SEASONAL MIGRATION OF NORTH PACIFIC ALBACORE, *THUNNUS ALALUNGA*, INTO NORTH AMERICAN COASTAL WATERS: DISTRIBUTION, RELATIVE ABUNDANCE, AND ASSOCIATION WITH TRANSITION ZONE WATERS

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ABSTRACT

In the spring months of 1972-74, fishery-oceanography surveys were conducted in the eastern North Pacific which combined intensive oceanographic sampling by research vessels with concurrent fishing effort for albacore by chartered commercial fishing vessels. The catches demonstrate an association of albacore distribution with the Transition Zone and its boundaries. The relative abundance of albacore was found to be high in the eastern sector of the Transition Zone or a period just prior to their movement across the California Current and into the traditional nearshore fishing grounds. These centers of high relative abundance of albacore are sometimes sufficient to support commercial fishing earlier and farther offshore than the traditional fishing season. Variations in the pattern of migration occur in apparent response to variations in the character and development of the Transition Zone and its frontal structure. Analyses of albacore tagging and size frequency data provide evidence that the shoreward-migrating albacore of the Pacific Northwest and California are independent groups.

The North Pacific albacore, *Thunnus alalunga* (Bonnaterre), is a wide-ranging species which spawns in the central subtropical Pacific, performs transpacific migrations, and supports important commercial fisheries in the western, central, and eastern North Pacific. That marked variations in distribution and relative abundance of albacore occur in the eastern North Pacific is indicated by major latitudinal shifts in the location of the U.S. fishery off the west coast of North America (Laurs et al. 1976). In order to evaluate factors which may affect variations in distribution, relative abundance, and migration patterns of albacore in the eastern North Pacific, and to improve our understanding of the underlying factors affecting the onset and subsequent development of the fishery, early season surveys were conducted in offshore waters of the North American Pacific coast in 1972-74.[2] These surveys found that relative abundance of albacore was high in the vicinity of oceanic fronts of the Transition Zone waters in the eastern North Pacific. Survey results also provide the basis for a hypothesis concerning migration of albacore into coastal waters off the west coast of North America. During these surveys albacore were taken in commercial concentrations farther offshore than traditionally, and several weeks earlier than the fishing season which usually commences in mid-July.

BACKGROUND INFORMATION

Numerous exploratory albacore fishing and albacore oceanographic surveys have been conducted in the central and eastern North Pacific. From surveys conducted during the 1950's, scientists described seasonal variations in distribution of albacore in the central and parts of the eastern Pacific, and demonstrated the association of albacore with Transition Zone waters in the central North Pacific (Shomura and Otsu 1956; Graham 1957; McGary et al. 1961). Flittner (1963, 1964) reported on albacore trolling experiments conducted from U.S. Navy picket vessels operating approximately along long. 130° to 135°W, and presented a schematic model of albacore movement off the Pacific coast (Flittner 1963). Neave and Hanavan (1960) showed that the northern limit of albacore catches made during high-seas salmon gillnetting studies conducted between long. 125° and 175°W was about lat. 45° to 47°N in July and

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[2]These surveys were carried on cooperatively by the National Marine Fisheries Service, Southwest Fisheries Center La Jolla Laboratory, and the U.S. albacore fishing industry through the American Fishermen's Research Foundation.

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lat. 45° to 50°N in August and September. According to Brock (1943), yachts sailing between Hawaii and Oregon during June made albacore catches between lat. 30° and 44°N in waters between long. 154° and 140°W.

Numerous exploratory fishing and oceanographic surveys also have been conducted within a few hundred miles of the coast to obtain information on distribution, availability, and migration patterns of albacore during early season in waters off the Pacific Northwest (Powell 1950, 1957; Powell and Hildebrand 1950; Powell et al. 1952; Schaefers 1953; Owen 1968; Meehan and Hreha 1969; Pearcy and Mueller 1970; and others), and in waters off California (Graham 1959; Clemens 1961; Craig and Graham 1961; and others listed in Clemens 1961 and Pinkas 1963). Johnson (1962), Laurs et al. (1976), and others have discussed variations in distribution and relative abundance of albacore in waters off North America where the U.S. fishery takes place. These studies have shown: 1) the limits of where albacore are found; 2) their general migration patterns; 3) the importance of environmental conditions and changes, notably ocean temperature, in relation to the distribution and relative abundance of albacore; and 4) the considerable annual variation in location of available concentrations of albacore.

In the present study early season albacore surveys were planned to encompass a portion of the eastern sector of the Transition Zone during a period prior to the commencement of the nearshore fishery. The primary objectives of these surveys were:

1) To investigate the early season distribution and abundance of albacore off the North American Pacific coast.
2) To investigate the eastward migration path of albacore entering the American west coast fishery.
3) To determine if migrating albacore are associated with major offshore oceanographic features, particularly the Transition Zone and the ocean fronts that form its boundaries.

METHODS

The general work plan for each offshore survey employed one National Marine Fisheries Service (NMFS) research vessel (*Townsend Cromwell* in 1972 and *David Starr Jordan* in 1973 and 1974) and a group of 5 to 12 commercial albacore fishing vessels on charter to the American Fishermen's Research Foundation (AFRF). The research vessel and chartered fishing vessels worked cooperatively to obtain estimates of distribution and relative abundance of albacore in the offshore area and to make concurrent oceanographic measurements. The research vessel collected physical, chemical, and biological oceanographic data and conducted supplementary fishing activities. The fishing vessels conducted exploratory fishing, tagged fish, and collected surface and subsurface temperature data. The oceanographic findings made on meridional transects were used in directing the exploratory fishing operations, particularly at the onset of each survey. In several instances, especially in 1973 and 1974, the findings of large numbers of fish were used to redirect the research vessel to conduct detailed oceanographic observations in the vicinity.

Operations Aboard Research Vessels

Three meridional oceanographic sections were taken along long. 135°, 137°30′, and 140°W between lat. 31° and 41°N in 1972 and 1973; in 1974 the middle section, portions of the section along long. 135°W, and additional transects were taken (Figure 1). Hydrographic stations were occupied at 25- to 30-n.mi. intervals. Figure 2 shows station positions occupied in 1973; Lynn and Laurs[3,4] gave figures of the station positions for other years. Observations included: 1) salinity-temperature-depth profiles to 500 or 1,000 m using an STD;[5] 2) Nansen bottle or command rosette sampler[6] bottle casts for collection of water samples for determination of dissolved oxygen, chlorophyll, and salinity; 3) oblique zooplankton net hauls and simultaneous surface hauls with neuston plankton nets; and 4) at night stations,

[3]Lynn, R. J., and R. M. Laurs. 1972. Study of the offshore distribution and availability of albacore and the migration routes followed by albacore tuna into North American waters. *In* Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1972, p. 10-44. (Unpubl. rep.)

[4]Lynn, R. J., and R. M. Laurs. 1973. Further examination of the offshore distribution and availability of albacore and migration routes followed by albacore into North American waters. *In* Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1973, p. 3-35. (Unpubl. rep.)

[5]Plessey model 9006 electronic salinity-temperature-depth profiler. Use of a trade name does not imply endorsement by the National Marine Fisheries Service, NOAA.

[6]General Oceanics, Inc.

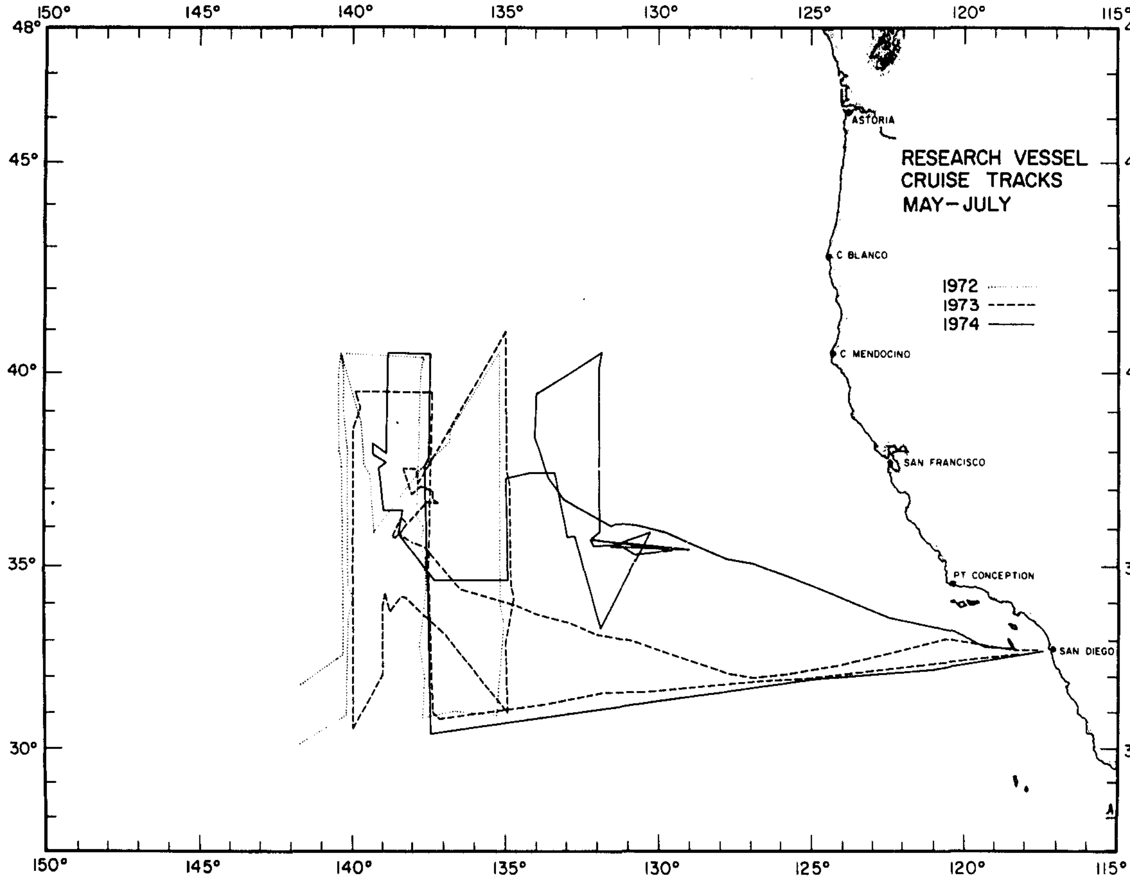


FIGURE 1.—Albacore research vessel cruise tracks for the 1972-74 offshore research surveys.

oblique midwater trawl hauls using an Isaacs-Kidd Midwater Trawl. Also, surface temperature, salinity, and chlorophyll were recorded continuously while underway.

Generally, 10 jiglines (five on *Townsend Cromwell* cruise in 1972) were trolled for albacore on transects between oceanographic stations during daylight. In some regions that were not covered by fishing vessels, trolling was carried on by the research vessel exclusively throughout daylight. On such fishing days, three or four expendable bathythermograph (XBT) drops were made in addition to continuous monitoring of surface temperature, salinity, and chlorophyll.

Operations Aboard Fishing Vessels

The AFRF charter vessels which took part in the offshore surveys were jigboats, except for two baitboats in 1973 which were outfitted to conduct either live-bait fishing or jig fishing. Twelve fishing vessels participated in the operations in 1972 and 1973 and five in 1974.

The fishing vessels sailed in groups of four from San Diego, Calif., and Astoria, Oreg., at 15- to 20-day intervals during 1972 and 1973, and all vessels sailed together from San Diego in 1974. The vessels usually worked in pairs. A schematic diagram of the cruise tracks for the 1972-74 offshore surveys is shown in Figure 3. Detailed cruise tracks showing daily positions and locations of XBT stations for each fishing vessel or pair of fishing vessels by 10-day period are given in Lynn and Laurs[7] (see footnotes 3 and 4).

[7]Lynn, R. J., and R. M. Laurs. 1974. Cooperative NMFS-AFRF early season offshore studies conducted during 1974. *In* Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1974, p. 3-18. Southwest Fish. Cent. Admin. Rep. LJ-74-47.

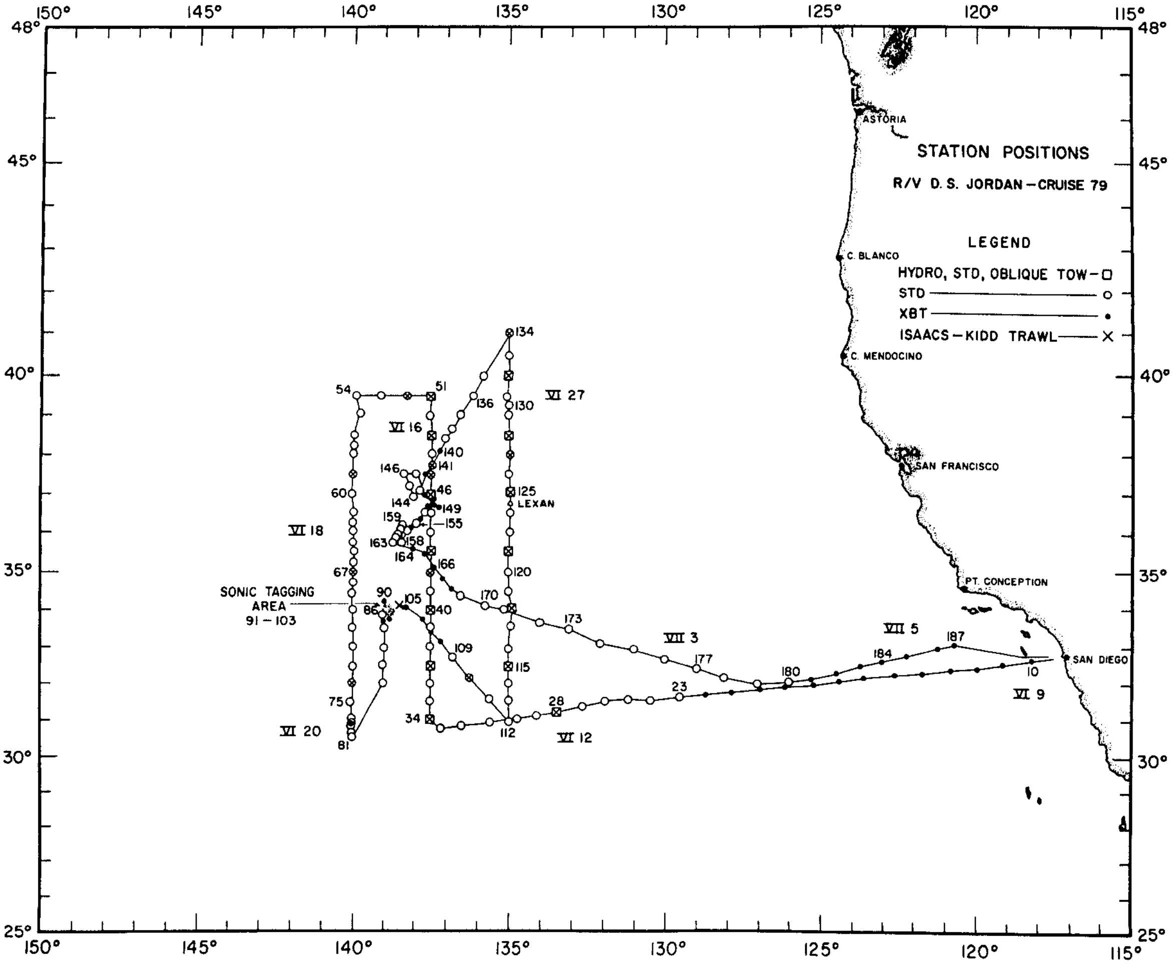


FIGURE 2.—Track and station positions for RV *David Starr Jordan* cruise 79, 9 June-6 July 1973.

