

ALBACORE OCEANOGRAPHY OFF OREGON — 1970

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ABSTRACT

During July 1970, albacore boats trolling surface jigs (jig boats) had record catches in an area off the mouth of the Columbia River. The jig fishery declined suddenly in late July and was poor throughout the remainder of the summer. No obvious oceanographic changes were correlated with these drastic changes in fishing success. Favorable water temperatures extended through August, traditionally the month of highest albacore landings in Oregon.

Bait boats, which chum with live bait, had good fishing off Oregon from mid-August to October, indicating that the poor success of jig boats during this time was caused by the behavior of albacore relative to surface-trolled fishing gear. It is postulated that albacore descended into subsurface water in response to a change in availability of their preferred prey, the saury; here they were less accessible to jig boats than bait boats. Saury were common in the stomachs of albacore during periods of good jig fishing and were usually the dominant food where high albacore catches were made by our research vessel.

The first albacore catches of the season were probably from an area of warm temperature and low salinity representing Columbia River plume water. The subsequent migration to the north appeared to be along the oceanic edge of the plume. In general, high catches by boats were not within the core of the plume but in 15.5°C water, especially in areas where a horizontal thermal gradient was apparent.

During the summer season albacore (*Thunnus alalunga*) usually migrate into waters off the Oregon coast where upwelling and Columbia River water form a complex ecotone between coastal and oceanic waters (Owen, 1968; Pearcy and Mueller, 1970; Pearcy, 1971). The albacore fishery here fluctuates greatly among years as a result of variations of abundance and availability of albacore and fishing effort (Johnson, 1962).

Marked fluctuations of catches may also occur within a single summer and the 1970 albacore season off Oregon is a spectacular example of within-season changes in fishing success. The fishery got off to an early start in mid-July and jig boats reported exceptionally high catches (up to 1,400 fish/boat day) during late July. Record landings of over 4,000 tons were recorded for July. During late July and early August, however, the jig fishery virtually disappeared. Boats fishing in the region of the Columbia River, where high catches of

800-1,300 fish per boat day were reported on 30 July, averaged only 50 fish on 31 July.² Although jig fishing continued to be poor during the rest of the summer off Oregon, bait boats enjoyed good fishing into October.

The purpose of this paper is to describe ocean conditions and albacore catches in Oregon waters during the summer of 1970 in hopes of better understanding the small-scale spatial distribution of albacore tuna and the dramatic changes in their availability that occurred in 1970.

SOURCES AND TREATMENT OF DATA

Catch data for the 1970 albacore season off Oregon were derived from fish boat logs sent directly to us from fishermen or obtained through other agencies from fishermen. Thirty-three jig boats and two bait boats submitted usable records to us from our original dis-

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² Laurs, R.M. 1970. U.S. Bur. Commer. Fish., Albacore Bull. No. 70-3 and 70-4, La Jolla, Calif.

tribution of 421 special logs to fishermen in Oregon, Washington, and California prior to the 1969 albacore season. These logs were unique in that they were designed to obtain several entries per day from fishermen so that variations of catch rate over small spatial areas could be examined. In addition, the Fish Commission of Oregon obtained 116 jig boat and 8 bait boat logs, California Department of Fish and Game made available 45 jig boat and 8 bait boat logs, and the Inter-American Tropical Tuna Commission provided 2 jig boat and 11 bait boat logs.

The catches of each type of boat were averaged for each day regardless of fishing location off Oregon. Catches of jig boats were also assigned to 10' latitude \times 10' longitude blocks based on their reported loran positions. Generally catches could be assigned to a specific block. If a boat cruised over a large area and catches could not be assigned to specific blocks, the data were not plotted. No adjustment was made for the effect of boat size or number of lines on catches. It should be pointed out that our catch data do not necessarily represent average catches made by the fleet in an area because they are from only part of the fleet.

Sea-surface temperature was measured on remote sensing overflights using a Barnes PRT-5 infrared radiometer³ at an altitude of 150 m or 500 ft (Pearcy and Mueller, 1970). A total of 15 flights were made from 22 July to 15 September on HU-16 aircraft either from the U.S. Air Force 304th Aerospace Rescue and Recovery Squadron, Portland, Oreg., or from the U.S. Coast Guard Station, Port Angeles, Wash.

On two RV *Cayuse* cruises, temperature was measured with bathythermographs, and temperature and salinity with a Salinity-Temperature-Depth system. Stations were usually 10 miles apart. On the 27 July-2 August cruise, water transparency was determined with a submarine photometer, and 6-ft Isaacs-Kidd midwater trawl collections were taken at 5 knots to a depth of about 100 m

along the cruise track at night. Volume of water filtered was estimated from flowmeters mounted in the mouth of the trawl.

Albacore were caught from the *Cayuse* by fishing between hydro stations using standard trolling methods with a maximum of eight lines. Time and location of catches during daylight hours were recorded. All fish collected were measured in fork length; stomachs removed and preserved immediately with Formalin for subsequent examination of their contents.

