OCEANOGRAPHY AND NORTH PACIFIC ALBACORE

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The purpose of this presentation is to summarize briefly the Honolulu Biological Laboratory's (HBL) oceanographic studies in the North Pacific and the oceanographic features with which are associated albacore distribution and abundance. These studies were begun in 1954 following two rather significant developments. On the negative side, the Washington and Oregon landing had fallen from a high of 34 million pounds in 1944 to less than a million pounds in 1953. On the positive side, at least scientifically, recoveries of albacore tagged with the "spaghetti" tag (Wilson 1953) had clearly demonstrated that the albacore could and did migrate from the American to the Japanese fishery (Ganssle and Clemens 1953), thus giving evidence that the oceanwide stocks are interrelated.

The HBL oceanographic and biological surveys north of Hawaii were planned to determine (1) the geographical limits and relative abundance of albacore and (2) the relationship, if any, of these to the environment, as described by oceanographic data. These studies were coordinated with those of the other research agencies through an informal Albacore Steering Committee composed of representatives of the Bureau of Commercial Fisheries and the States of Washington, Oregon, and California.

Three years were alloted for exploratory cruises to determine the distribution of albacore in the North Central Pacific, and three for the study of their abundance, migrations, and seasonal fluctuations in abundance. The latter effort was based on the premise that concentrations of commercial potential would be found. The results of a commercial charter in 1958 were disappointing, primarily because the locations of commercial concentrations of albacore are subject to large annual variations.

The major portion of both the fishing and oceanographic efforts have been to the west of 140° W. longitude. Cruises have, however, been made to the coastal areas in cooperation with other agencies and as part of our studies of the geographical and seasonal limits of albacore and their migration routes. There has been at least one complete systematic fishing survey, with limited oceanographic observations, of the area north of the Hawaiian Islands from 180° to the west coast of North America during each season of the year.

Both the oceanographic features and the summer distribution of albacore indicate that the area can be divided at about 150°-135°W. longitude, and we will follow this division in our discussion.

Figure 1 shows the extent of our oceanographic coverage to the west of 140°W. All the cruises were made in summer or winter with the exception of one made during the 1954 September-November period.

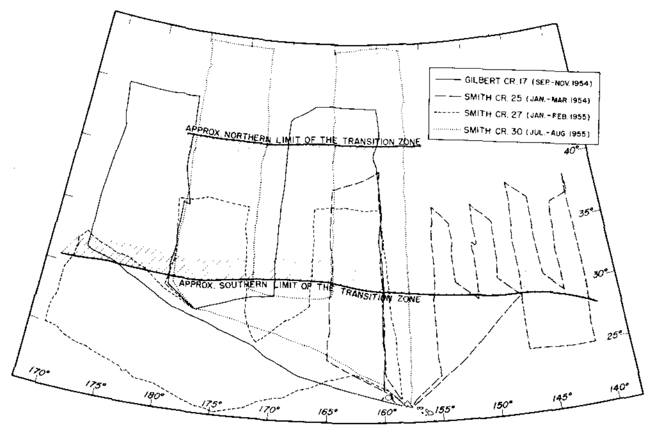

FIGURE 1. Tracks of four HBL oceanographic cruises to the central North Pacific.

Figure 1 is from an earlier paper (McGary et al., 1958) in which the oceanographic features were reviewed in a discussion of the possible enrichment patterns of the area. In that report the term "Transition Zone" was used to refer to the area in which the water characteristics changed from those typical of the two central North Pacific Water masses to those of the Subarctic Water mass. It was used because the authors preferred to avoid the use of the term "Polar Front", which implies a single, abrupt change. Oceanographic data showed, instead, a series of small but frequently abrupt changes. Furthermore, the large seasonal migration attributed to the Polar Front was only apparent in the surface temperature field. The zone of most abrupt change observed in winter at about 35°N. is not comparable in structure or origin to the similar zone located farther north during summer at about 43°-46°N.