Standard commercial albacore fishing equipment and regular commercial fishing methods were used. Most of the jig vessels trolled 10 lines and baitboats 6 or 8 lines when jig fishing. (Baitboats had better success when trolling than when baitfishing.) Daily records pertaining to fishing operations were maintained aboard each vessel, including number of fish caught, fork length of most fish caught (except for two vessels in 1972), positions where fishing was started and ended, amount of fishing effort expended, and fishing conditions and signs of fish. In addition, sea-surface temperature, sea conditions, and surface weather conditions were recorded. Half of the fishing vessels chartered in 1972 and 1973, and all in 1974, were equipped with an XBT system; generally one or two XBT probes were launched each day. Sea-surface temperature measurements were made using bucket thermometers.

EARLY SEASON DISTRIBUTION AND RELATIVE ABUNDANCE OF ALBACORE IN OFFSHORE WATERS

Distribution of Catches Made By Charter Vessels

Nearly 27,000 albacore were caught by the chartered fishing vessels during the three offshore surveys (Table 1). In all three surveys, albacore were taken in substantial numbers in an offshore region between lat. 31° and 36°N from late May through June. Catch rates were generally low or zero in surrounding regions and during explorato-

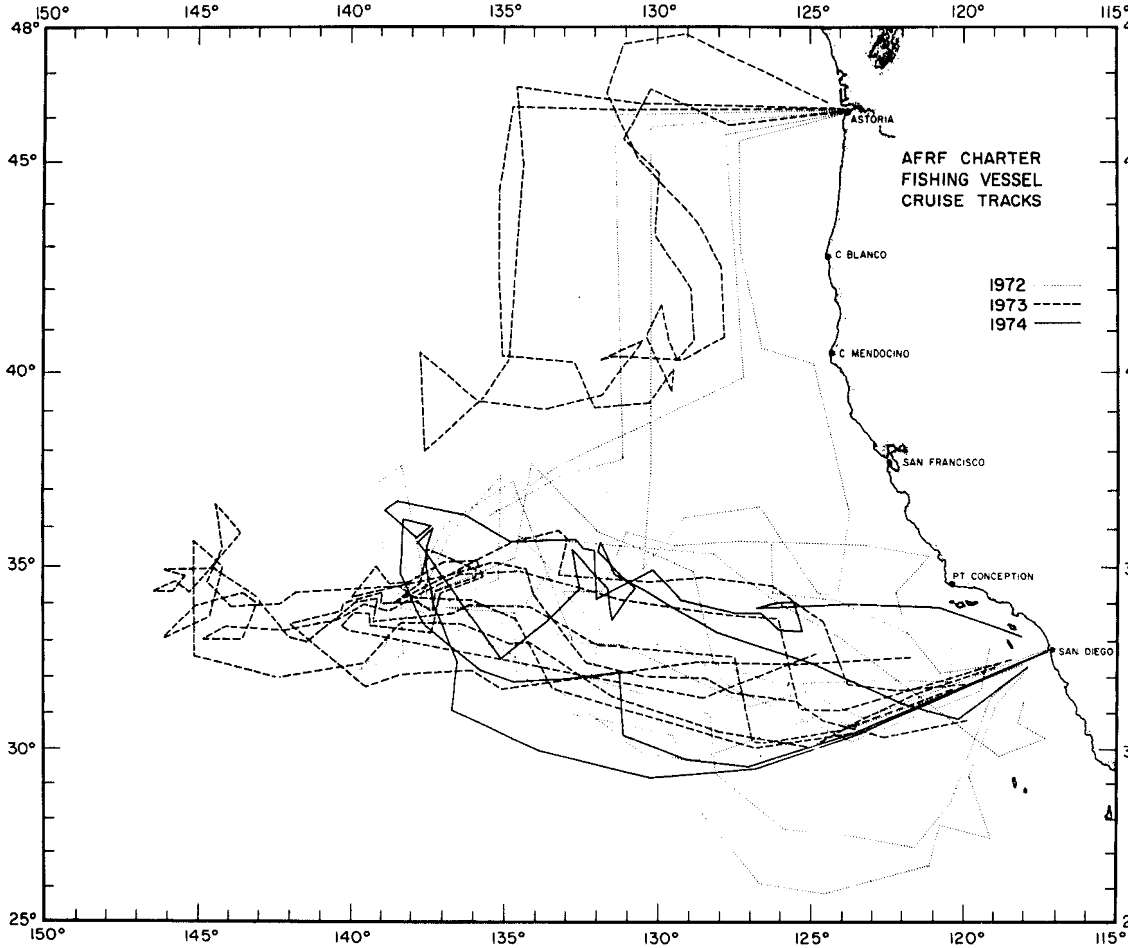


FIGURE 3.—American Fishermen's Research Foundation charter fishing vessel cruise tracks for the 1972-74 offshore research surveys.

ry fishing before late May. Variations in distribution and relative abundance of albacore were observed within and between surveys.

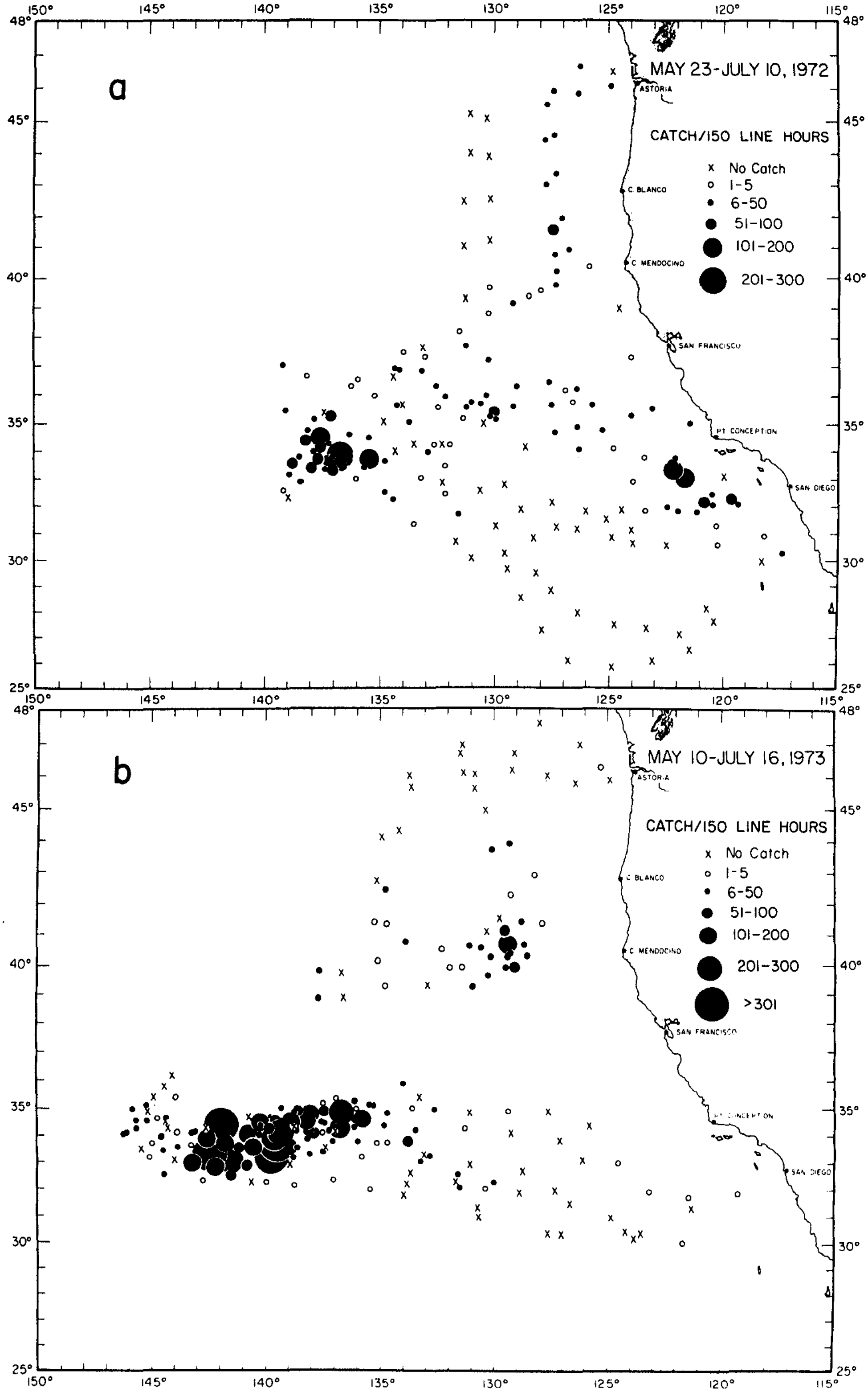
Differences Between Surveys

Plots of the charter vessel catches for each survey are given in Figures 4a-c. The catches represented in these and other plots have been standardized to the number of fish caught per 150 line-hours (averaged between pairs of vessels that fished together for 1972 and 1973) and presented graphically by proportionately increasing size of dots.

TABLE 1.—Albacore survey catches.

Year	Total catch by charter vessels	Tagged and released	Total catch by research vessel
1972	6,746	1,431	155
1973	11,027	1,738	130
1974	9,146	1,369	495
Total	26,919	4,538	780

In 1972 and 1973, relative abundance of albacore was high between lat. 32° and 35°N, long. 135° and 140°W, and lat. 32° and 35°N, long. 135° and 143°W, respectively (Figure 4a-b). In both of these years small or no catches were made in the region between long. 135°W and inshore waters within 150 mi of the coast where fishing takes place during the traditional albacore fishing season. In 1974 (Figure 4c), high catch rates were again made offshore of long. 135°W, but over a larger latitudinal range, lat. 31° to 36°N, and somewhat more scattered than in the two preceding years. Also, high catches were made at about lat. 33° to 36°N, long. 124° to 135°W in the region between


a
MAY 23-JULY 10, 1972
CATCH/150 LINE HOURS
No Catch
1-5
6-50
51-100
101-200
201-300
ASTORIA
C. BLANCO
C. MENDOCINO
SAN FRANCISCO
PT. CONCEPTION
SAN DIEGO
b
MAY 10-JULY 16, 1973
CATCH/150 LINE HOURS
No Catch
1-5
6-50
51-100
101-200
201-300
>301
150°
145°
140°
135°
130°
125°
120°
115°
48°
45°
40°
35°
30°
25°