CATCHES AND EFFORT

Statistics on catches and effort of jig and bait boats reporting to us are summarized in Figure 1. The 1970 Oregon jig season got off to an early and intense start. The first albacore of the season were reported on 15 July, the day that fishermen and processors reached a price agreement. Thereafter, three peaks of excellent fishing success occurred for jig boats: on 17, 22, and 28 July. Catches on these days averaged between 300 and 400 fish per boat day. The catch rate then declined drastically to about 55 fish per day between 28 and 31 July and never fully recovered during the remainder of the season, although success improved from 17-20 August.

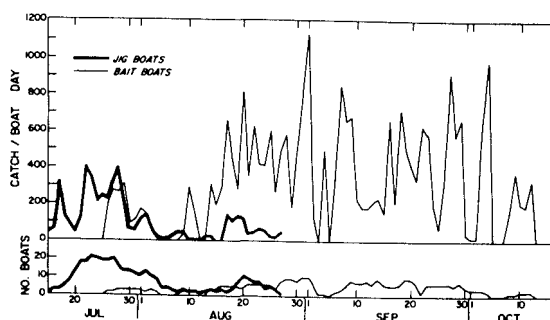


FIGURE 1.—Average number of albacore caught per day by jig boats and bait boats that submitted log sheets (above) and the number of reporting boats (below), 15 July-20 October 1970.

The number of jig boats reporting catches increased rapidly after the season began and then declined steadily from 27 July to mid-August (Figure 1). According to Laurs (see footnote 2), as jig fishing deteriorated off

³ Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Oregon, it improved off southern California to its best level in about 3 years. For this reason the west coast jig fleet largely emigrated to California waters in August after the early collapse of the Oregon fishery.

Similar trends in the catches by both bait and jig boats existed between mid-July and early August. Peaks in catches occurred on 26-29 July and 1-2 August, followed by a common decline to very low catches on 4 August (Figure 1).

In contrast to these trends early in the season, bait boats often had excellent fishing after July, while jig fishing was poor or non-existent. Average daily catches of bait boats remained below 320 fish per day until mid-August, followed by catches that often exceeded 500 fish per boat day from mid-August to early October. The large daily fluctuations in the catches are due in part to the small number of boats reporting.

Statistics for landings of albacore in 1970, provided by Hreha (unpublished data, Fish Commission of Oregon), are shown in Table 1. Jig boat landings were largest in July, the

month when most albacore are landed in Oregon. Since 1961, August ranked first during 7 years and September ranked first during 2 years. July, the best month in 1970, had not ranked first in landing during the preceding 20 years (Ayers and Meehan, 1963; Meehan and Hreha, 1969).

Table 1 also reveals the importance of the large jig fleet in the Oregon albacore fishing. Total landings by jig boats exceeded those by bait boats despite the deterioration of the fishing after July and despite the larger tonnage per landing (Table 1) or average catch per day (Figure 1) by the larger, but less numerous, bait boats.

MOVEMENT OF THE FLEET

Figure 2 shows the approximate location of albacore jig boats that reported catches during the summer of 1970. Generally boats were highly aggregated on a geographic basis—

TABLE 1.—Oregon albacore landings (metric tons and number) (Hreha, pers. comm.)

| Month | Jig boat landings | | Bait boat landings | |
|-----------|-------------------|--------|--------------------|--------|
| | Tons | Number | Tons | Number |
| July | 3,342 | 450 | 0 | 0 |
| August | 2,760 | 869 | 492 | 13 |
| September | 569 | 89 | 2,038 | 55 |
| October | 306 | 59 | 130 | 6 |
| Total | 17,218 | 11,515 | 2,660 | 74 |

¹Totals for jig boats include minor landings for November and December.

month of highest catches as shown in Figure 1, and progressively declined during subsequent months. According to Hreha (unpublished) about one-half of the albacore landed in August were caught in July by jig boats, and about one-half the total catch of both jig and bait boats for the 1970 season was actually caught in July. This seasonal distribution of Oregon landings in 1970 is unusual compared with other years. August is commonly the

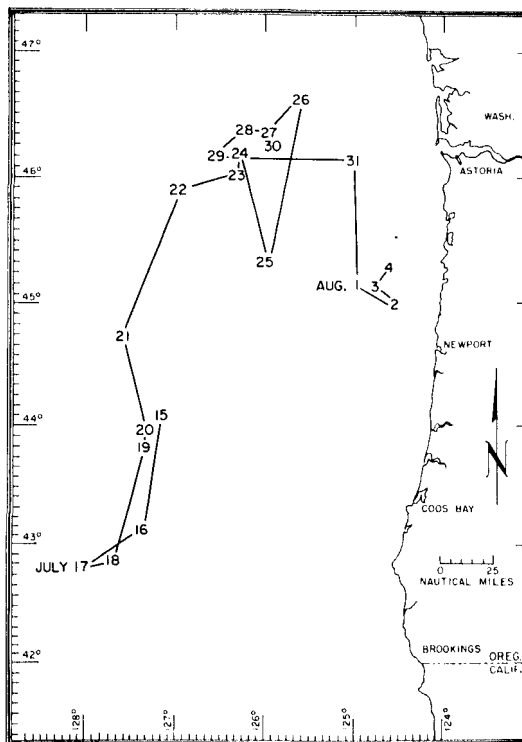


FIGURE 2.—Approximate geographic center of the albacore jig fleet from 15 July to 4 August 1970.

this plot thus estimates the central location of the fleet.