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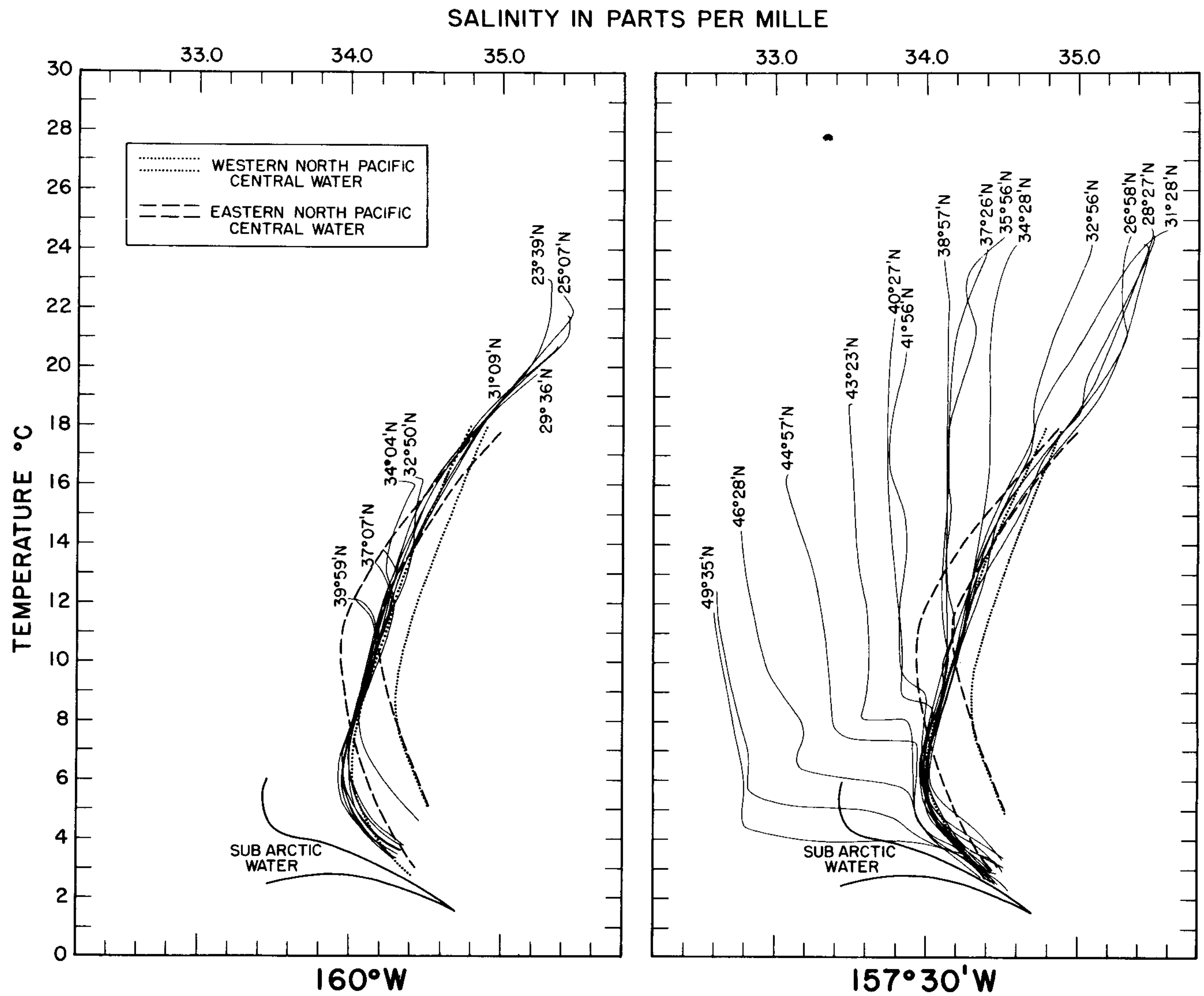


FIGURE 2. LEFT PANEL—superimposed temperature-salinity curves for the meridional station series along 160°W. longitude *Hugh M. Smith* cruise 25, January 1954. RIGHT PANEL—same along 157°W. longitude *Hugh M. Smith* cruise 30, August 1955 (McGary et al. 1958).

The temperature-salinity curves (fig. 2) from HBL winter and summer cruises, in the vicinity of 160°W., show the features used in a preliminary definition of boundaries, as well as the effect of seasonal temperature changes in the surface portion of the curves. Those from *Hugh M. Smith* cruise 25, January 1954, (McGary and Stroup 1956), show an abrupt shift in the T-S characteristics of the surface waters between 31°09′N. and 32°50′N. Shifts in the T-S curves continued northward and corresponded to areas of relatively large geostrophic currents. The position of the northern boundary cannot be defined with confidence, since this cruise did not extend far enough north to reach Subarctic Water. T-S curves from *Hugh M. Smith* cruise 30 (NORPAC)[3] (McGary et al., 1958; Hidâ 1957) shows two regions of abrupt shift in the surface portions of the curves. The most abrupt shift occurred between 32°56′N. and 34°28′N. Farther to the north another such shift occurred between 41°56′N. and 43°23′N. North of that latitude, the shifts were large but were uniform latitudinally. At 43°23′N. and northward, a salinity minimum was present at the surface, which is in keeping with the definition of Subarctic Water (Sverdrup et al., 1942, p. 722).

The salinity cross sections were examined and boundaries roughly set by the following criteria (see fig. 3). The southern boundary was set as the northern limit of the area within which the warming during all seasons was sufficient to maintain a lens of high salinity water at the surface. The northern boundary was taken as the southern extreme of the area in which the lens of low salinity water, from precipitation or other sources, was sufficient to withstand the effects of winter cooling or was not mixed

[3] NORPAC was the code name given to a quasi-synoptic oceanographic survey of the North Pacific during the summer of 1955 by research agencies of Canada, Japan, and the United States.

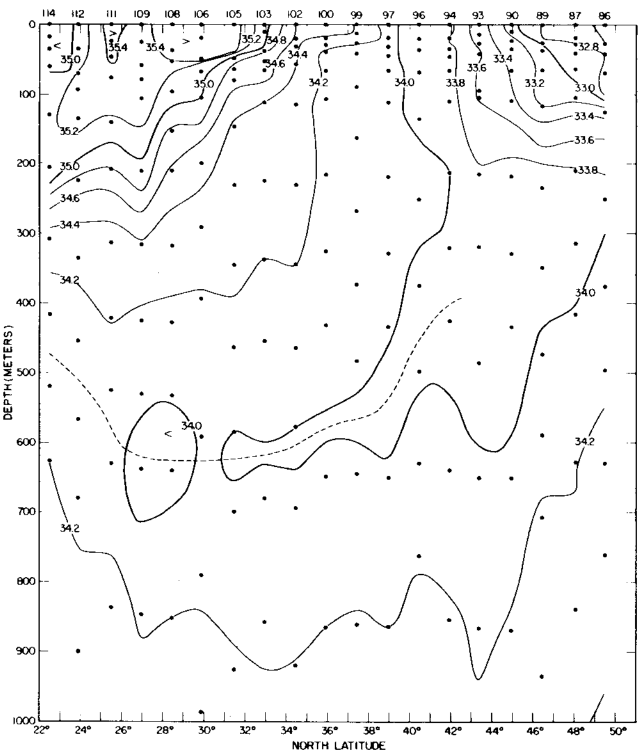


FIGURE 3. Salinity cross section 157°30'W., *Hugh M. Smith* cruise 30, August 1955.