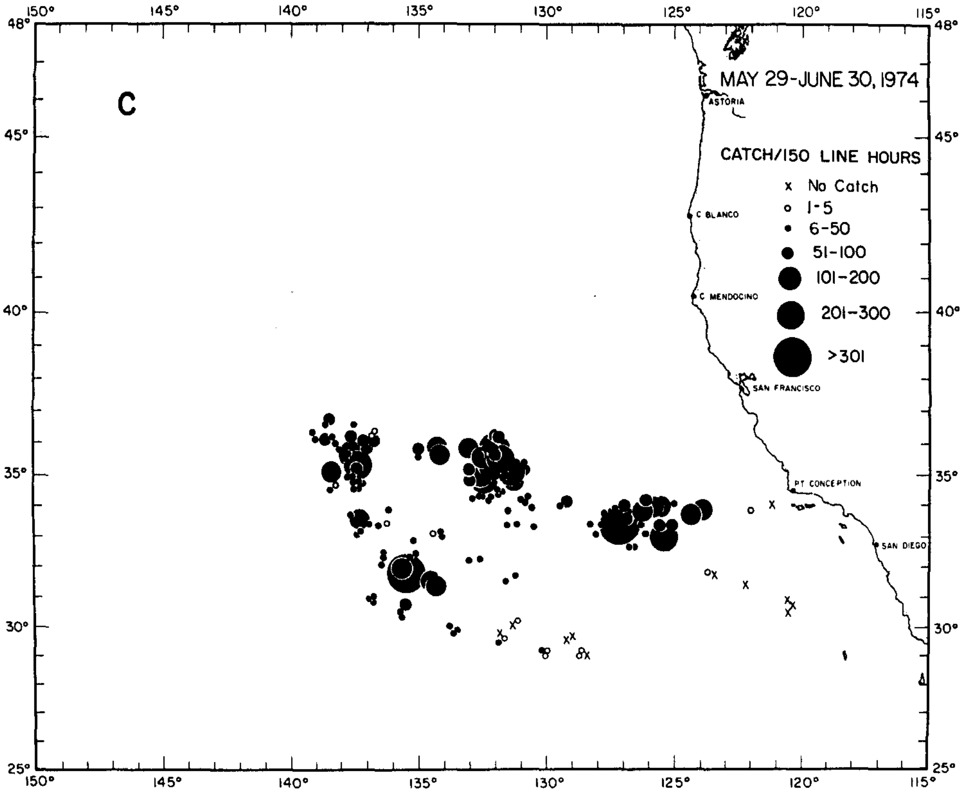
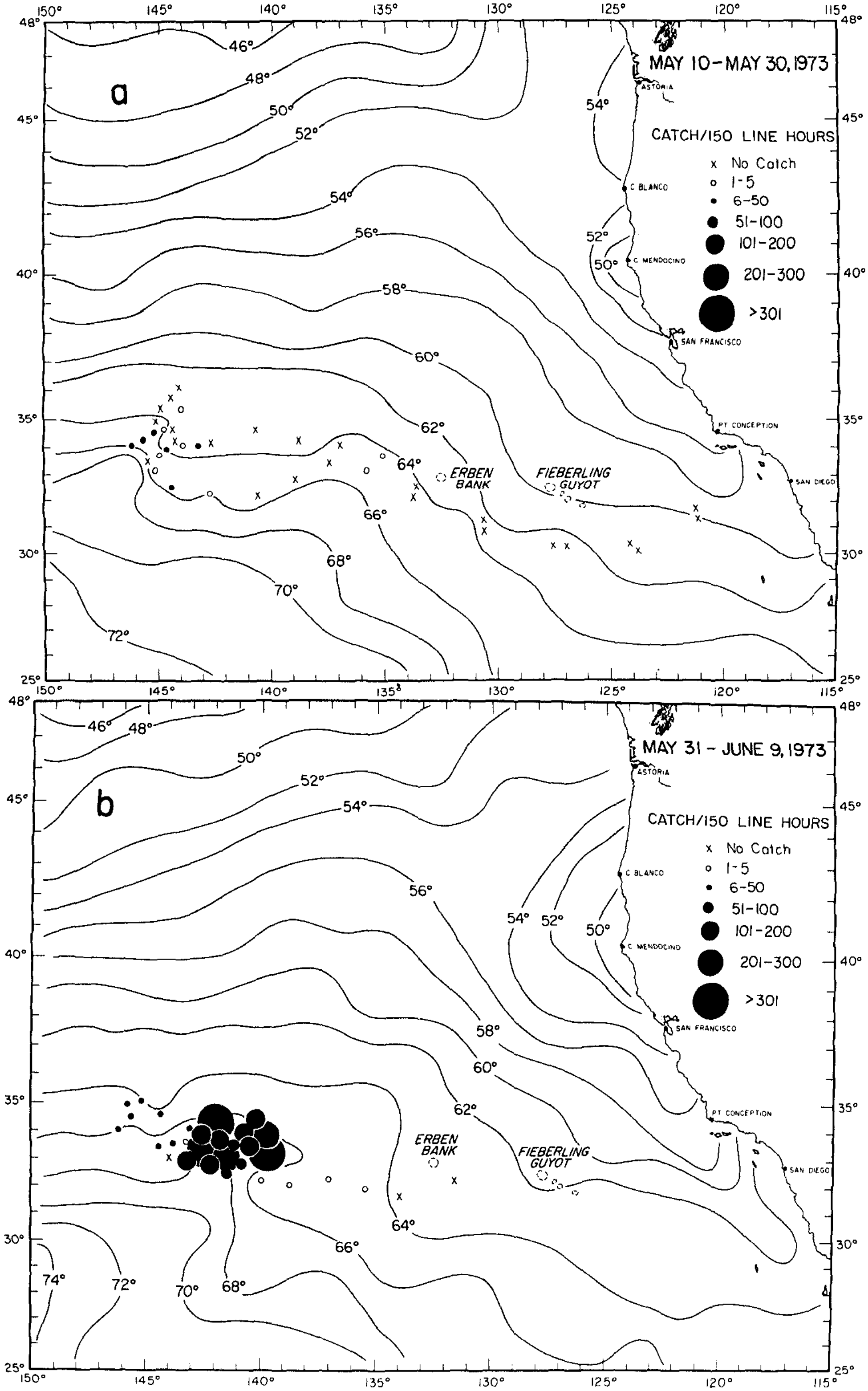


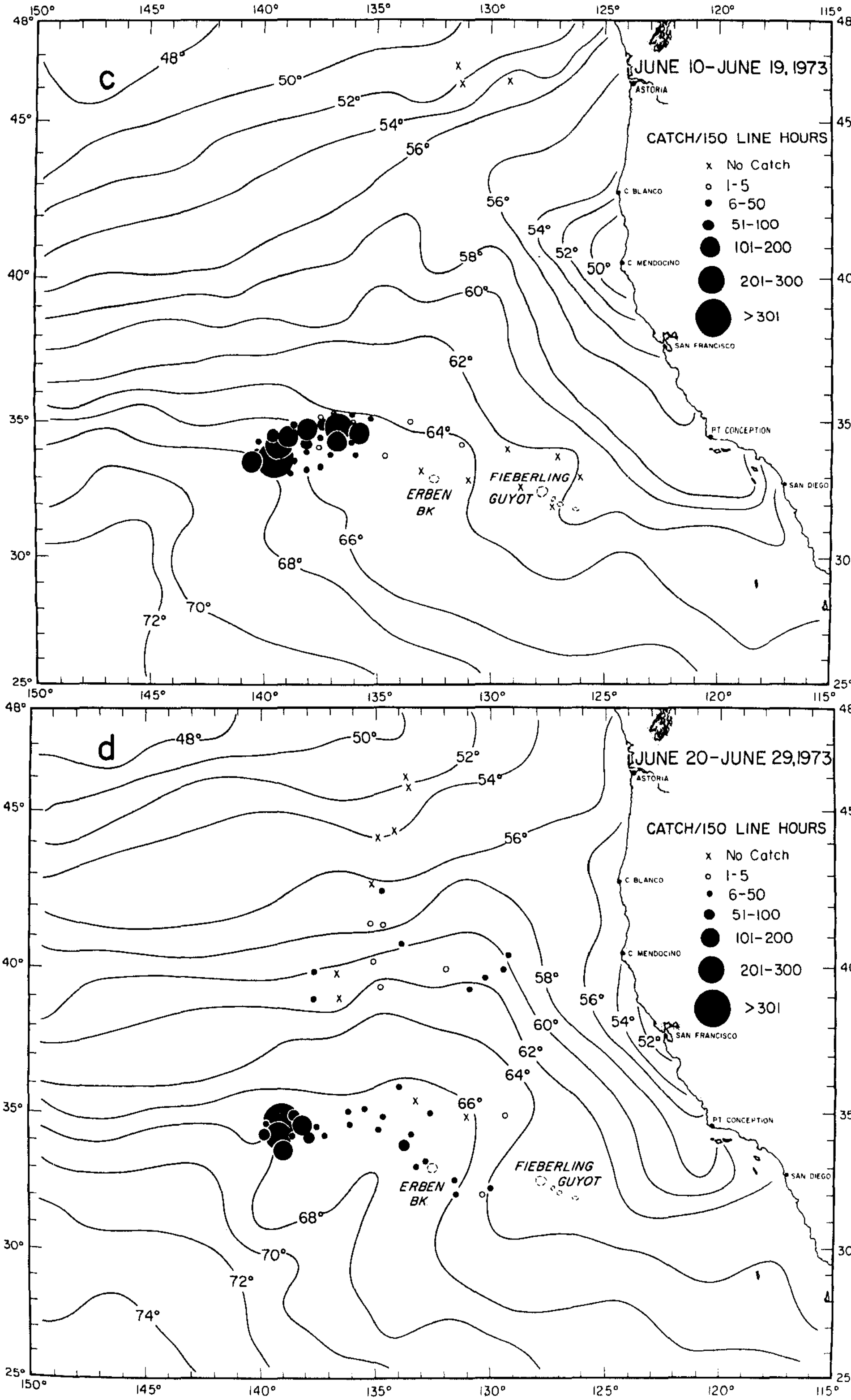
FIGURE 4.—Albacore catch per 150 line-hours by American Fishermen's Research Foundation charter vessels: a. 23 May-10 July 1972; b. 10 May-16 July 1973; c. 29 May-30 June 1974.

the offshore area of high catches and inshore waters.

Differences Within Surveys

Representative information on spatial and temporal variations in the distribution and relative abundance of albacore in offshore waters during May and June is given in Figure 5a-e. In the early part of the 1973 survey, 10 to 30 May, four vessels worked westward making only small scattered catches between lat. 31° and 35°N, long. 142° and 145°W. In the second time period, 31 May to 9 June, the vessels returned through waters they had scouted earlier and began making catches of over 100 fish/day between lat. 32° and 34°N, long. 139° and 143°W. Good catches continued to be made in the general area of lat. 33° to 35°N, long. 135° to 143°W for several weeks with charter vessels landing up to 300 fish/day on many days. A second group of four charter boats, which left San Diego on 25 May, did not catch any fish until 4 June when they moved westward of long. 139°W near lat. 33° to 35°N. On their return to San Diego during mid-June, the first group of boats failed to catch any fish east of long. 135°W despite favorable ocean temperature conditions. Similarly, on the return to San Diego near the end of June, catches by the second group of charter boats dropped off abruptly east of long. 135°W with only small scattered or no catches made east of Fieberling Guyot (long. 128°W). The four vessels surveying the area north of lat. 38°N found generally poor to moderate catches. (The region lat. 35° to 38°N was not covered by the fishing vessels.) This sequence of catch charts shows that: 1) albacore were apparently unavailable to jig fishing, except for scattered catches, through May in a region which subsequently was to prove very productive; 2) albacore became available to trolling gear in the first week of June in a region which will be shown later to be associated with the subtropic boundary of the Transition Zone; 3) good catches persisted within a block of 2° latitude by 7° longitude for


a
MAY 10 – MAY 30, 1973
CATCH/150 LINE HOURS
x No Catch
1-5
6-50
51-100
101-200
201-300
>301
ASTORIA
C BLANCO
C. MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
ERBEN BANK
FIEBERLING GUYOT
46°
48°
50°
52°
54°
56°
58°
60°
62°
64°
66°
68°
70°
72°
b
MAY 31 – JUNE 9, 1973
CATCH/150 LINE HOURS
x No Catch
1-5
6-50
51-100
101-200
201-300
>301
74°


c
JUNE 10–JUNE 19, 1973
CATCH/150 LINE HOURS
x No Catch
1-5
6-50
51-100
101-200
201-300
>301
ASTORIA
C BLANCO
C MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
ERBEN BK
FIEBERLING GUYOT
48°
50°
52°
54°
56°
58°
60°
62°
64°
66°
68°
70°
72°
d
JUNE 20–JUNE 29, 1973
CATCH/150 LINE HOURS
x No Catch
1-5
6-50
51-100
101-200
201-300
>301
ASTORIA
C BLANCO
C MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
ERBEN BK
FIEBERLING GUYOT
48°
50°
52°
54°
56°
58°
60°
62°
64°
66°
68°
70°
72°
74°
150°
145°
140°
135°
130°
125°
120°
115°
25°
30°
35°
40°
45°
48°

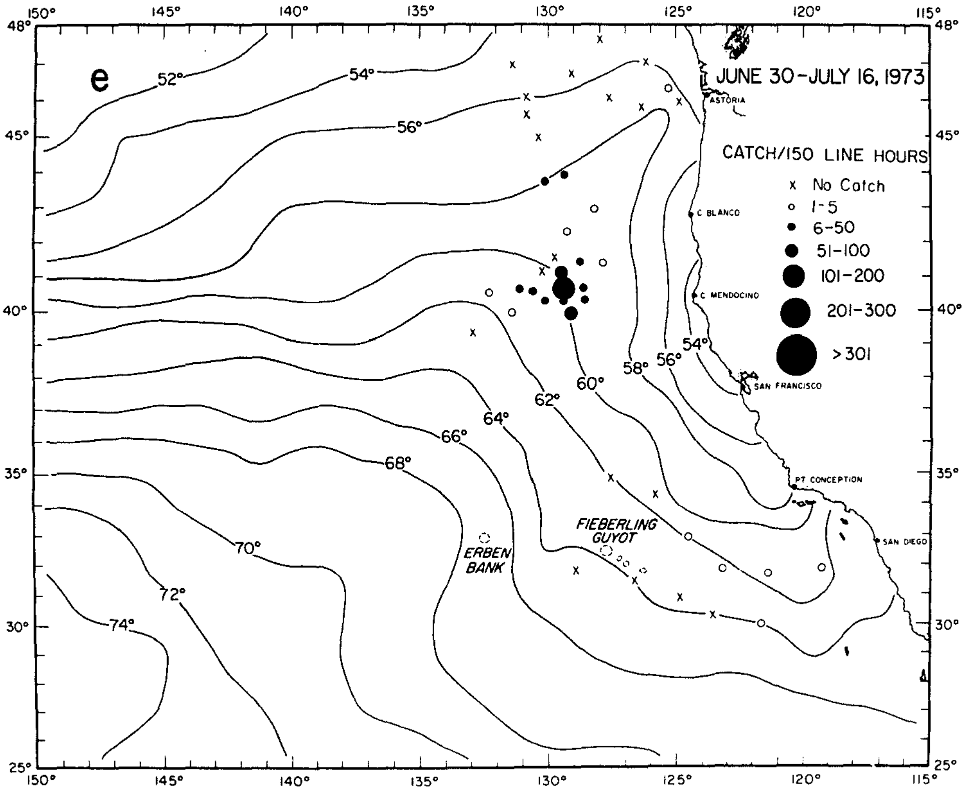


FIGURE 5.—Albacore catch per 150 line-hours by American Fishermen's Research Foundation charter vessels and sea-surface temperature: a. 10-30 May 1973; b. 31 May-9 June 1973; c. 10-19 June 1973; d. 20-29 June 1973; e. 30 June-16 July 1973.