The first albacore of the 1970 season off Oregon were caught between Newport and Coos Bay on 15 July, and the subsequent early fishery during 15-21 July was localized about 140 miles off the central and southern Oregon coast. Boats shifted rapidly northward during 20-22 July and then were localized about 100 miles off the Columbia River during 22-29 July. (An exception was 25 July, when most boats moved south about 50-60 miles.) Between 29 and 31 July, during the major decline of the fishery, boats moved inshore to within 60 miles of the mouth of the Columbia River. This was followed by a shift to the south in early August and then an additional inshore movement to within 30 miles off the central coast. After 4 August the number of jig boats reporting catches was less than 11 and positions are not noted in Figure 2.

Thus the jig fishery off Oregon moved northward during July and became localized in the region off the Columbia River, where most of the fish were caught during the 1970 season. During the rapid decline of catches, jig boats moved inshore and to the south. Fishermen say that such an inshore movement of albacore may occur late in the season (September-October) when fish apparently form dense schools closer to shore and are often difficult to catch on trolled jigs. The bait boat fishery for albacore usually peaks late in the season, after jig catches decline (R. M. Laurs, pers. comm.). Thus both the inshore movement of the jig fishery and the good bait fishery occurred anomalously early in 1970.

OCEANOGRAPHIC CONDITIONS

In hopes of learning more about oceanographic conditions off Oregon and how changes in catches are related to upwelling and the Columbia River plume, we conducted weekly aircraft flights to obtain data on sea-surface temperature using infrared radiometers and fielded several cruises to determine ocean conditions both before the albacore season and later in the area of the albacore fleet. This section summarizes ocean features found during the

1970 albacore season. North-south and east-west components of winds are given in Figure 3 to aid in interpretation of wind-driven ocean circulation.

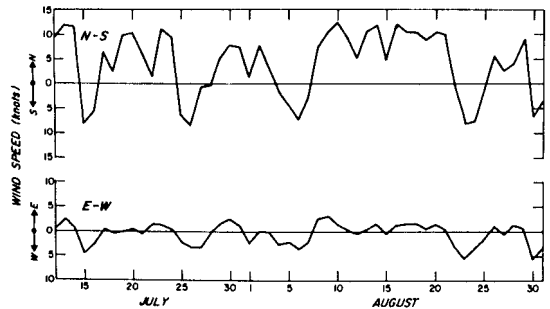


FIGURE 3.—Components of average daily wind velocities recorded at Newport, Oreg.

Cruise—7-10 July

Results of this pre-season albacore cruise, off northern and central Oregon (Figure 4), illustrate the influence of both upwelling and

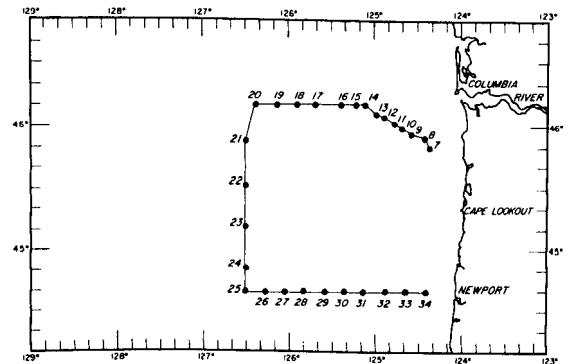


FIGURE 4.—Location of STD (Salinity-Temperature-Depth probe) stations during the pre-season albacore cruise, 7-10 July 1970. (Cayuse 7007A).

Columbia River plume on the ocean environment. Isolines of salinity and temperature in the east-west sections (off the Columbia River and Newport, Figure 5a, b, e, f) slope upwards towards shore and are indicative of upwelling, the replacement of near-surface waters with deeper, saline, low-temperature water. The low-salinity waters of the Columbia River plume are evident in all sections. Plume