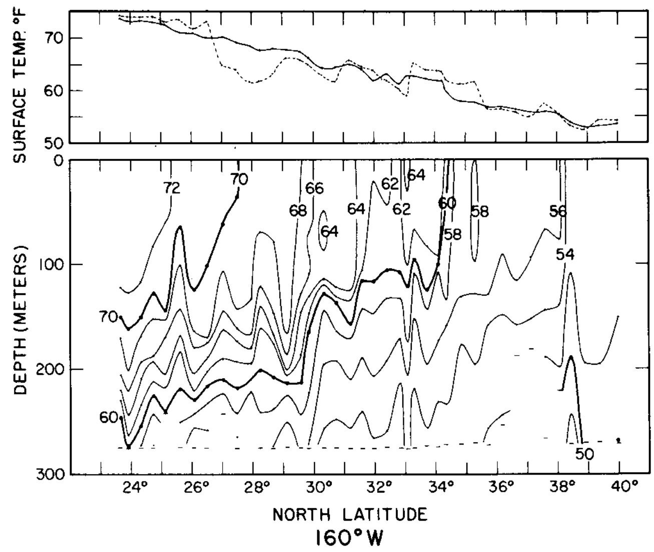


FIGURE 4a. Temperature section from BT casts along 160°W., *Hugh M. Smith* 25, January 1954. Broken line in upper panel shows surface air temperature.

sufficiently with more saline water to the south to cause it to sink even during winter. The limits of the Transition Zone shown in figure 1 were drawn on this basis. The differences in the sections for the various seasons showed, as expected, that the southern limit was 1°-2° of latitude farther south in winter than in summer. Only summer data were available to the north but no doubt the northern limit shifts to the north in winter, since cooling would break up the shallow southern limit of the lens.

Comparison of the longitudinal sections from *Hugh M. Smith* cruise 25 (January-March 1954) showed that boundaries and sharp changes in the T-S curves became less distinct from west to east (Stroup and McGary, 1956).

Reports by Japanese oceanographers suggest that the Transition Zone extends westward to the area immediately off Japan and that it narrows to the west. Uda (1943) described a double frontal system in the Kuroshio, and Masuzawa (1957) discussed the structure in more detail. The latter reported the width of the "Frontal Zone" between the warm and cold water to be 200-300 miles within about 500 miles of the coast. In general, he stated that the "Polar Frontal Zone" shows particularly predominant discontinuities along both the northern and southern edges. He also found that the northern edge was not as well defined as the southern edge.

The surface and vertical temperature distributions typical of the Transition Zone are shown in figure 4. The contrast between the summer and winter profiles shows the effect of seasonal heating and cooling. During both cruises the subsurface isotherms rose abruptly, e.g. 60°F., in the vicinity of the southern limit of the Transition Zone. In winter, the northern limit of this ascent marked the beginning of the zone with little or no distinct surface layer; in summer, it marked the beginning of a very shallow surface layer with an extremely sharp thermocline. At the northern limit of the Transition Zone, the 50°F. isotherm marked the boundary of a distinct difference in the subsurface structure; to the north it marked the beginning of an area with frequent small inversions below the thermocline. The surface temperatures of both seasons showed a striking coincidence in the temperature range at which the greatest horizontal gradient occurred: on both sections inspection showed it was between 56° and 68°F. with the maximum usually occurring between 58° and 62°F. Inspection of other transects shows that this is true of all seasons of the year, both in the central and eastern Pacific (Shomura and Otsu, 1956; Graham, 1957). In spring, the zone of surface temperature discontinuity is associated with the development of the shallow thermocline and its northward advance as summer approaches. It also coincides with the southerly movement of the breakup of the shallow warm surface layer in fall and winter.

Hida (1957), in a study of the distribution of chaetognaths and pteropods in the North Pacific, found that these oceanographic divisions coincided with faunal divisions and, in fact, the term "Transition Zone" in the sense used here was introduced in his report. Jones (McGary et al., 1958), in a study of copepods, found that the formation of the warm surface layer apparently offered favorable conditions for phytoplankton blooms, followed by an increase in zooplankton standing crop. However, the latter was not characterized by a meridional advance of tropical species, but rather by the development of "blooms" of eurythermal forms such as *Calanus helgolandicus* and *C. tonsus*.

It cannot be ascertained from the data at hand whether (1) the distribution of albacore is controlled directly by surface temperature (presumably through physiological mechanisms) or whether (2) the distribution of albacore is related only indirectly to surface temperature through the seasonal march of events leading to a large standing crop of forage organisms. In rebuttal to the hypothesis of direct relationship, data from other areas do not always show the same albacore-temperature relationship, and within the survey area uniform distribution with temperature did not occur from area to area or season to season. In rebuttal to the forage hypothesis, the seasonal movement of the biological frontier coincided with the movement of the isotherms, but it did not indicate the presence of albacore in all seasons nor in all parts of the survey area.