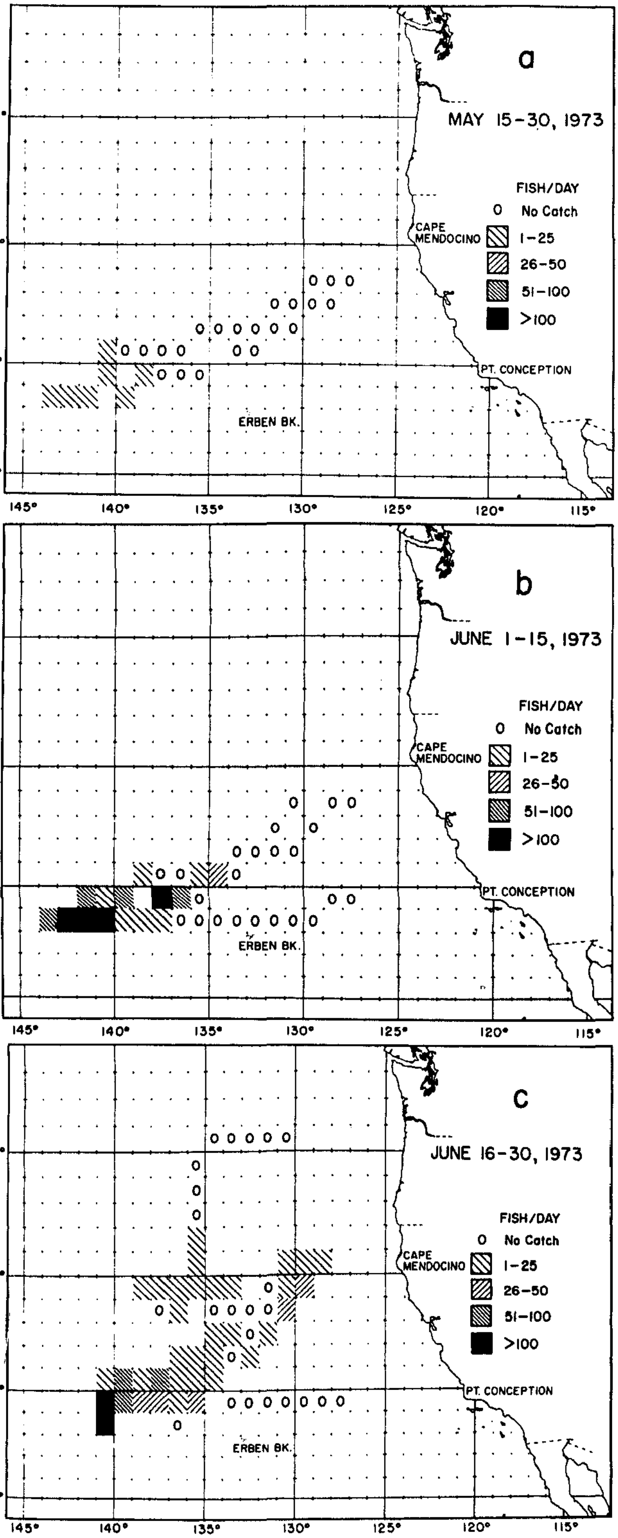
over a 3-wk period in June, and 4) elsewhere catches were substantially lower.

Catches Made By Noncharter Commercial Fishing Vessels

Because of the fishing success of the chartered fishing vessels, in the years following the first survey (1972), noncharter commercial albacore vessels have fished in the offshore region concurrently with the chartered fishing vessels and research vessels. During June 1973 and June 1974 it is estimated that, respectively, 25 to 30 and 50 to 60 albacore vessels fished across a large zone of latitudes in the offshore regions (Jack Bowland pers. commun.). Additional information on the distribution and relative abundance of albacore is provided by these catch data.

Figure 6a-e shows estimates of mean catch-per-unit effort by 15-day period and 1° quadrangle of latitude and longitude for May through July 1973, for those commercial albacore vessels from which logbook records were available. [Logbook records were standardized by methods given in Laurs et al. (1976).]

As with the charter vessels, a center of high relative abundance was found in the offshore region between lat. 33° and 35°N and long. 139° and 143°W. From mid-May through mid-June (Figure 6a, b) no catches were reported north of lat. 36°N nor (with one exception) east of long. 134°W. In the latter half of June (Figure 6c), a scattering of catches was made in the intervening zone. The distribution and relative abundance of albacore, indicated by the charter and noncharter fishing vessel catches, were similar. Catches by noncharter vessels were made over the same latitudinal range and the same offshore to nearshore sequence was observed. The fishing success of the noncharter vessels further demonstrates that commercial concentrations of albacore were available 4 to 6 wk earlier than the normal fishing season in waters hundreds of miles offshore of the area where the fishery has traditionally operated.



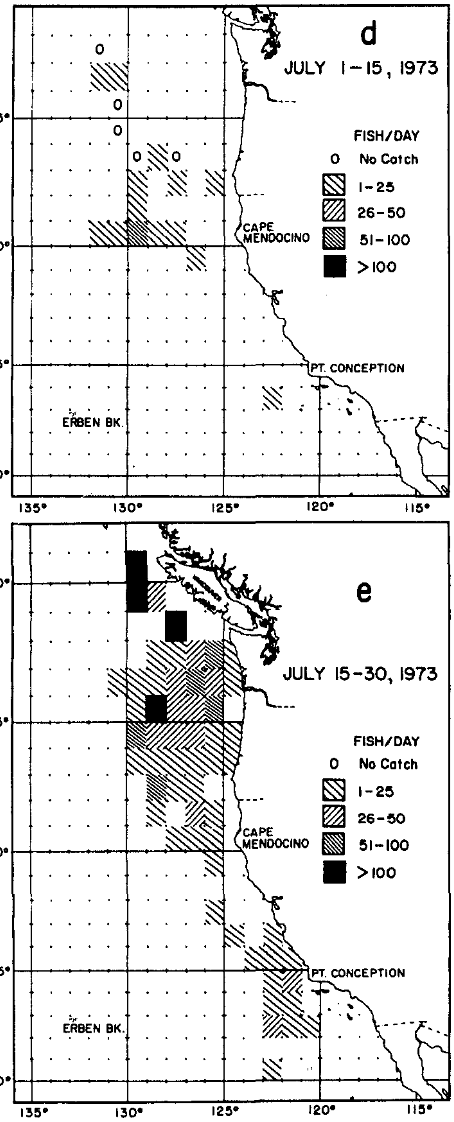


FIGURE 6.—Mean daily albacore catch-per-unit effort by 1° quadrangles for noncharter vessels for the period: a. 16-30 May 1973; b. 1-15 June 1973; c. 16-30 June 1973; d. 1-15 July 1973; e. 16-31 July 1973.

The last two charts in this series (Figure 6d, e, through the end of July 1973) reveal subsequent stages of albacore migration and commencement of the nearshore fishery. The relative abundance of albacore was high in nearshore waters by late July. In comparison to recent years, the 1973 nearshore fishery started about 3 weeks late.

SIZE COMPOSITION OF FISH

Three size modal groups of fish were caught in each year by the AFRF charter vessels; however, the relative proportions of the size groups varied among the years (Figure 7; Table 2). In 1972 about equal proportions of each size modal group were caught. In 1973 and 1974 the medium-size modal group was predominant and the larger one nearly absent.

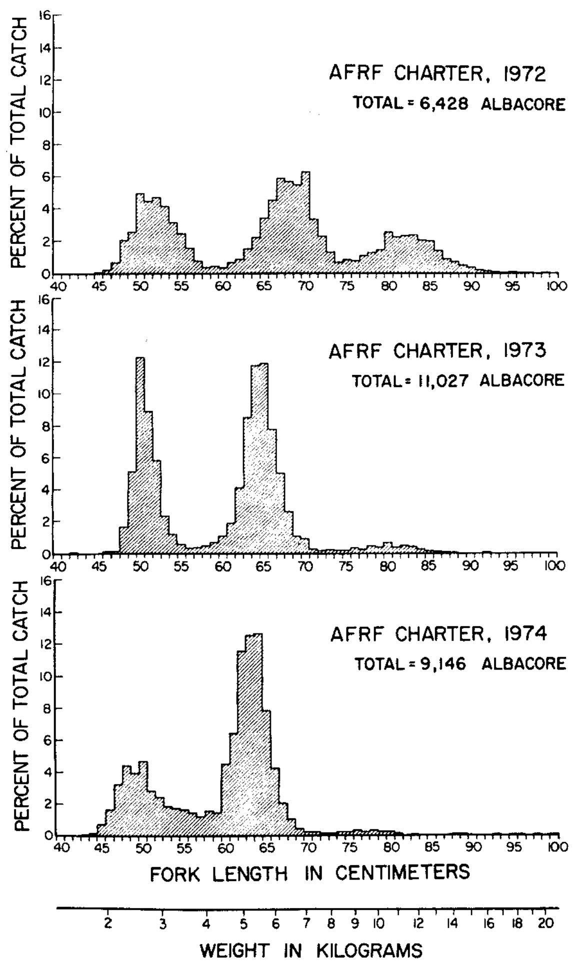


FIGURE 7.—Size composition by percent frequency of catch versus fork length for total catches of albacore from the research surveys in 1972-74.

TABLE 2.—Percentage size composition by number and by weight for albacore catches made by American Fishermen's Research Foundation charter vessels in the offshore area west of long. 130°W and south of lat. 38°N.

Year	<4 kg	4-8 kg	>8 kg	<4 kg	4-8 kg	>8 kg
	Percent by number			Percent by weight[1]		
1972	39	33	27	18	33	49
1973	43	53	4	25	65	10
1974	37	61	2	22	73	5

[1]Estimated from length-weight relationship given by Clemens (1961).

THE MARINE ENVIRONMENT

Albacore were found mainly in Transition Zone waters. Variations in distribution and relative abundance between each of the surveys appeared to be related to oceanographic conditions of the Transition Zone. Transition Zone waters lie between the cool low salinity Pacific Subarctic waters to the north and the warm, saline Eastern North Pacific Central waters to the south and have temperatures and salinities that are characteristic of a mixture of these two primary water masses (Sverdrup et al. 1942; Christensen and Lee 1965). Transition Zone waters are found in a band across the North Pacific middle latitudes within the North Pacific Current and are bounded by sharp horizontal gradients in temperature and salinity (McGary and Stroup 1956; Roden 1970, 1972, 1975). These bounding gradient regions are sometimes referred to as the Subtropic and Subarctic fronts. The dynamic processes which produce and maintain these gradients also enrich these waters (McGary and Stroup 1956).

An oceanographic section of the vertical distribution of temperature and salinity was taken along long. 137°30′W in June 1972, 1973, and 1974 (Figure 8). In 1972 and 1973, Subarctic waters were found north of lat. 35 °N and Central waters south of lat. 31°30′N and 32°N, respectively. Boundaries of the Transition Zone between these water masses were well developed and readily identifiable. The Subarctic front was marked by abrupt shoaling of the 33.8‰ isohaline and 58°F (14.4°C) isotherm and a sharp horizontal gradient in salinity extending from the surface to greater than 175 m. The Subtropic front was delineated by steep shoaling of the 34.2‰ isohaline and 62°F (16.7°C) isotherm and a sharp gradient in salinity extending from the surface to greater

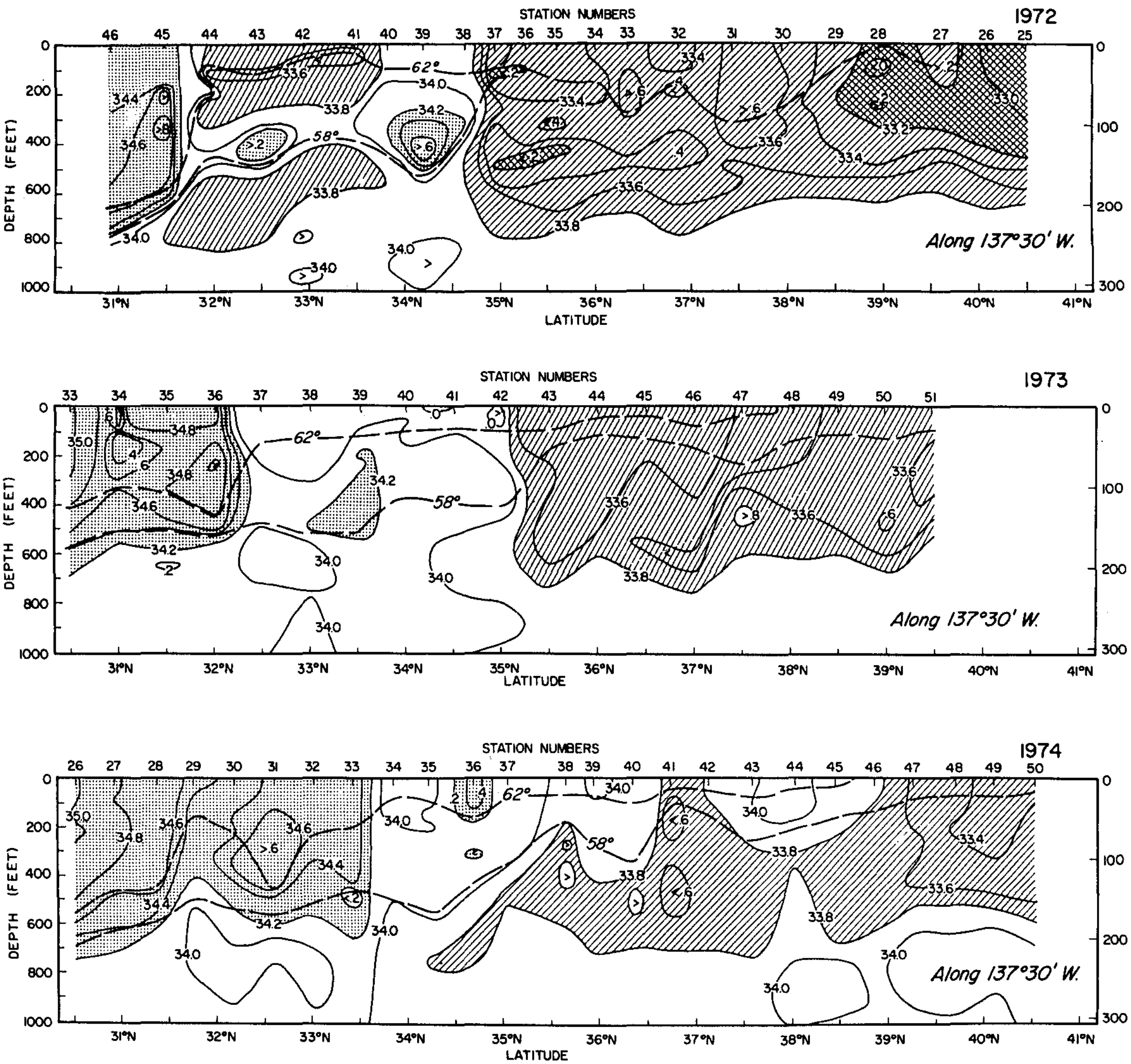


FIGURE 8.—Vertical sections of temperature and salinity along long. 137°30′W during June 1972, 1973, and 1974. Low salinity water (<33.8‰) indicative of Subarctic water is hatched and crosshatched. High salinity water (>34.2‰) indicative of Central water is shaded with a dot pattern. The 58° and 62°F isotherms are shown by heavy dashed lines.

than 150 m. A temperature gradient on the order of 0.6°C in 13 km was often found to mark these fronts at the sea surface. At other times, however, seasonal heating in the surface layer eroded the horizontal temperature gradient at the surface. Mixing was evident in the Transition Zone in 1972 with low-salinity water penetrating southward and some high-salinity water northward at intermediate depths.