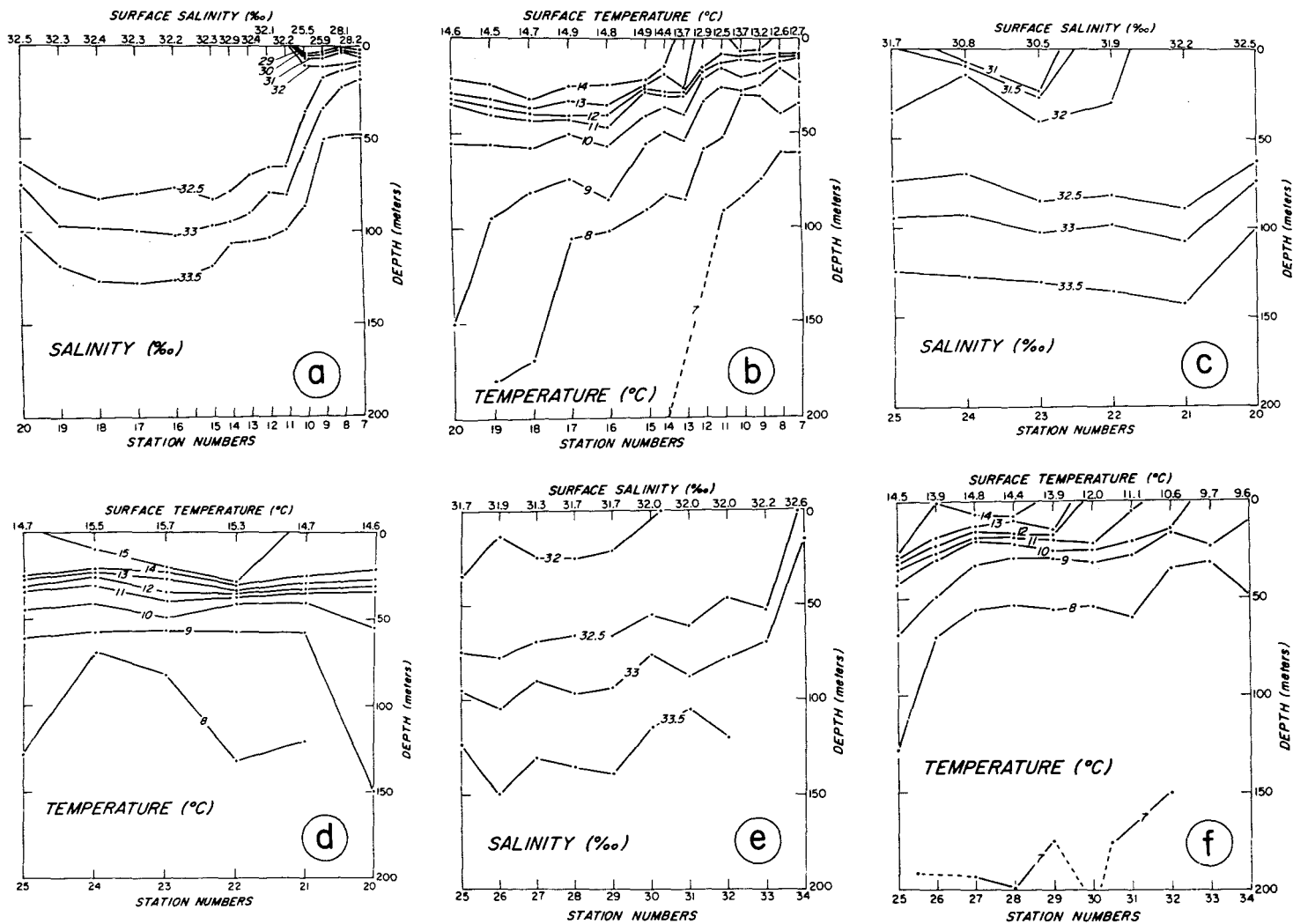


FIGURE 5.—Salinity sections: a) Stations 7-20, west of the Columbia River; c) Stations 20-25, along the north-south station line; e) Stations 25-34, along the Newport Station line. Temperature sections: b) Stations 7-20, d) Stations 20-25, f) Stations 25-34.

waters with salinities less than $32.20/00$ (Owen, 1968) were found within 30 miles of shore near the mouth of the Columbia River (Stations 7-10, Figure 5a), as a lens of low-salinity water located along the north-south section 110 miles offshore (between Stations 22 and 25, Figure 5c), and greater than 50 miles offshore along the Newport transect (Stations 25-30, Figure 5e). The warmest water encountered on the cruise was along the north-south section, 110 miles offshore, where water 15°C and warmer was localized in a lens to a maximum depth of 20 m and surface temperatures as warm as 15.7°C were recorded (Figure 5d). This water, which was warmer than average in July, coincided with the low-salinity lens from the Columbia River plume. The correlation between low salinity and warm temperature early in the summer has been previously observed by Owen (1968) who described a causal basis. The strong pycnocline produced by the low-salinity water constrains mixing, and near-surface waters are heated by insolation more rapidly than surrounding waters. This relationship between salinity and temperature depends on heating rates and varies with season. Evans (1972) found that highest temperatures in the plume occurred inshore of the salinity minimum and that heat content was not a good indicator of the plume even though the temperature pattern is.

Infrared SST—15 July (Figure 6)

Our first sea-surface temperature (SST) flight was made by coincidence on the day that albacore catches were first reported off Oregon. Fish were caught about 120-160 miles off Heceta Head (Figures 2 and 6) where the fishing vessel *Spirit* reported surface temperatures of 16°C . This warm water was probably associated with a lens of low-salinity Columbia River plume water, similar to the situation found earlier in July on the cruise (Figure 5). As a result, the early location of the fishery and its subsequent movement to the north (Figure 2) may have been along plume waters, which are often the warmest waters available

off Oregon during the early summer (Owen, 1968).