In figure 5, the total catch of albacore is shown as the percentage of the catch made at different surface temperatures. The total catch includes all of the albacore taken by HBL in the central Pacific by troll and gill net during all seasons. For comparative purposes, similar examples from the east and west have been included. The curve shows that the central Pacific catches were made within a narrow temperature band, with a dominant mode between 58° and 60°F. The overall range may be narrowed to about 55°F-66°F., since almost all of the catches at temperatures below 55°F. were made in the fall immediately after periods having winds of Force 6 or greater and it was evident that the area had experienced a recent sharp temperature decline because of wind-induced overturn (Shomura and Otsu 1956, Graham MS[4]). The *Cobb* data are typical of the fishery which frequently develops off the coast of British Columbia, Washington, and Oregon during the late summer (Powell and Hildebrand, 1950) and indicate that the albacore occur in the same narrow temperature range as in the central Pacific. The *Jini Maru* plot was constructed from data collected in the spring live-bait fishery off Japan during a cooperative tagging program conducted in the spring of 1956 by the Japanese Fishery Agency and HEL (Van Campen and Murphy, 1957). These data are representative of this fishery. Here, the temperature range and mode are even more sharply defined than in the other two plots. These conditions

[4] J. J. Graham, "Macroecology of the albacore, **Thunnus germo** (Lacepede), in the central North Pacific" MS.

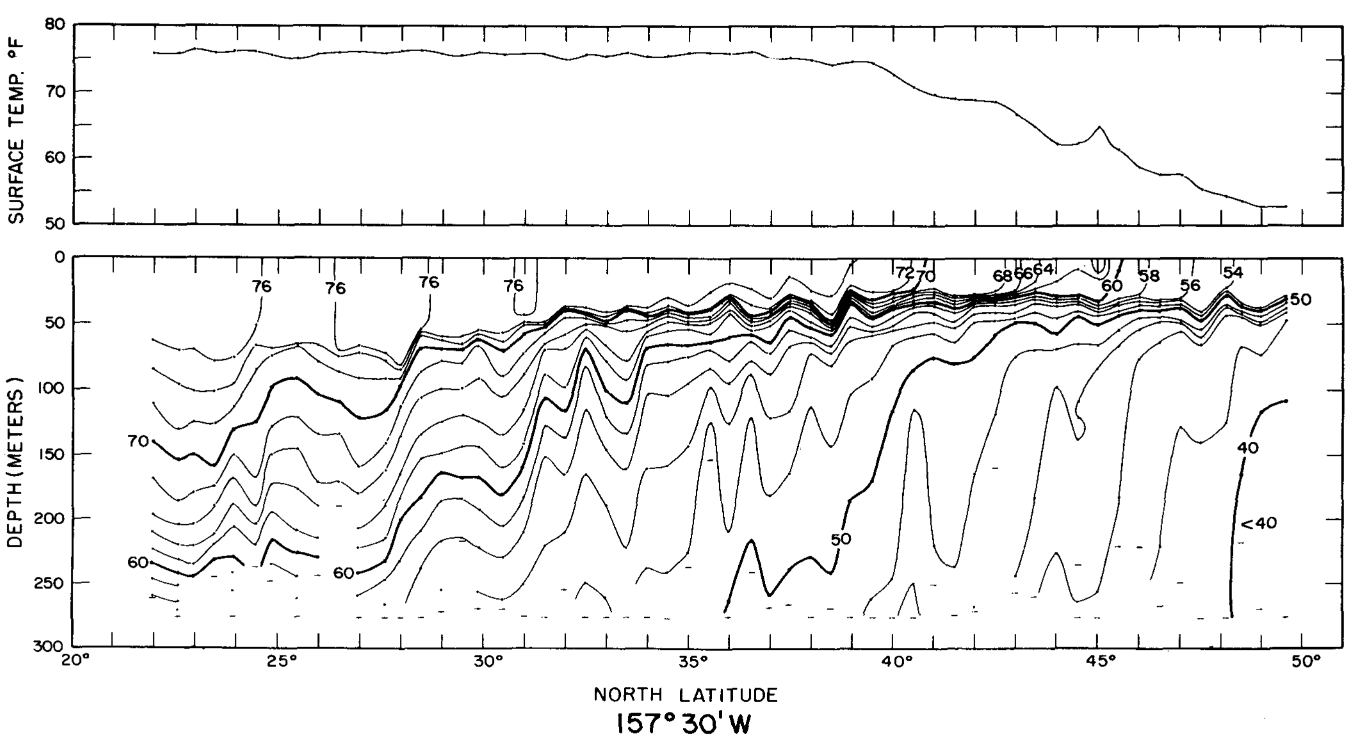


FIGURE 4b. Same along 157°30'W., *Hugh M. Smith* 30, August 1955 (McGary et al. 1958).