Oceanographic conditions were different in the region of the Transition Zone in 1974 from those which were observed in 1972 and 1973. In 1974, boundaries of the Transition Zone were poorly developed and broken. Salinity gradients were diffuse and changes in depth of the isotherms gradual and variable in the regions of the Subarctic and Subtropic fronts. The Subarctic front was virtually nonexistent and Transition Zone waters graded gradually into Subarctic waters. The Subtropic front was weak and spread between lat. 31°30′ and 33°30′N. Saur[8] found that the diffuse

[8]Saur, J. F. T. 1976. Anomalies of surface salinity and temperature on the Honolulu-San Francisco route, June 1966-June 1975. NORPAX Highlights 4:2-4. (Unpubl. rep.)

nature of the Transition Zone and its frontal boundaries became evident late in 1973 and persisted throughout 1974.

ALBACORE CATCHES IN RELATION TO OCEANIC FRONTS

Graphical depictions of the frontal gradients that form the boundaries of the Transition Zone[9] and standardized albacore catches for June of each of the three surveys are shown in Figure 9a-c. This figure indicates that the catches were largely made within the Transition Zone in all 3 yr. During June 1972 and 1973, productive centers of fishing, indicating high relative abundance of albacore, developed in the Transition Zone between lat. 33° and 35°N and west of long. 135°W (Figure 9a, b). These centers persisted for several weeks before fishing effort was ended. In these years, the frontal structure was strongly developed and the Transition Zone easily identifiable. During June 1974 when the frontal structure was poorly developed and water mass boundaries were less distinct, catches were distributed over a larger range of latitude and longitude (Figure 9c). Overall catches in 1974 were substantial but they were not persistent in any area for more than a few days. Thus, while albacore were still associated with Transition Zone waters, the influence of extensive lateral mixing between water masses and the diffuse nature of the boundary frontal structure apparently failed to concentrate fish in a given location for periods of time as had apparently occurred in the previous 2 yr.

While graphical depictions of frontal structure outline the location of the boundaries associated with Transition Zone water (Figure 9a-c), they do not indicate the intensity of the gradients of the frontal structure. The frontal structure has been shown generally to have weak gradients during

[9]The temperature and salinity fields measured by the research vessel, augmented by the XBT data collected by the charter fishing vessels, were analyzed to delineate the frontal gradients.

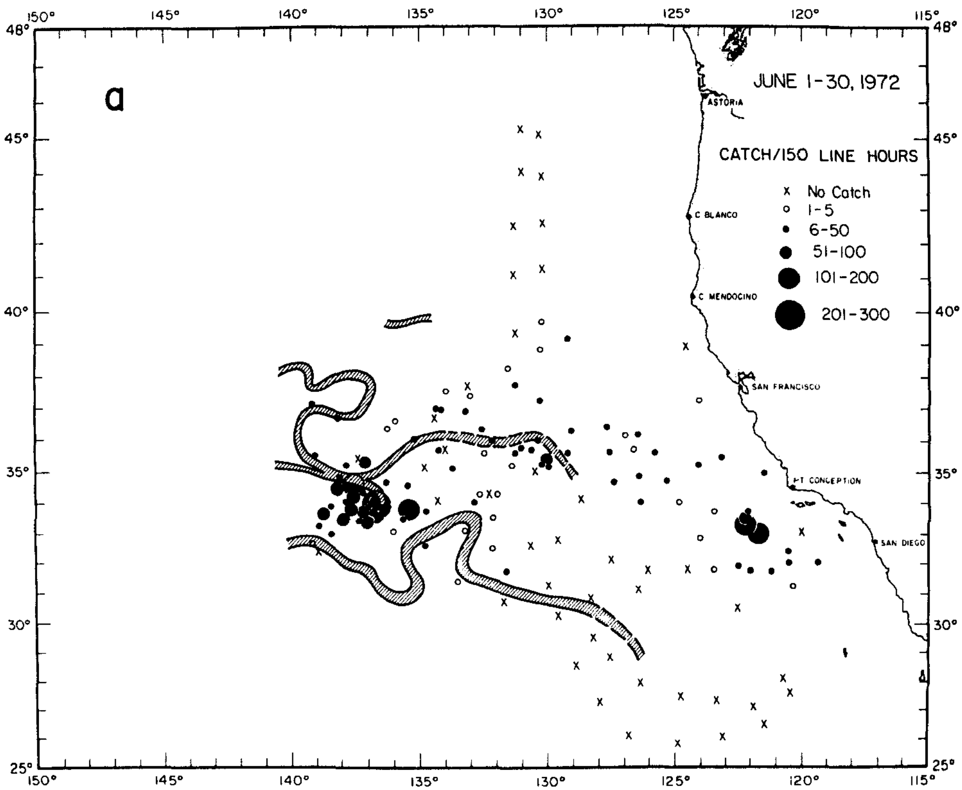
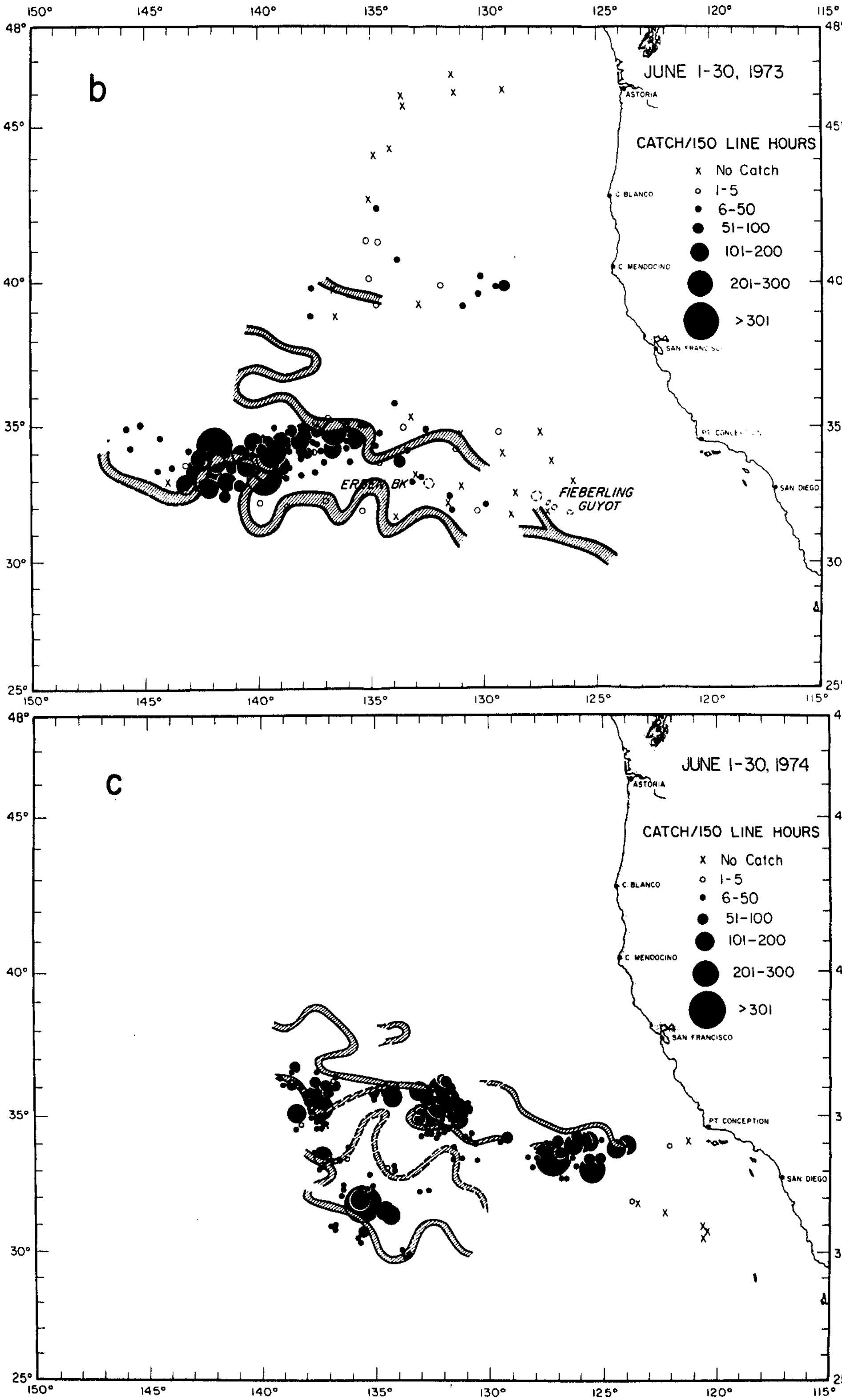


FIGURE 9.—Albacore catch per 150 line-hours by American Fishermen's Research Foundation charter vessels and locations of fronts delineating Transition Zone waters during: a. 1-30 June 1972; b. 1-30 June 1973; c. 1-30 June 1974.


b
JUNE 1-30, 1973
CATCH/150 LINE HOURS
x No Catch
1-5
6-50
51-100
101-200
201-300
>301
ASTORIA
C BLANCO
C MENDOCINO
PT CONCEPTION
SAN DIEGO
ERBEN BK
FIEBERLING GUYOT
c
JUNE 1-30, 1974
CATCH/150 LINE HOURS
x No Catch
1-5
6-50
51-100
101-200
201-300
>301
ASTORIA
C BLANCO
C MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
150°
145°
140°
135°
130°
125°
120°
115°
48°
45°
40°
35°
30°
25°

June 1974; however, one localized area did have sharp, abrupt gradients. The eastward protruding tongue of Transition Zone water centered at lat. 35°30′N, long. 132°30°W had salinity gradients comparable with those found in previous years. Substantial catches of albacore persisted in this one region for a week after which fishing effort was terminated.

Further information on the distribution of albacore can be derived from the catches made by the research vessels (Figure 10a-c).[10] The research vessels trolled for albacore along tracks that crossed the oceanic fronts and expended fishing effort in Central, Subarctic, and Transition Zone waters. With few exceptions, they did not catch albacore in Central or Subarctic waters. In 1972 and again in 1973, when a large meander developed in the Subarctic front, albacore were taken in the northward protrusion of Transition Zone water (Figure 10a, b). Albacore often were found close to the front. During each of the surveys, catches were made by the research vessel as the frontal gradients were being recorded by shipboard instrumentation.

Analyses of variance were performed upon the charter vessel catch data to test the hypothesis that catch rates were dependent upon water mass in the offshore area during June. For the 1972 survey, daily or twice daily XBT casts were matched with the daily catch data. Because specific isotherms were found to fall within very different depth ranges from one water mass to another, the dependence of catch rate upon classes of depth ranges for these isotherms was tested. Thus for this statistical test the water masses may be defined as follows:

Water mass	*Isotherm*	*Depth*
Pacific Subarctic	58°F (14.4°C)	<60 m
Transition Zone	58°F	≥60 m

[10]Catches are expressed in number of fish caught per 15 line-hours in 1972 and 1973 and per 60 line-hours in 1974. These numbers of line-hours approximate the amount of fishing effort expended each day by the research vessels during respective years.

