowfin were taken.

Shark damage was light. A higher percentage of yellowfin (to 20.6 percent) than bluefin (to 12.5 percent) was attacked at any one exploratory station. Whitetip sharks appear to be responsible for a large share of shark damage to tunas in the western Atlantic.

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