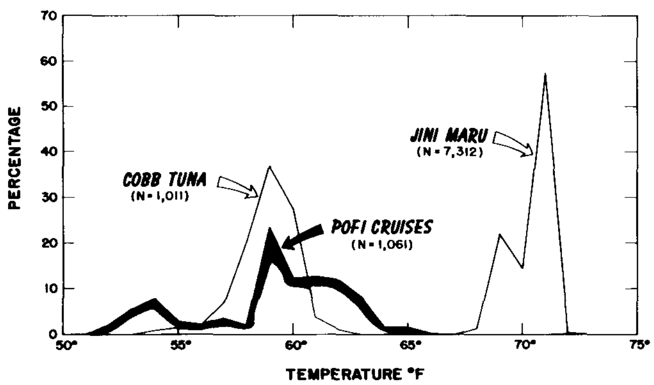


FIGURE 5. Percentage of albacore catch versus temperature of catch.

arise in part from the fact that the *Jini Maru* was engaged in commercial fishing and an effort was made to stay with the maximum concentration of fish. However, in spite of the fact that the general oceanographic features of the area indicate that the *Jini Maru* data were taken in the western extremity of the Transition Zone, the temperature range does not even overlap that of the central and eastern Pacific.

A discussion of the seasonal distribution of albacore will serve to illustrate the use and limitation of temperature as an indicator of the areas in which albacore might be expected to occur. Beginning with winter, a comparison of the catches of *John R. Manning* cruise 19 along 160°W. (fig. 6) during January 1954 with the temperature profile from *Hugh M. Smith* cruise 25 (see also fig. 4a) shows that the deep swimming albacore captured on longline gear occurred in an area having surface temperatures of 56°-66°F. and just south of the point where the largest horizontal temperature gradients occurred.

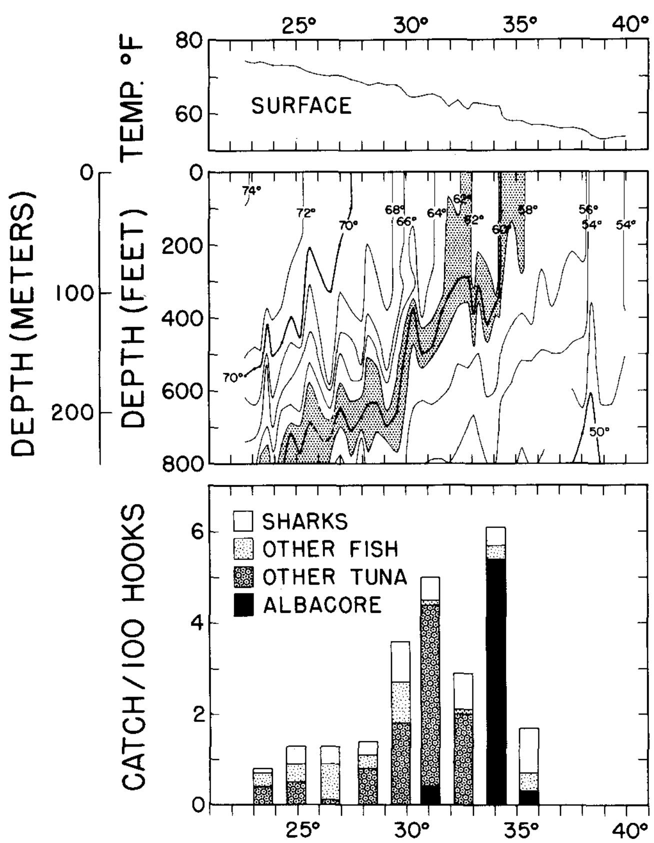


FIGURE 6. Vertical temperature profile, *Hugh M. Smith* cruise 25, January 1954 and longline catch/100 hooks, *John R. Manning* cruise 19, January 1954, along 160°W. longitude.

Figure 7 shows the winter distribution of albacore in the eastern North Pacific as indicated by the surveys of 1955 and 1956 and the Japanese winter fishery. It shows quite clearly that the latitudinal limits are almost coincident with the southern boundary of the Transition Zone (fig. 1) and the temperature front (fig. 4 and 6) and are not associated with the subtropical convergence as originally hypothesized. The dynamic topographies from the 1954 and 1955 winter cruises indicate that the subtropical convergence was in the vicinity of 24°-27°N. during both years (McGary and Stroup, 1956 and 1958). Suda (1958) also described the subtropical convergence as an area of minimal albacore catch in the western Pacific.

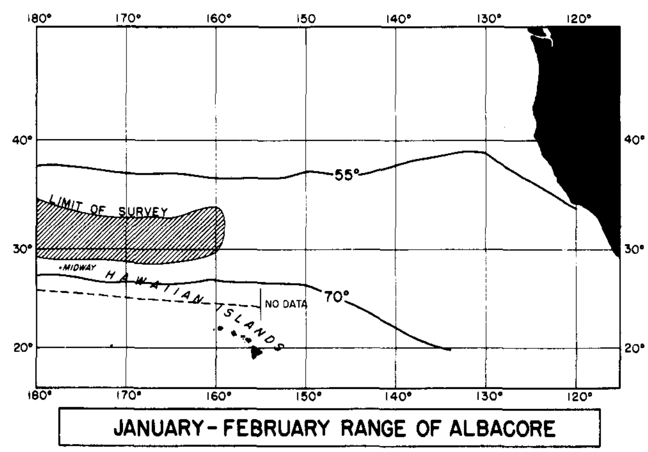


FIGURE 7. Winter distribution of albacore in the eastern North Pacific. Dashed lines indicate position of Subtropical Convergence from *Hugh M. Smith* cruises 25 (January-March 1954) and 27 (January-February 1955).