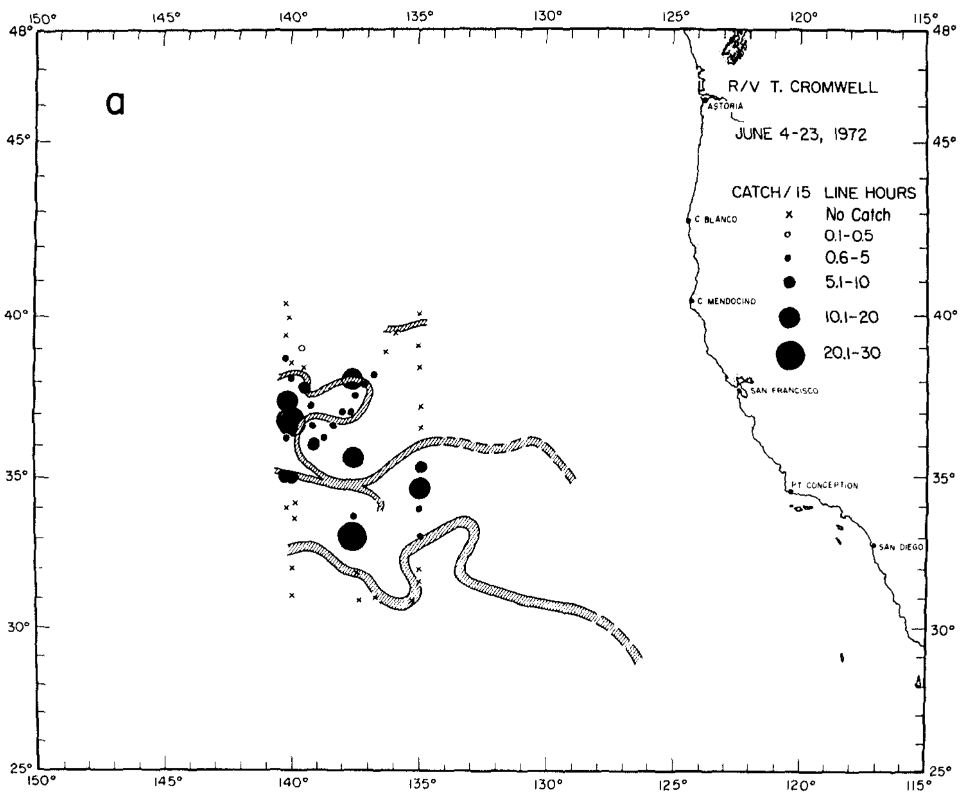
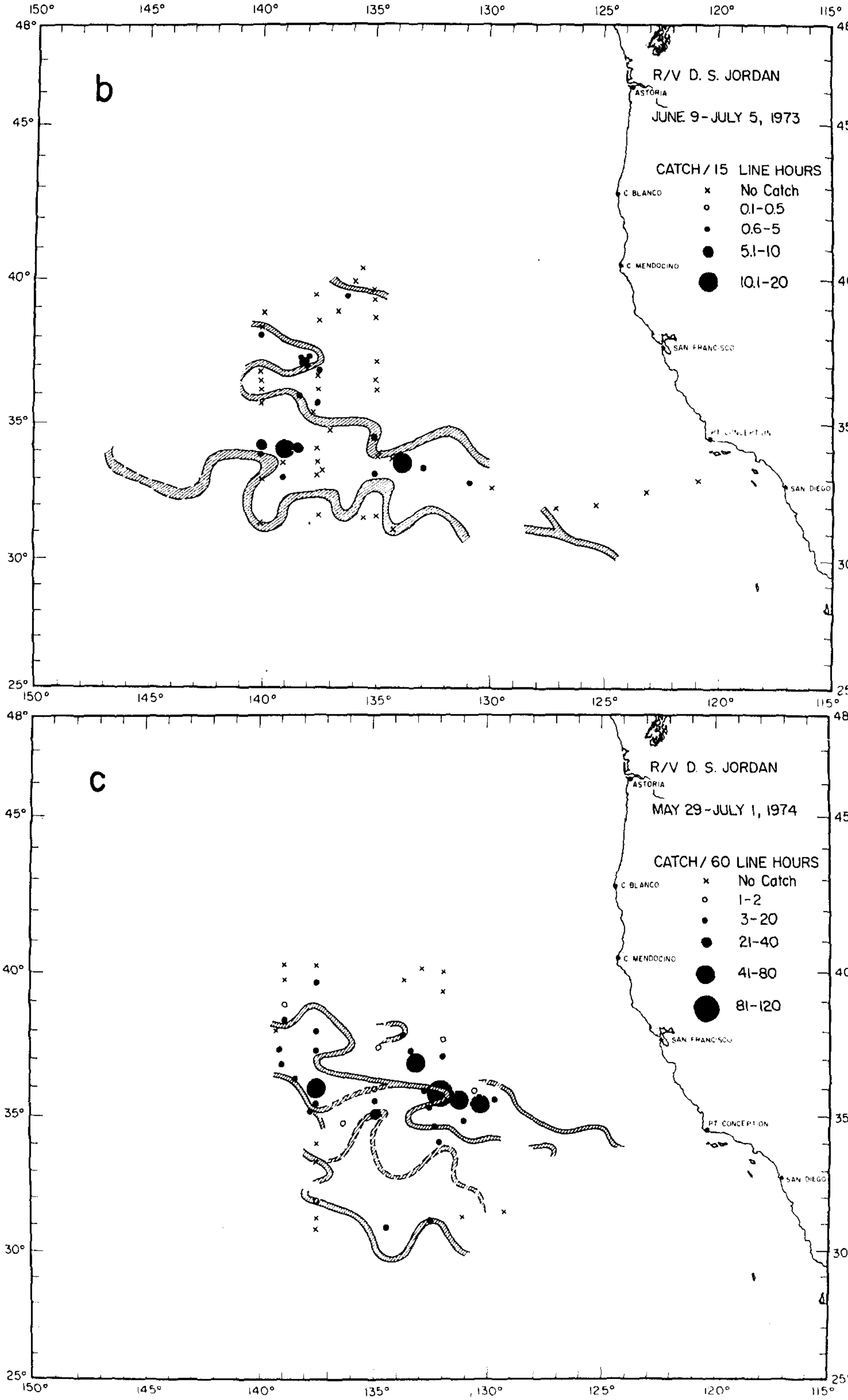


FIGURE 10.—Albacore catch per 15 line-hours by National Marine Fisheries Service research vessel and location of fronts delineating Transition Zone waters during: a. 4-23 June 1972; b. 9 June-5 July 1973; c. 29 May-1 July 1974.


b
R/V D. S. JORDAN
JUNE 9 - JULY 5, 1973
CATCH / 15 LINE HOURS
No Catch
0.1-0.5
0.6-5
5.1-10
10.1-20
ASTORIA
C BLANCO
C MENDOCINO
SAN FRANCISCO
SAN DIEGO
c
R/V D. S. JORDAN
MAY 29 - JULY 1, 1974
CATCH / 60 LINE HOURS
No Catch
1-2
3-20
21-40
41-80
81-120
ASTORIA
C BLANCO
C MENDOCINO
SAN FRANCISCO
PT CONCEPTION
SAN DIEGO
150°
145°
140°
135°
130°
125°
120°
115°
48°
45°
40°
35°
30°
25°

	62°F (16.7°C)	≤90 m
Pacific Central	62°F	>90 m

The data were transformed to logarithms in order to standardize between-sample variance. Results of the analysis of variance show that mean catch in the Transition Zone, which was greatest, is significantly different ($P = 0.01$) from those in other water masses.

For the 1973 survey, both charter and noncharter vessel catches were available for test. The fronts were assumed fixed for this time frame, as shown in Figure 9b, and catches were assigned to a water mass based upon reported geographic position. Because no fishing effort was expended in Central waters, except close to the Subtropic front where catches are expected, an analysis of this division could not be included. Both the charter and noncharter vessel data revealed that mean catches were significantly greater ($P = 0.01$) in the Transition Zone than those in the Subarctic waters.

The poor development of the boundary fronts between water masses during 1974 precludes a definitive assignment of catch to water mass; therefore, a test of the 1974 data was not considered.

Catches made by both the charter fishing vessels and the research vessel during each of the three surveys demonstrate that albacore are distributed within the Transition Zone and may be absent (or unavailable) or nearly so in water masses to the north and south during this phase of their shoreward migration. Relative abundance is high in offshore areas within the Transition Zone waters and at times close to the oceanic fronts that form the boundaries of Transition Zone waters. Further, when the oceanic fronts are diffuse and widely spread there is likely to be a corresponding spread in the distribution of albacore and a dislocation of the centers of high relative abundance.

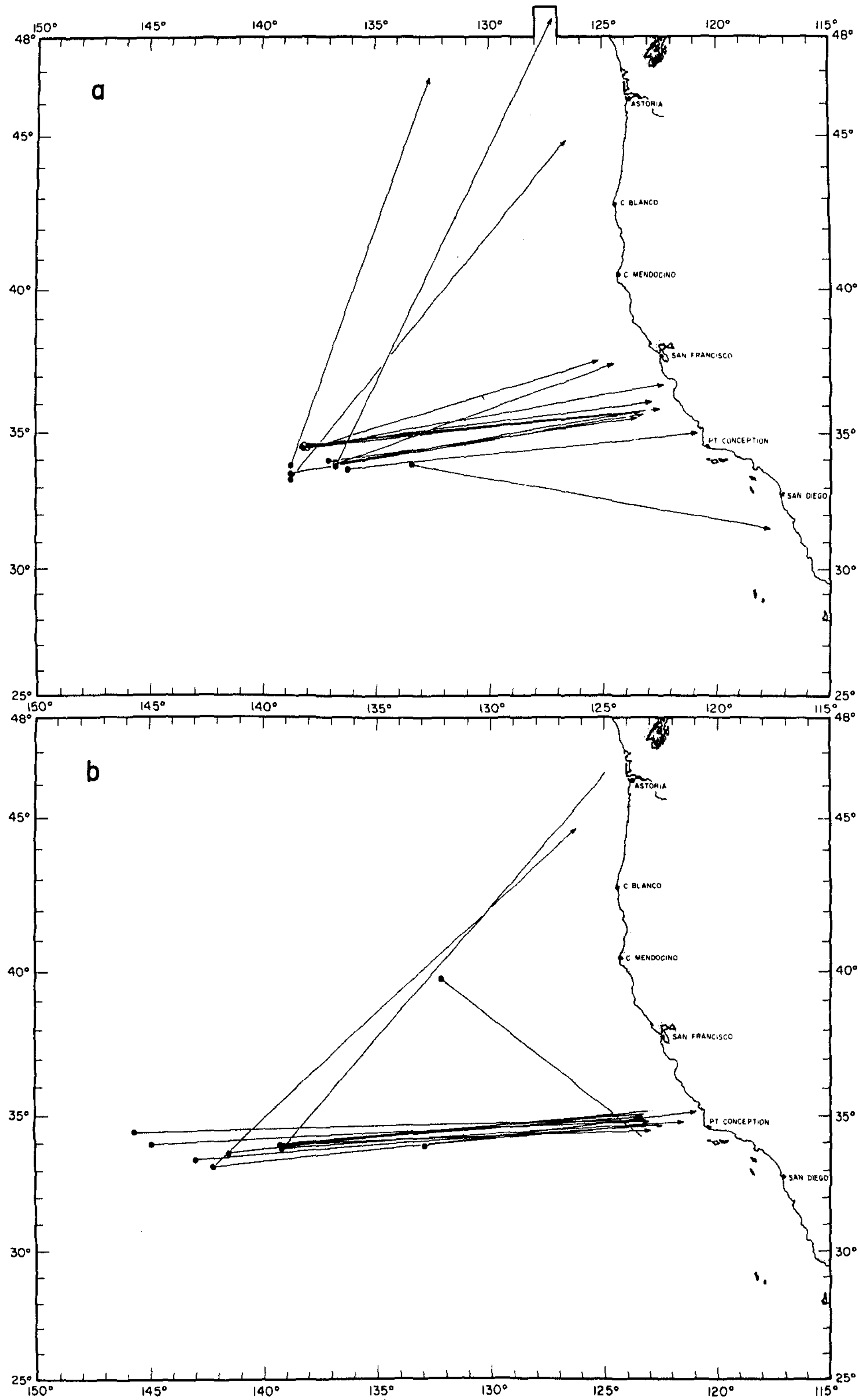
MIGRATION PATTERN FROM OFFSHORE TO NEARSHORE WATERS

We view the general pattern of seasonal migration of albacore into coastal waters where the U.S. fishery traditionally takes place during summer-fall as proceeding in three main stages: First, albacore migrate eastward from central North Pacific regions and form centers of high relative abundance within the eastern sector of the Transition Zone waters 600 to 1,000 mi off the coast. This development initially occurs in late May and June, a time when seasonal warming has raised the surface layer temperature of these waters to values considered to be within the habitat preference for albacore. These concentrations of fish may persist in offshore waters for several weeks. Next, as nearshore waters warm in ensuing weeks, albacore migrate toward coastal regions. Fishing efforts in the intervening zone usually produce only scattered catches, thus suggesting that during the shoreward migration the behavior of the fish is such that they are not available to fishing gear and/or that albacore may not be concentrated. Then, usually by mid-July, concentrations of high relative abundance are found near the coast, often in the vicinity of oceanic fronts related to coastal upwelling. Although variations may occur in this general pattern, the main features of the migration tend to repeat each year. The stages of shoreward migration and initial development of the albacore fishery can be seen in the two series of charts showing nominal catch per unit effort for 1973 (Figures 5a-e, 6a-e).

The shoreward migration of albacore from the central North Pacific into coastal waters appears to continue through the summer months. Albacore trolling experiments conducted from U.S. Navy picket vessels operating approximately between long. 130° and 135°W (Flittner 1963, 1964) showed albacore to be available there throughout the summer. Also, two albacore tagged by the Japanese in the western Pacific (near lat. 35°N and long. 171°E) in mid-June 1974 were recovered in the U.S. fishery in September 1974 (Japanese Fisheries Agency 1975).

Division in Migration Pattern

In order to examine migration of albacore from offshore to nearshore waters, an albacore tagging program was conducted during each of the offshore surveys. Over 4,500 albacore were tagged and released (Table 1). Recoveries of tagged fish made during the same season as released provide information on migration of albacore into nearshore waters (Figure 11a-c). Most recoveries of tagged fish made in 1972 of fish tagged during early season 1972 in waters offshore of long. 130°W were made in central-southern California waters and only a few recoveries were made in Pacific Northwest waters (Figure 11a). A similar recovery pattern was observed in 1973 (Figure 11b). A contrasting recovery pattern was observed in 1974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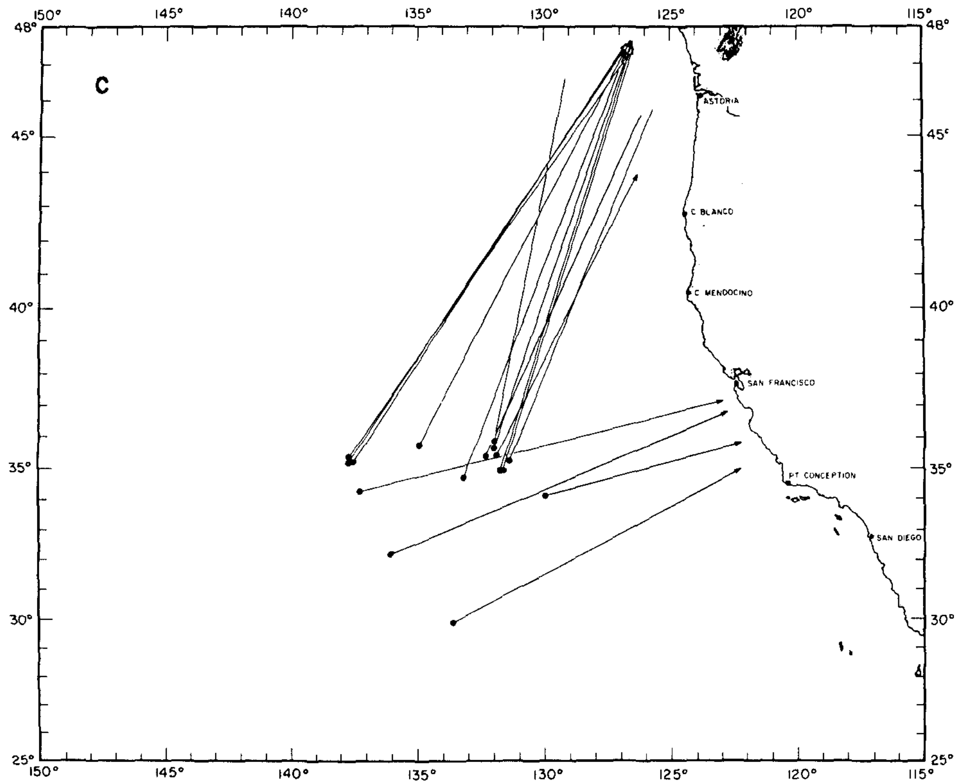

FIGURE 11.—Recoveries made during the same season as release of fish tagged during the early-season surveys in: a. 1972; b. 1973; and c. 1974.

when almost all of the recoveries of fish tagged in 1974 were made in waters off the Pacific Northwest (Figure 11c).