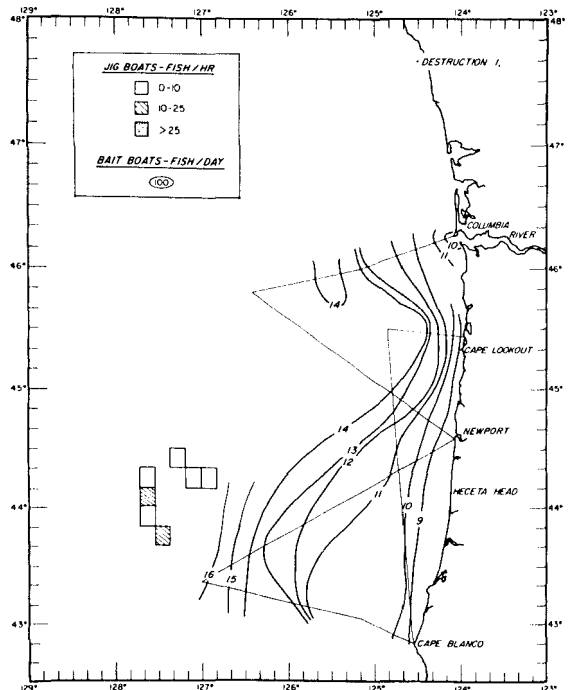


FIGURE 6.—Sea-surface temperatures (degrees Celsius) recorded by infrared radiometry on 15 July 1970. The flight track of the aircraft is shown by the narrow lines. Catch rates of albacore are indicated for jig boats by shading of 10' blocks. In other figures, dashed lines denote isotherms based on temperatures recorded by fish boats. Daily catches of bait boats are shown by encircled numbers.

Coastal upwelling was obvious on this flight as a long band of cold (8° - 9°C) water along most of the coast (Figure 6). Although average winds on 15 July were not from the direction to induce upwelling, winds on the preceding days were northerlies (Figure 3) and hence conducive to coastal upwelling. Mixture of these upwelled cold waters with the warmer Columbia River water probably masked the inshore portion of the Columbia River plume which often contrasts with upwelled water as a tongue of warm water emanating from river mouth in early summer (Budinger, Coachman, and Barnes, 1964; Owen, 1968; Percy and Mueller, 1970).

Infrared SST—22 July (Figure 7)

This was the day of the first large peak in average jig boat catches. (Figure 1). Most of the catches were made northwest of the SST front and were arranged in a northeast-southwest pattern, possibly along the seaward boundary of the Columbia River plume. Highest catch rates (25-55 fish/hr) in this area were reported by fishermen trolling along the 15.5°C isotherm. High catches were also made along the 15.5°C isotherm 55 miles off Cape Lookout and along the 15°C isotherm 70 miles off the southern Washington coast.

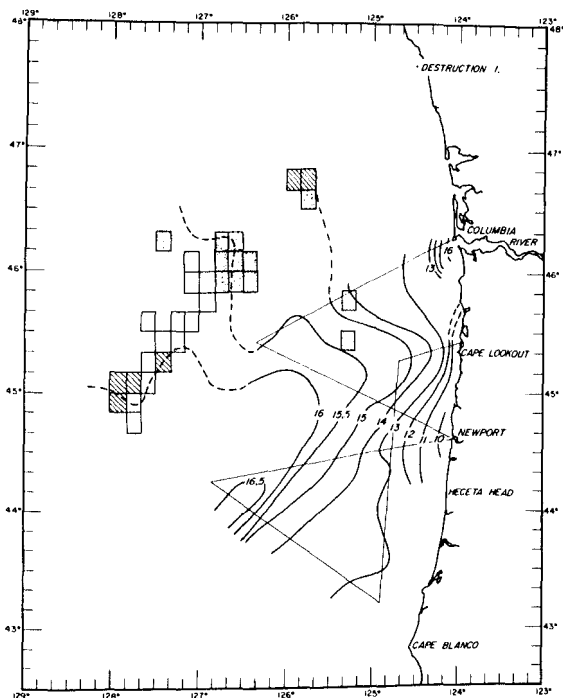


FIGURE 7.—Sea-surface temperature and albacore catch rates, 22 July 1970. Dashed lines are isotherms based on temperatures reported by fishing boats. See Figure 6 for explanation of catch notation.

The surface temperatures show an inshore-offshore gradient produced by upwelling and plume waters. Temperatures were generally warmer than on 15 July (Figure 6), however, suggesting less intense upwelling or more heating of surface waters on 22 July than on 15 July. The plume is apparent as a tongue

of warm water (maximum 16.8°C) extending towards the mouth of the Columbia River.

Infrared SST—29 July (Figure 8)

This SST pattern for the day after the second big peak in jig catches (Figure 1) reflects obvious changes compared to previous patterns. Temperatures are much warmer—over 13°-14°C nearshore and over 18°C within 25 miles of the coast. These high temperatures are explained by the absence of northerly winds to induce upwelling during 26-28 July (Figure 3) and by the rapid heating of surface waters during this period of reduced wind-induced mixing, especially in the low-salinity plume that has been shifted close inshore.

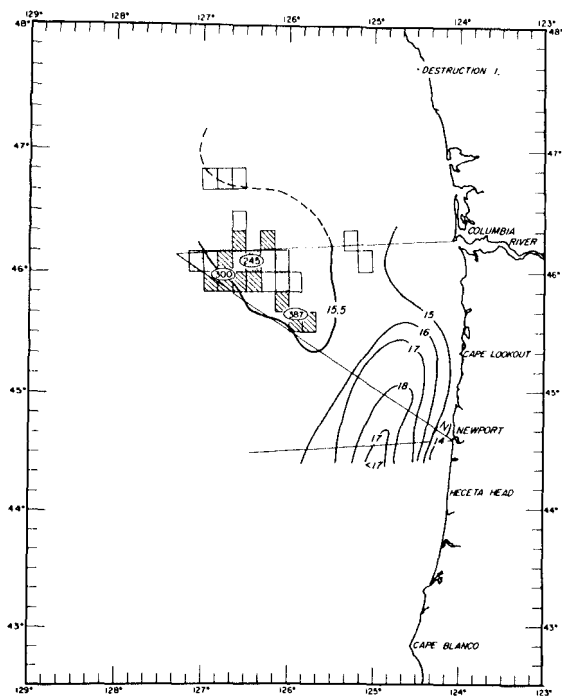


FIGURE 8.—Sea-surface temperatures and albacore catch rates, 29 July 1970. Dashed line is an isotherm based on temperatures reported by fishing boats. See Figure 6 for explanation of catch notation.