Our spring cruises (1955 and 1956) showed a conspicuous band of phytoplankton and zooplankton abundance in the 55°65°F. surface temperature range between 180° and 140°W. There was an abundance of forage organisms and a rich phytoplankton bloom was indicated by the Forel color of the water, but few albacore were caught. Only one was taken east of 170°W., and only a few scattered fish to the west of 170°W. on all three types of gear (troll, longline, and gill net).

During the fall of 1954, 1955, and 1956 albacore were taken in considerable quantities from offshore of San Francisco to 170°E. longitude, the western limit of the survey area. They were taken in waters with surface temperatures between 55°F. and 65°F., with the peak catches ocurring in the 58°-60°F. range.

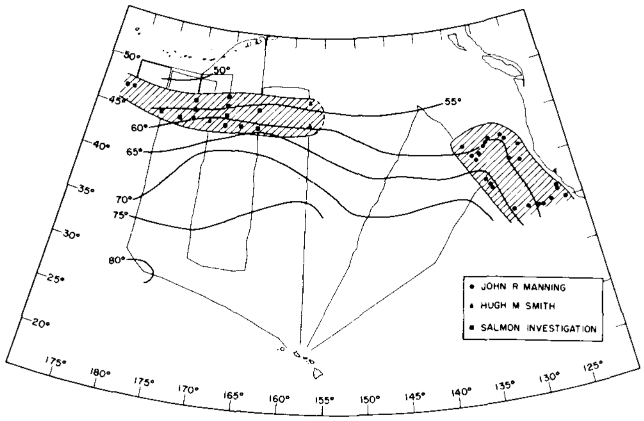


FIGURE 8. Location of albacore taken in the North Pacific by exploratory vessels, July-September 1955.

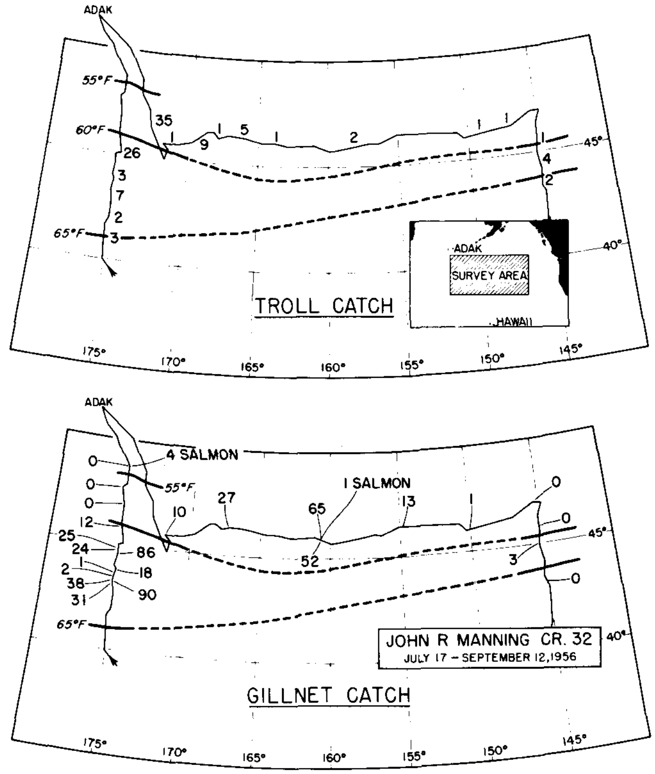


FIGURE 9. Summer 1956 albacore survey, *John R. Manning* cruise 32.

Again, this temperature appeared to coincide quite well with the biological frontier.

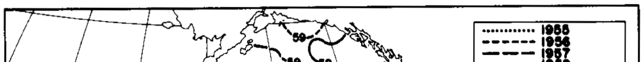
During the summer of 1955, because of NORPAC and the activity of the North Pacific Salmon Investigations, there was excellent coverage between 175°E. and the west coast of North America. The results showed two interesting features. Firstly, the albacore were divided into two groups, one in mid-ocean extending as far east as 155°W. (fig. 8) and the other extending northwest from the California fishery. The existence of the area of albacore scarcity has been at least partially verified in all subsequent summer surveys. Secondly, comparison of figure 4 and figure 8 shows that the mid-ocean albacore were in a shallow surface layer in Subarctic Water (figure 2) and at about the same surface temperature range as during the other seasons. The *J. R. Manning* returned to the area in 1956 and found a similar situation (fig. 9) with an even more pronounced biological frontier indicated by the plankton abundance and light penetration readings. In 1958 the 1955 and 1956 summer surveys were followed up by a commercially unsuccessful gill net effort from the chartered vessel *Paragon*. Again the fish were found in the warm layer in the southern limits of Subarctic Water, but the center was 3°-4° farther south, and the standing crops of plankton and forage were much less than observed at corresponding temperatures for the previous years.

The hydroptic charts for the mid-August period for the past four years illustrate the amount the temperature field can shift in mid-ocean and the radical changes in local temperature that result. The lower panel, figure 10, shows the variation in location of the 55° to 66°F. surface temperature band that approximates the limits of albacore distribution. As a result of such variations, annual differences of up to 10°-12°F. can occur at a given locality. This could make considerable difference in the development of the seasonal plankton cycle in the area, particularly when one considers that the average seasonal range in temperature is only 15°F. The upper panel shows the latitudinal changes in the temperature range that corresponds to the peak of the albacore abundance in the central and northeastern Pacific. It illustrates the small amount of latitudinal change necessary to produce the 10°-12°F. temperature anomalies.