Differences in recovery pattern cannot be accounted for by geographic variations in fishing effort and fish catch. In all 3 yr, 70% or more of the fish caught during the commercial fishery was off the Pacific Northwest. It appears, instead, that differences in recovery patterns could be related to the location where tagged fish were released. In both 1972 and 1973, most of the tagging effort in offshore waters was between lat. 33° and 34°N and in 1974 it was farther north, between lat. 35° and 36°N. The different and divergent patterns apparently are the result of the albacore following different and divergent migration routes toward the nearshore waters. Tagging efforts of 1972 and 1973 and those of 1974 were apparently concentrated upon different branches of the migration. The division in the migration pattern appears to have occurred near lat. 35°N and must have occurred west of, and prior to, the appearance of the fish in the survey region.

Support for this proposed division in the migration pattern of albacore is indicated by differences in length-frequency distribution of albacore caught in the commercial fishery off California and north of California. Differences in size composition of fish caught in 1972 in the two regions (Figure 12 upper and lower) include: 1) the mode of large-size fish was about 5 cm larger in fish caught off California than in fish caught off the Pacific Northwest; 2) the mode of the medium-size fish, which formed the dominant size group in both regions, was 1 to 2 cm larger in fish caught off California than in fish caught off the Pacific Northwest; and 3) occurrence of three modal size groups taken in the fishery off California, but only two off the Pacific Northwest, where the smallest modal size group was absent. Examination of size-frequency distributions for 1973 and 1974 yielded similar results.

The size composition of albacore caught west of long. 130°W by charter vessels in 1972 (Figure 12 lower) was very similar to that for fish taken in the commercial fishery off California (Figure 12 mid-

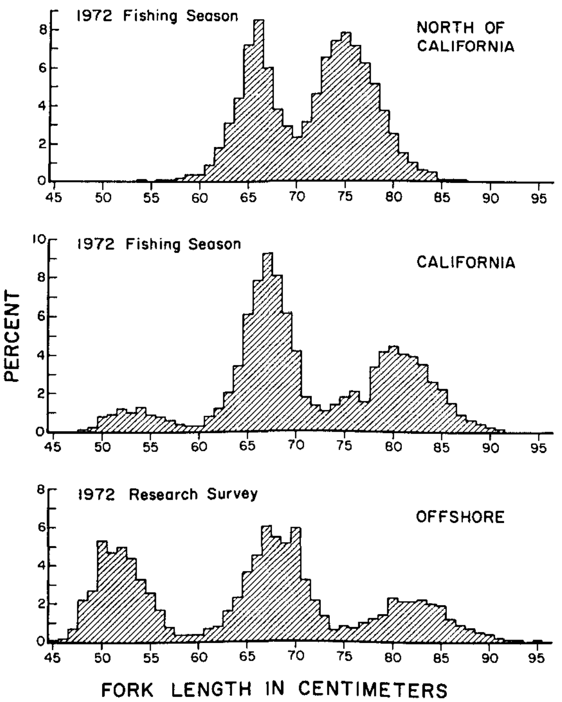

FIGURE 12.—Size composition of albacore caught by U.S. fishermen during 1972 north of California (upper), off California (middle), and size composition of albacore caught during the 1972 National Marine Fisheries Service-American Fishermen's Research Foundation offshore survey (lower).

dle) and hence different from the size composition of fish taken in the commercial fishery north of California (Figure 12 upper). It appears, then, that albacore caught in the offshore region of high relative abundance south of lat. 35°N in 1972 were a part of the migration of fish that reached regions off California.

We interpret the findings concerning offshore-nearshore and north-south geographic variations in size composition as supporting the hypotheses 1) that the fish which compose the fishery off California are separate from those which make up the fishery off the Pacific Northwest, and 2) that these two groups of fish follow different migration routes into nearshore waters.

Movements of Albacore by Size Groups

The size composition data for the 1972 charter vessel catch were stratified into offshore and nearshore regions at long. 130°W and into one 8-day and four 10-day time periods. Graphs of the stratified data standardized by fishing effort for 1972 (Figure 13) show that albacore initially appeared offshore near the end of May and there was an abrupt increase in relative abundance in the beginning of June. A decline in relative abundance was observed offshore after 19 June as centers of abundance shifted to nearshore where there was an increase in early July. Within these overall trends, changes in each of the three modal size groups can be followed. The mid-size modal group (fork length centered about 67 to 69 cm), initially dominated early offshore catches and then diminished in relative importance. It formed almost the entire catch of the first nearshore catches and continued to dominate nearshore catches into July. The large-size modal group (fork length centered about 82 to 85 cm) showed similar trends: a rise and fall in relative abundance offshore and with a subsequent shift to nearshore, but lagging behind the mid-size modal group by one 10-day period. The small-size modal group (fork length centered about 52 and 53 cm) was dominant offshore after 10 June but made little appearance in the nearshore region during the survey. This size group subsequently entered the nearshore fishery, however, as is evident from the size composition of the 1972 fishery off California (Figure 12 middle). An additional geographic division in

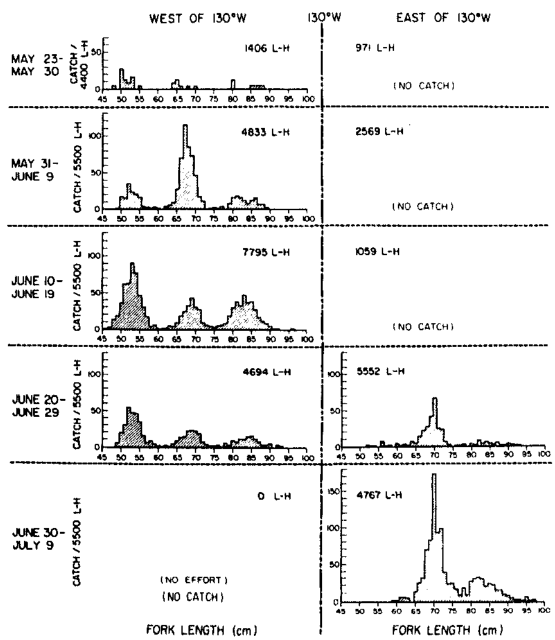

FIGURE 13.—Size composition of albacore caught by American Fishermen's Research Foundation charter vessels in 1972 by time periods and east and west of long. 130°W.

the offshore region, splitting the catch north and south of lat. 35°N showed that the catches first developed south of lat. 35°N and then moved north. By the fourth period (20 to 29 June), the small-size modal group composed almost the entire catch south of lat. 35°N and offshore of long. 135°W.

Several conclusions are evident from these temporal and areal changes in size composition. While catches persisted for up to 4 wk within a 2° by 4° quadrangle of latitude and longitude in the offshore region, changing patterns of size composition suggest that albacore were moving through the region within a period of 10 days or less and that the size groups migrated somewhat independently. The mid-size group, which composes the major portion of the U.S. fishery, led other size groups by 10 or more days. Also, the sequence of compositional changes of each size group and the geographic differences suggest that the migration from the offshore region to the nearshore fishery takes about 20 days or more; at least it did in 1972.

The 1972 catch data were chosen for examination of spatial and temporal changes in size composition because each of the size groups was well represented in the survey catches and all phases of the migration into the fishery are evident, including commencement of the fishery, by the completion of the survey. In 1973 the fishery started late, weeks after the survey, and in 1974 the patterns were less distinct, apparently in response to weak oceanic frontal conditions.

DISCUSSION

Association of Albacore Distribution With Oceanic Frontal Regions

The commercial fisheries on North Pacific albacore and the migration of albacore among these fisheries have frequently been associated with oceanic frontal regions in the western Pacific (Yamanaka et al. 1969; Uda 1973; other works), in the central North Pacific (Shomura and Otsu 1956; McGary et al. 1961), and in coastal upwelling regions (Pearcy and Mueller 1970; Panshin 1971; Laurs 1973; Laurs et al. 1977).

Results of our study provide evidence for the continuity of the association of albacore distribution with the Transition Zone and frontal boundaries into the eastern North Pacific. Catches made by the AFRF charter fishing vessels and the research vessel during each of the three surveys demonstrate that albacore are distributed mainly within the Transition Zone and usually are absent (or unavailable) in water masses to the north and south. Furthermore, our work strengthens the general concept that the distribution and relative abundance of large, highly migratory fish may be markedly influenced by oceanic frontal features. Other studies usually have had to rely on mean ocean conditions and/or statistically averaged fishery data, whereas our fishery and oceanographic data were collected concurrently during several surveys, and the amounts of fishing effort, fish catch, and oceanographic data were substantial.

Relative Abundance of Albacore in the Eastern Sector of the Transition Zone

We have found centers of high relative abundance of albacore in June within the eastern sector of the Transition Zone and often close to its frontal boundaries. Annual and intra-annual areal variations in relative abundance of albacore were observed and appeared to be related to development of the frontal boundaries of the Transition Zone. When the Subarctic and Subtropic fronts were strongly developed, areas of high relative abundance developed within relatively narrow bands in the Transition Zone and persisted for several weeks. When the Transition Zone was broader and the fronts were poorly developed, centers of high relative abundance were found over a larger area within the Transition Zone and did not persist for more than several days in any one location.

Based on scouting results from several research surveys, it appears that the timing and the location of fishing effort may be critical in locating centers of high relative abundance of fish in the eastern sector of the Transition Zone. In 1973, charter vessels first found a center of high relative abundance on 4 June near lat. 34°N, long. 140°W in Transition Zone waters. For several weeks prior to this finding, the AFRF charter vessels had made only scattered catches while scouting in and about this same area. Thus, it seems that the center of high relative abundance appeared in a surge within the first week of June. In 1955, an albacore survey cruise by a single U.S. Bureau of Commercial Fisheries (BCF) research vessel *(Hugh M. Smith)* scouted this area in late May and early June (Graham 1957). Seven longline sets and trolling conducted between lat. 41° and 28°N along long. 139°W resulted in only a single albacore being taken before the vessel departed the area on 5 June. The 1955 scouting effort may have been too early by a matter of days to weeks to locate substantial numbers of fish. In 1957, a BCF fishery research vessel *(John R. Manning)* scouted to the north and east of this area in late June (Callaway and McGary 1959). Small to modest catches of albacore were made by trolling and in gill net sets in and about the Transition Zone, but the area which we have found to have a center of high relative abundance was not scouted.

Extension in Space and Time of U.S. Albacore Fishery

The cooperative NMFS-AFRF albacore research surveys have demonstrated the feasibility of extending the U.S. fishery for albacore in space and time. Albacore were caught by chartered fishing vessels in commercial concentrations considerably farther offshore than where the albacore fishery has traditionally taken place and up to 6 wk prior to the usual beginning of the fishing season. Noncharter commercial albacore fishing vessels, attracted to the early season offshore fishery by the research survey findings, have begun operating in this fishery in increasing numbers.

While fishing results of the AFRF-chartered and the nonchartered fishing vessels indicate that commercial amounts of fish can be caught earlier and farther offshore than the usual fishing season, additional experience is needed to examine the variability of this extension of the fishery, especially in terms of timing and availability, in order to judge properly whether it can provide a dependable contribution to the U.S. fishery. If in the long-run the early season offshore fishery proves viable, its development could be an important factor in reducing annual fluctuations in the catch of albacore. According to Clemens (1962) large annual fluctuations in catch are a prominent feature of the U.S. albacore fishery. Stabilization of catch among years could contribute significantly to the proper utilization and ultimately to the effective management of the resource.

The fishing success by charter and noncharter albacore commercial fishing vessels in 1972-74 is in contrast to an earlier attempt to establish commercial fishing in waters offshore from where the U.S. fishery has historically operated. According to McGary et al. (1961), an unsuccessful gill net and trolling effort was made in the summer of 1958 by a chartered commercial fishing vessel in areas of the central North Pacific where albacore were caught during research surveys conducted in summers of 1955 and 1956. The failure to catch albacore in amounts sufficient to support commercial fishing may have been an accidental event related to intense anomalous oceanic conditions which occurred ocean-wide and affected numerous fisheries in 1957-58 (Sette and Isaacs 1960).

Association of Shoreward Albacore Migration With Transition Zone and Possible Mechanisms

Shoreward Migration and Transition Zone

Based on association of albacore distribution and relative abundance with the Transition Zone and its frontal boundaries, we conclude that the shoreward migration of albacore is linked to the Transition Zone and that variations in the pattern of migration occur in response to variations in the character and development of the Transition Zone and its frontal structure. When the Transition Zone is narrow and its fronts are well developed, as in 1972 and 1973, the migration pattern of the fish is narrow and relatively well defined. In contrast, when the Transition Zone is broad and its fronts weakly formed, as in 1974, the migration pattern of fish is wide and less well defined.