Fishing activity was localized almost entirely in a tongue of 15.5°C, blue-green water off the Columbia River (Pearcy, 1971). All the high catch rates during this day were reported

along the southern edge of this tongue. Note that three bait boats were also fishing this same region. They reported scores of 245-387 fish per day, not much higher than the jig boats which averaged 215 per day on 29 July, and below the 400 fish averaged by jig boats on 28 July.

Infrared SST—30 July (Figure 9)

The results of this SST flight show how rapidly the surface conditions can change in an area in 1 day. As a result of the onset of northerly winds (see Figure 3), renewed upwelling is now apparent along the coast between Cape Lookout and Newport. Surface temperatures near Newport were less than 10°C compared with 14°C on 29 July. Moreover, offshore temperatures were cooler on the 30th than the 29th, and no 18°C water was found on 30 July. The cooler surface water probably resulted from mixing due to increased wind stress. Note also the two separate areas

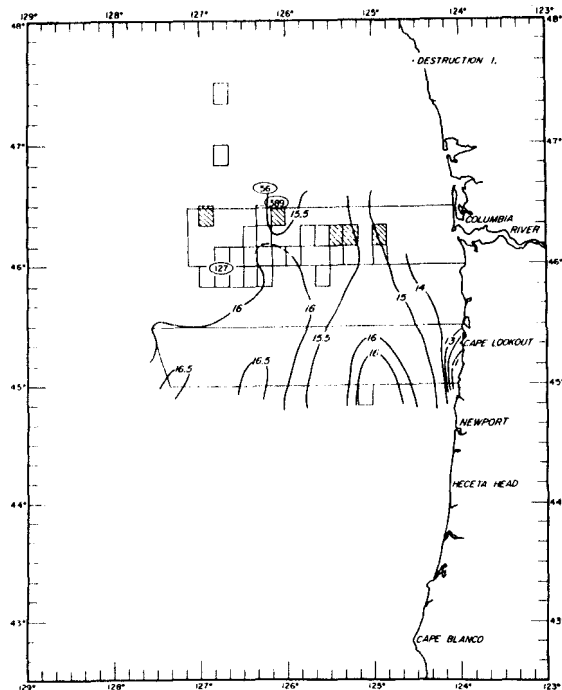


FIGURE 9.—Sea-surface temperatures and albacore catch rates, 30 July 1970. See Figure 6 for explanation of catch notation.

of 16°C water along the southern flight lines.

Most of the fishing activity this day was again located off the Columbia River. Catches continued to decline, however, from an average of 215 fish per boat on the 29th to only 65 fish per boat on the 30th. Best success on this day (up to 17 fish/hr) was in the vicinity of 15.5°C , blue water off the Columbia River.

Infrared SST—31 July (Figure 10)

Fishing success continued its decline on 31 July with no jig boats reporting catches over 10 per hr and daily catches averaging a meager 55 albacore. Two bait boats also reported low catches, 75 and 68 fish per day.

Winds were again northerly (Figure 3) and infrared coverage by the aircraft was interrupted inshore because of the fog along the coast produced by cold, upwelled water. A pool of cool (15°C), green water was found 65 miles offshore about the same distance offshore that the band of cooler water was located on 30 July (Figure 9).

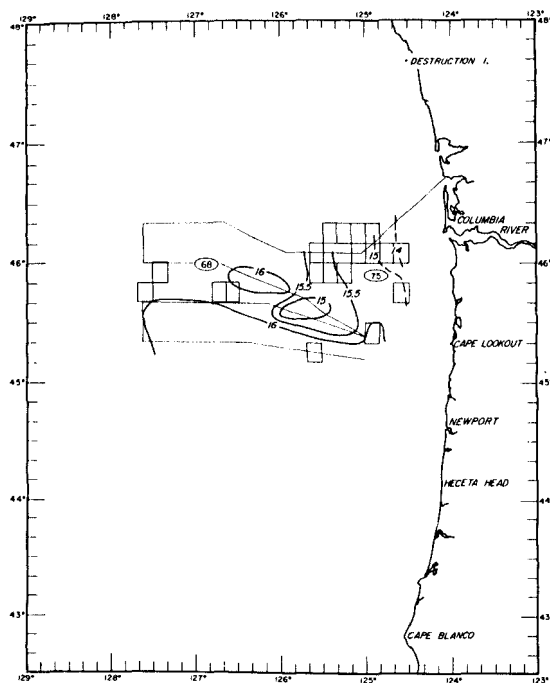


FIGURE 10.—Sea-surface temperatures and albacore catch rates, 31 July 1970. See Figure 6 for explanation of catch notation.