The existence of a "tongue" of albacore extending northwest from the California fishery in 1955 (fig. 8) and the work of Powell and Hildebrand (1950), Powell et al. (1952), Shaefers (1951), and Partlo (1950) suggest conditions under which the Pacific Northwest fishery develops. First, albacore may be present in the summer off the northwest coast during all years but move into and concentrate in the coastal waters of British Columbia, Oregon, and Washington only when oceanographic conditions (exact nature unspecified) are favorable. Second, the extent in time and space of the coastal band of upswelling may also influence the development of the fishery and limit its shoreward extent.

During the last 10 days of July 1957, nine chartered commercial trollers and two HBL vessels made a synoptic survey of the distribution and abundance of the albacore in the coastal area between 35°N. and 47°N. The results of the survey (fig. 11) showed that these fish were present in a wide band along the coast. In the northern part of the survey area, albacore were most abundant offshore of the area of largest surface temperature gradient which indicated the outer limit of the band of upwelling (fig. 12). However, their distribution was far from continuous and was not completely associated with any feature of the boundary, such as the tongues of relatively warm water which penetrated shoreward.

The radical annual temperature differences shown in hydroptic charts of the coastal areas (fig. 10) might



AUGUST 11-20 SURFACE ISOTHERMS

FIGURE 10. LOWER PANEL—mid-August mean and 1955 through 1958 positions of the 55° and 66°F. isotherms; UPPER PANEL—mid-August mean and center of the 58°-60°F. isotherms for 1955 through 1958.

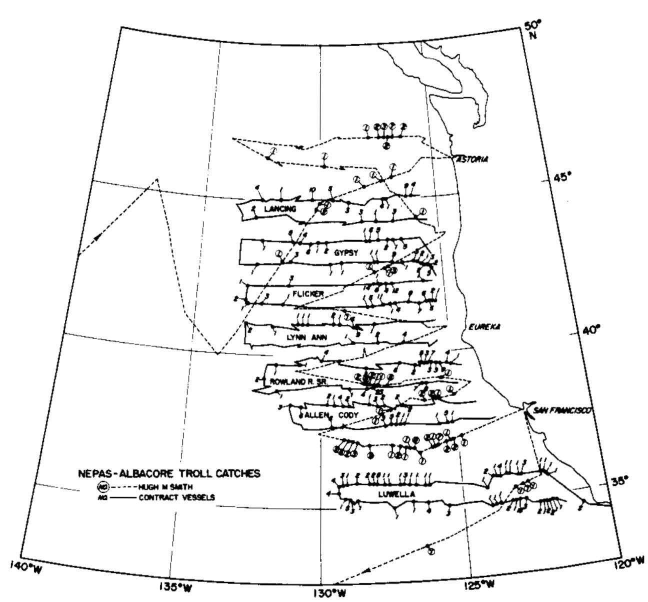


FIGURE 11. NEPAS (Northeastern Pacific Albacore Survey) troll catches, July 1957.

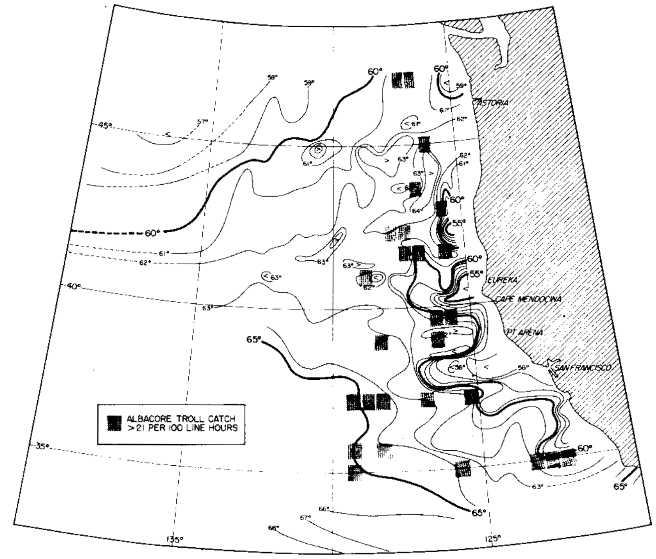


FIGURE 12. NEPAS surface temperatures and best albacore catch rates.

also account in part for the yearly fluctuations in the landings of the California fishery as well as the radical fluctuations in the Pacific Northwest fishery. The charts show that suitable temperature conditions for albacore may in some years occur as far north as Kodiak Island and lend credence to reports of albacore in the Gulf of Alaska in 1957 and 1958.