There is also some suggestion that the strength and continuity of the Transition Zone fronts in offshore waters may affect the timing of arrival of fish in nearshore waters. When the fronts are well developed, fish appear to aggregate in their vicinity, resulting in a tendency for the fish to remain in offshore waters for periods of time that delay their arrival in the nearshore fishing grounds. However, when the fronts are weak the fish appear to move through offshore waters with less delay and arrive earlier in nearshore waters. Initial showing of fish in nearshore waters during the years of the surveys supports this speculation. The nearshore commercial fishery and sport fishery off southern California commenced several weeks later in 1972 and 1973 than in 1974.

Possible Mechanisms for Association of Albacore With the Transition Zone

The mechanisms responsible for the relationship between albacore and the Transition Zone and its frontal boundaries may result from a number of factors acting in an interrelated matrix which impacts the fish both directly through physiological means and indirectly through forage availability. We postulate that the factors include, but are probably not limited to: 1) habitat temperature preference, 2) biological productivity, and 3) thermal gradients as they affect the albacore's thermoregulation processes, and that these factors act in an interrelated way superimposed on the innate drive of the fish to migrate across the North Pacific Ocean.

HABITAT TEMPERATURE PREFERENCE. — The distribution and relative abundance of albacore are related to sea-surface temperature (Clemens 1961; Johnson 1962; Panshin 1971; and others). The habitat temperature preference for albacore ranges from approximately 16° to 19°C (Clemens 1961; Laveastu and Hela 1970). This temperature range is found in the upper mixed layer waters of the Transition Zone in spring. Near-surface waters to the south of the Transition Zone are generally warmer than this and those to the north cooler.

The sequence of spring-summer warming of the surface layer along a section between Honolulu and San Francisco during 1972 is illustrated in Figure 14. The Transition Zone boundaries identified by the abrupt changes in depth of isotherms at intermediate depths fall between long. 130° and 140°W. The habitat temperature preference range for albacore (16° to 19°C) is shown with shading. In early and mid-spring (upper left) only the Central waters have preferred temperatures and these waters occur down to a considerable depth, almost 200 m. In subsequent time periods, a shallow sur-

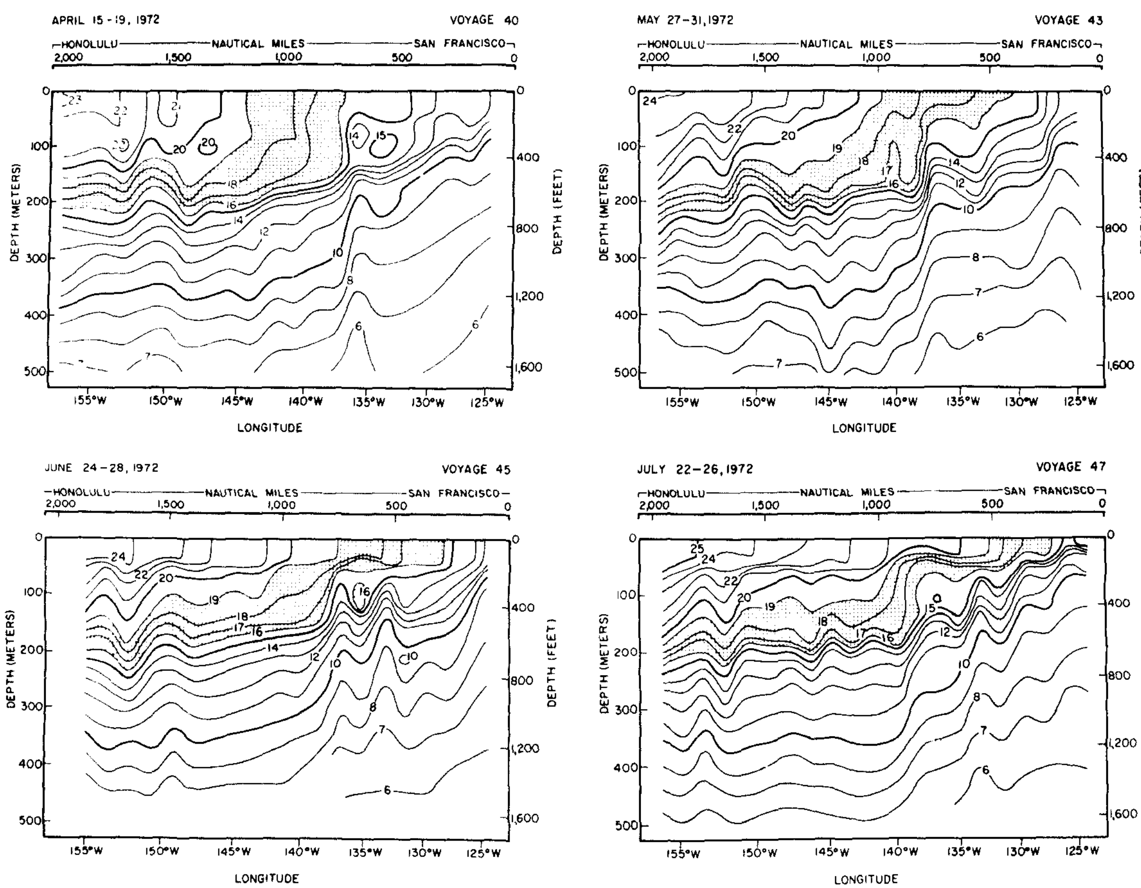

FIGURE 14.—Vertical temperature sections on a transect from Honolulu to San Francisco during April to July 1972. The temperature range between 16° and 19°C (60.8° and 66.2°F) is shaded.

face layer develops and warms to preferred temperatures, initially in the Transition Zone and then in more nearshore waters. It is near the end of May and through June that the preferred temperature range occurs in the Transition Zone and is generally restricted to depths <70 m. The depth limitation of preferred waters greatly improves the vulnerability of albacore to surface trolling gear.

BIOLOGICAL PRODUCTIVITY.—Tagging data show that migration of albacore from the western to the eastern North Pacific is active with an average migration speed of 48 km/day for 78- and 80-cm fish (Japanese Fisheries Agency 1975). This suggests that an albacore requires considerable energy to complete the transpacific migration. Sharp and Dotson (1977) calculated that the caloric expenditure per hour for a swimming albacore 63 cm in fork length is 5.02 kcal/h. They also speculated that fat stores may be an important energy source utilized by albacore for migration. Studies of the food habits of albacore caught during the surveys[11] show that albacore feed actively in offshore waters during their shoreward migration. The composition of the food found in the stomachs is different from that of fish caught in inshore waters (Pinkas et al. 1971, Laurs and Nishimoto MS[12]), but average volumes of food in stomachs from the two regions are similar. Therefore, availability of forage is likely to be an important factor influencing the route of albacore migration.

There are three major oceanic habitats in the North Pacific which are separated by pronounced latitudinal faunal boundaries and steep latitudinal gradients in standing stocks of phytoplankton and zooplankton (McGowan and Williams 1973). These species and biomass boundaries are coincident with the boundaries of the Pacific Subarctic, Transition Zone, and Pacific Central waters (Johnson and Brinton 1963). A northward increasing step-cline occurs among the North Pacific habitats in standing stocks of phytoplankton (Venrick et al. 1973; McGowan and Williams 1973), zooplankton (Reid 1962; McGowan and Williams 1973), and micronekton (Aron 1962), and in primary production (Koblents-Mishke 1965). Zooplankton and micronekton standing stock estimates made during the offshore albacore surveys show similar results with values generally being highest in Subarctic waters, intermediate in Transition Zone waters, and lowest in Central waters.

Since biological productivity is higher in Subarctic waters than in Transition Zone or Central waters, it would be most advantageous from the standpoint of food availability for albacore to confine their migration path to Subarctic waters. However, during spring months the temperature of the Subarctic waters is much lower than the habitat preference for albacore. We conclude, then, that the northern limit of the albacore migration route during spring is determined by ocean temperature and that the limiting temperature is found near the northern boundary of the Transition Zone. The temperature of the upper layer of the Central waters is higher than the habitat temperature preference for albacore, but there are temperatures below the upper layer which lie within the habitat temperature preference for albacore. Thus, temperature could restrict the distribution of albacore from the upper layer but not at some depth interval below the upper layer. We propose that while temperature may play a role in determining the southern limit of the albacore distribution and migration route, the major factor is the abundance and availability of forage organisms which drop off sharply near the southern boundary of the Transition Zone.

OCEAN THERMAL GRADIENTS AND THERMOREGULATION OF ALBACORE.—Thermoregulation processes by albacore may be an important factor in determining their association with the Transition Zone and its frontal boundaries. Thermoregulation is characteristic of tunas and certain other fishes (Carey et al. 1971). According to Neill (1976) for fishes as a group, the only effective means of regulating body temperature is by behavioral regulation of the immediate environmental temperature through locomotory movements.

Computer simulation models developed by Neill (1976) indicate that where environmental conditions are characterized by large expanses of isothermal or nearly isothermal water separated by relatively narrow thermal discontinuities (e.g., oceanic frontal systems), fishes will be relatively concentrated near the discontinuities.

[11]Laurs, R. M., and R. N. Nishimoto. 1973. Food habits of albacore caught in offshore area. *In* Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1973, p. 36-40. (Unpubl. rep.)

[12]Laurs, R. M., and R. N. Nishimoto. Food habits of albacore in the eastern North Pacific. (Unpubl. manuscr.)

Division in the Migration of Albacore Into the American Fishery

Our study indicates that there is a division in the migration pattern of albacore into the American fishery with fish which compose the fishery off the Pacific Northwest and off California following different routes. We believe that the "northern" branch of the migration progresses as described by Powell et al. (1952) who, during an exploratory albacore fishing survey over a region off the Pacific Northwest, found albacore along a warm-water edge that develops seasonally 400 to 500 n.mi. offshore of southern Oregon in late June and early July. The warmwater edge was observed to progress northward and coastward in a bulge or pouchlike pattern as seasonal warming of the surface waters took place over the ensuing weeks. The occurrence of albacore was found to follow the progression of the warmwater zone shoreward and northward along the coasts of Oregon and Washington and by mid-August to waters off the Queen Charlotte Islands, British Columbia. Powell et al. (1952) concluded that these findings, as well as earlier observations, indicated that the main barrier directly or indirectly influencing the distribution of albacore throughout their northern range is water temperature.

Clemens (1961) investigated the onset and movements of the albacore fishery off California and Baja California for the fishing seasons 1951 through 1953. From catch records he found that albacore entered the coastal waters as far south as 200 n.mi. south of Guadalupe Island (lat. 29°N) in some years and as far north as the San Juan Seamount (lat. 33°N) in others. He also presented tag recovery data which showed that albacore move from Baja California or southern California in the early season northward to central California as the season progresses (however, only one recovery of a tagged fish was made off northern California). Clemens concluded that albacore entering the American fishery initially migrate to Baja California or southern California and that longshore movement was the dominant mode of their dispersal into coastal zones to the north. Although he allowed that albacore may reach Oregon and Washington waters by following the seasonal bulge of warm offshore water as suggested by Powell et al. (1952), Clemens stated that a large part of the main body of albacore travel northward up the coast to waters off the Pacific Northwest from Baja California and southern California. No evidence was given for this statement and our newer findings do not support it. We concur that northward longshore movement is important in nearshore waters, but conclude that fish entering waters off Baja California or southern California do not migrate farther north than about San Francisco before leaving the American fishery.

Flittner (1963) presented a schematic diagram of albacore movement off the Pacific coast based on albacore catches made by U.S. Navy picket vessels during 1960-62. The picket vessels, stationed 200 to 500 n.mi. offshore (no farther west than long. 135°W) and spaced at latitudinal intervals of 300 n.mi., each trolled several jig lines from May through October. Flittner said that albacore appeared to congregate within an "optimum-temperature" zone and seem to split into two migratory components. Early arrivals proceed to southern feeding areas and late arrivals turn to the northern area, each movement depending upon the progression of seasonal warming.

Progression of seasonal warming continues to appear to be an important factor affecting paths of albacore migration. However, influence of the Transition Zone development and the division of migration pattern described here add considerable complexity to earlier ideas. Our findings suggest that events in offshore waters are important in determining the distribution and relative abundance of albacore in coastal waters.

Pacific Northwest and California Groups of Fish

Based on offshore-nearshore and north-south geographic variations in size composition of albacore we postulate that the group of fish which compose the albacore fishery off California are separate from those which make up the fishery off the Pacific Northwest. Brock (1943) arrived at a similar conclusion after comparing length-frequency distributions of albacore landed in San Pedro, Calif., and Astoria, Oreg. Brock found differences in size composition and stated, "This would argue that the schools of fish off the Oregon coast were not a part of the schools appearing off the California coast, even though, as indicated above, the two groups may have had a common origin. . . The time of arrival of fish and their abundance as shown by the monthly commercial catch for the ports discussed here (San Pedro and Astoria) make it seem likely that at least two separate groups of schools invaded the coastal area, one in the north off Oregon and the other in the south off southern California."

Results of studies on the artificial radionuclide ^{60}Co in albacore provide additional evidence that the "northern" and "southern" groups of fish are independent. Krygier and Pearcy (1977) found that the peak activity levels of ^{60}Co in albacore off Oregon occurred a year earlier than the peak activity levels seen by Hodge et al. (1973) off southern California. According to Krygier and Pearcy, the heaviest fallout input of ^{60}Co into the North Pacific occurred at about lat. 40°N. They speculated that due to circulation in the North Pacific, albacore which were associated with waters north of lat. 35°N could have experienced high levels of ^{60}Co up to a year before the tuna associated with waters to the south. They concluded that, "Circulation in the North Pacific and the latitudinal differences in the location of the two portions of the albacore population [as proposed by Laurs and Lynn in this paper] appear to be a plausible explanation for the difference of 1 yr in activity peaks between albacore caught off Oregon by us and those off southern and Baja California by Hodge et al. (1973)." Thus, strong evidence from several independent sources points toward two separate groups of albacore following separate migration paths.

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