Infrared SST—5 August (Figure 11)

By this time the average catch of jig boats was less than 50 per day and only eight boats were reporting. The continued decline of the jig fishery did not appear to be associated with drastic changes of sea-surface temperature conditions, however. Water of 15°-16°C, was widespread offshore and south of the Columbia River.

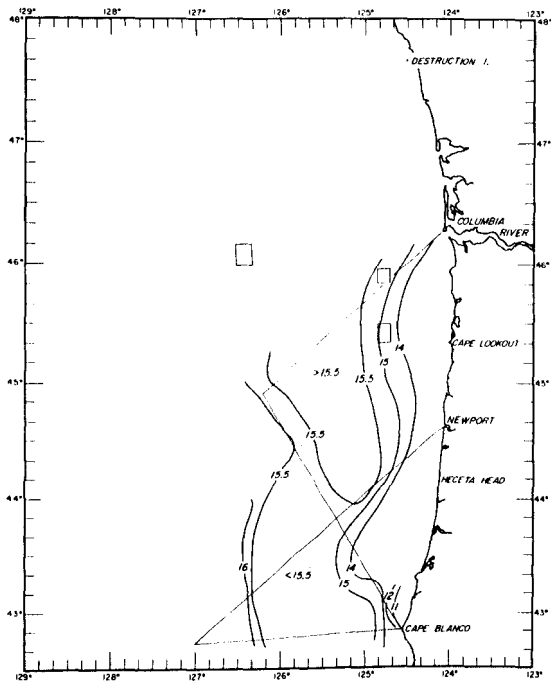


FIGURE 11.—Sea-surface temperatures and albacore catch rates, 5 August 1970. See Figure 6 for explanation of catch notation.

Coastal upwelling was not pronounced and cold water was absent inshore at Newport and the Columbia River. This situation is explained by south-westerly winds during the last 3 days (Figure 3). Plume waters were not obvious as a warmwater tongue off Oregon because of the general heating of offshore waters this late in the summer and possibly because of the lack of northerly winds that push the plume to the south along the Oregon coast.

Infrared SST—19 August (Figure 12)

During the period of 17-19 August jig catches increased to over 100 fish per day. These improved catches resulted in an increase in reported effort (10 boats on 20 August). Again sea-surface temperatures were similar to days in July when good catches were made by jig boats.

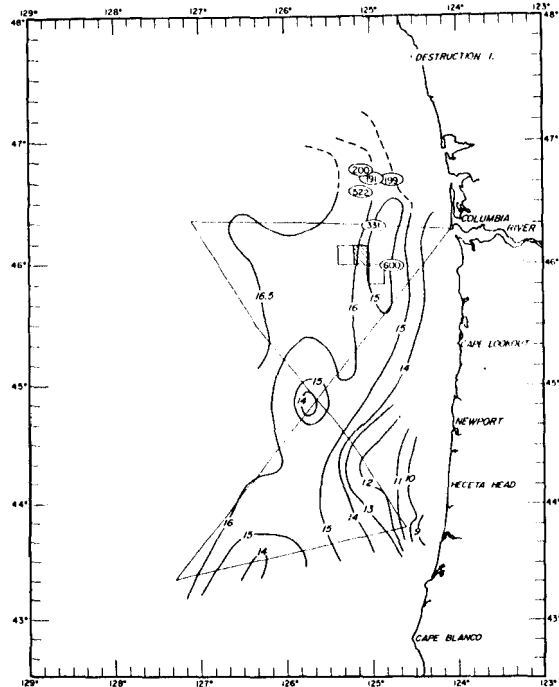


FIGURE 12.—Sea-surface temperatures and albacore catch rates, 19 August 1970. See Figure 6 for explanation of catch notation.

The six bait boats, reporting 191 to 600 fish per day, were located 30-40 miles from shore, near the mouth of the Columbia River in 15°-16.5°C water. This is the same general area where the jig boats were fishing.

Infrared SST—16 September (Figure 13)

Although no jig boats reported catches after late August, bait boats had good fishing throughout September and early October (Figure 1).

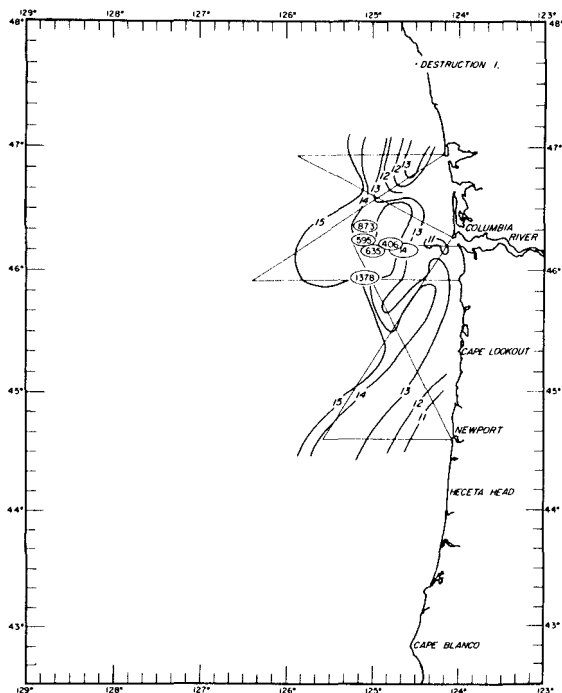


FIGURE 13.—Sea-surface temperatures and albacore catches, 16 September 1970. Numbers encircled indicate the daily catch of individual bait boats.