Not all of our efforts have been confined to exploratory fishing work. Results from our tagging experiment, literature research, and age, growth, and spawning studies have given us a reasonably plausible picture of albacore migration routes in relation to oceanographic features. One thousand two hundred and six albacore have been tagged. In addition, we have helped establish a tagging experiment in the Japanese live-bait fishery. Figure 13 shows the points of release and recapture of our 16 returns. It shows migration from the mid-ocean area to both the American and the Japanese fisheries and movement from the American to the Japanese fishery. Recoveries from California Fish and Game tag releases (Ganssle and Clemens 1953) also show this latter movement. Japanese tag returns (K. Mimura, personal communication) have shown rapid easterly movements within their spring live-bait fishery. On the basis of these returns, the oceanography, our spawning and growth studies (Otsu and Uchida, 1959a and b), and Suda's (1958) paper on migration within the Japanese fishery, we have arrived at the somewhat incomplete pattern of albacore migrations shown in figure 14. Here we show an easterly spring and summer migration along the 55°-65°F. temperature frontier in the Transition Zone and a westward migration along it in the fall and winter. The lack of an apparent connective link between the two segments of the eastern migration may be because the Japanese tagging experiment has only begun recently. Also, their tagging has been primarily in their live-bait fishery, which, in general, takes larger fish than the American west coast fishery. The postulated spawning area is located

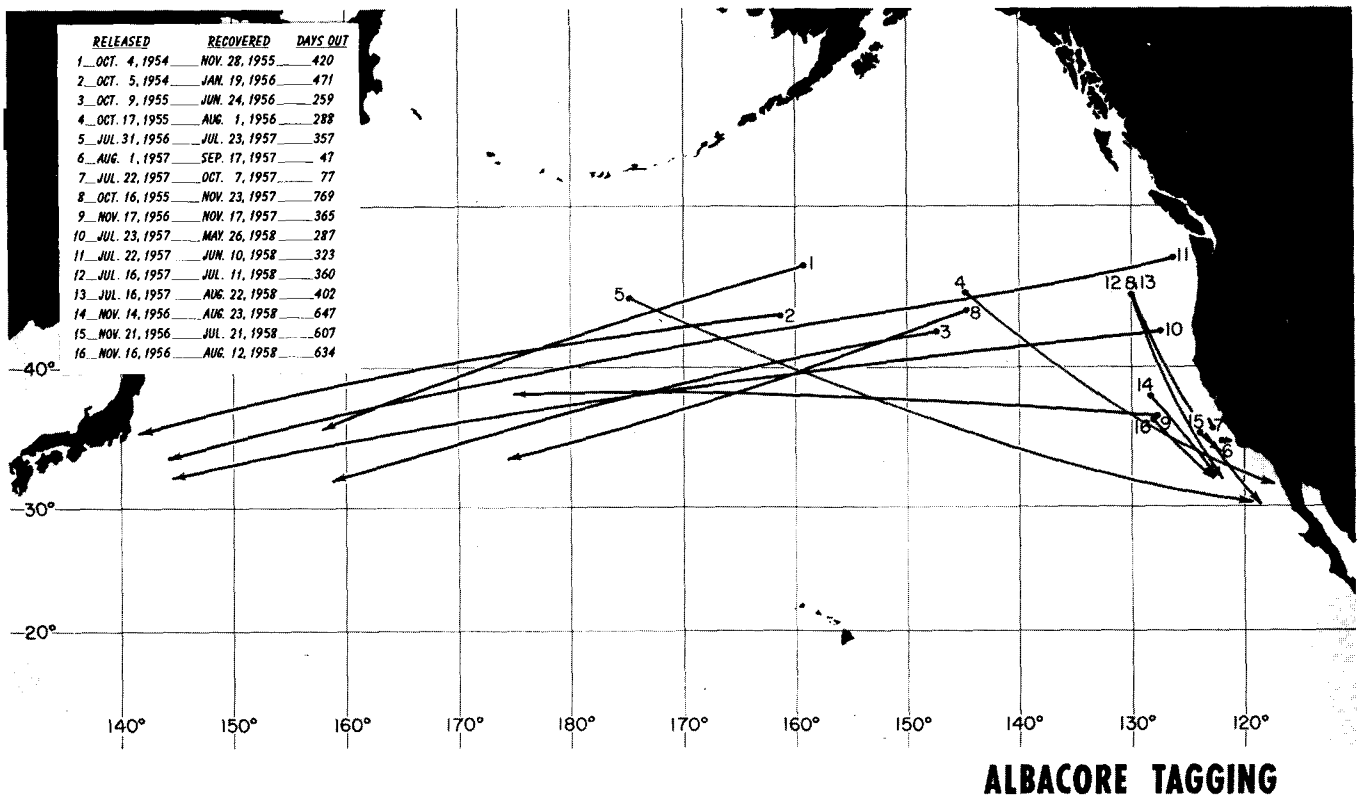


FIGURE 13. Chart of points of release and return of tagged albacore.

in the North Equatorial Current and is based on studies of albacore landed in the Hawaiian longline fishery as well as on HBL's exploratory cruises and data from the Japanese longline fishery in the west.

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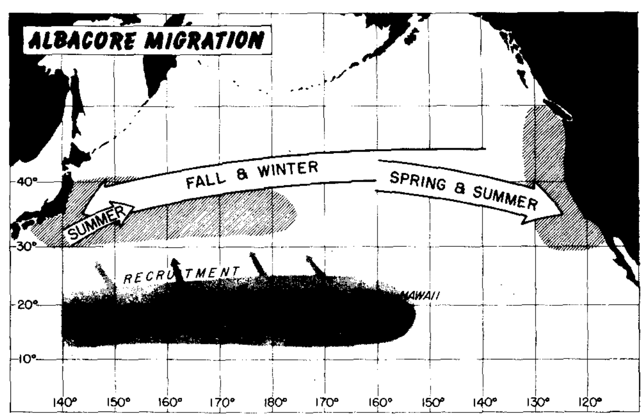

FIGURE 14. Albacore migration.

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