On 16 September bait boats were again concentrated near the mouth of the Columbia River where a finger of 14°C water extended toward shore. Judging from our data, this distribution of bait boats near the Columbia River was a common pattern, indicating favorable conditions for concentration of albacore in this area.

Cruise—27 July-2 August

A cruise was conducted in the general area of the early albacore fishery to compare oceanographic conditions in areas of high and low catch rates and to obtain albacore for a study of their food habits. The ship operated in the region of the jig fishery during the major decline in fishing success, 27 July to 2 August (Figure 1).

Oceanographic Conditions

Sea-surface temperatures measured during

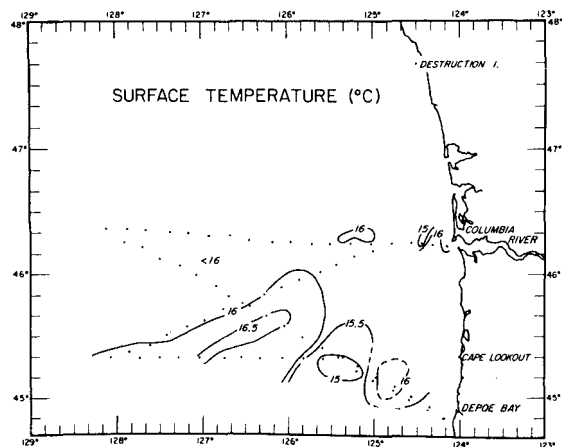


FIGURE 14.—Sea-surface temperatures recorded on the 27 July-2 August cruise. Dots indicate stations. (*Cayuse* 7007D)

the week of the cruise show two regions of warm (16°C or greater) water separated by a tongue of cooler 15° - 15.5°C water (Figure 14). This pattern corroborates that found on 30 July by infrared radiometry from an aircraft (Figure 9), when 16°C water was also located in two areas off the northern coast. The temperature section along the outbound cruise track extending offshore in a northwesterly direction (Depoe Bay stations) shows these two areas of warm (16°C) surface water (Figure 15). The slope of the isotherms towards the coast is indicative of upwelling, but nearshore surface temperatures were above 13°C , implying little upwelling during this period of weak winds (Figure 3). The thermocline was located between 20 and 50 m, generally deepening farther offshore.

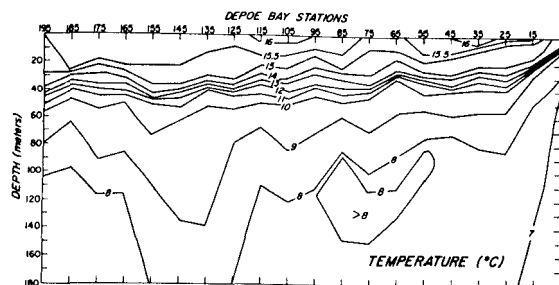


FIGURE 15.—Temperature section along the stations extending northwest of Depoe Bay on the outbound leg, 27-29 July.

The temperature section from the inbound track off Cape Lookout and Depoe Bay (Figure 16), made during the end of the cruise when

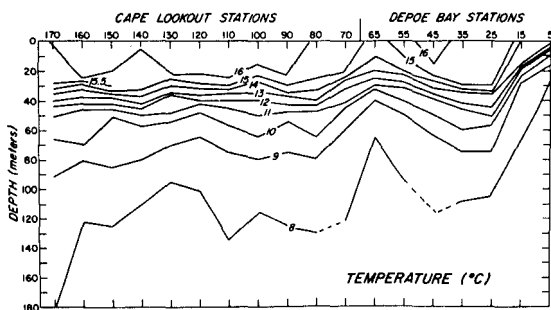


FIGURE 16.—Temperature section along the east-west stations offshore of Cape Lookout and Depoe Bay stations, inbound leg, 1 and 2 August. The Depoe Bay stations are the same ones shown in Figure 15 but 6 days later.

winds were blowing from the north, shows more evidence for upwelling than the earlier outbound track. The 15°C isotherm intersected the surface farther offshore and isotherms slope more steeply nearshore. However, surface temperatures are again not suggestive of strong upwelling. Inshore along the Depoe Bay Stations, the 16° and 15°C isotherms were deeper on the inbound than outbound legs, indicating a deepening of the mixed layer depth during the intervening time, but neither mixed layer depths beyond 75 miles off the coast or the depth of the 15°C isotherm increased noticeably with time. Surface water of 16°C was still located in two areas, which is consistent with the outbound leg, and facilitated the areal plot of surface temperature from all data.

Two extensions of low-salinity water ($<32\text{‰}$) are seen emanating from the Columbia River, one to the south and one to the southwest of the river mouth (Figure 17). These lobes of low salinity correspond with the regions of warmest temperature seen in Figure 14 and support the premise that warm water is often associated with low salinity. This correlation is not apparent close to the river mouth, however, because of admixture of plume with cool upwelled water and insufficient time for warming of the low-salinity lens.

Light extinction coefficients, calculated from photometer casts during daytime were lowest

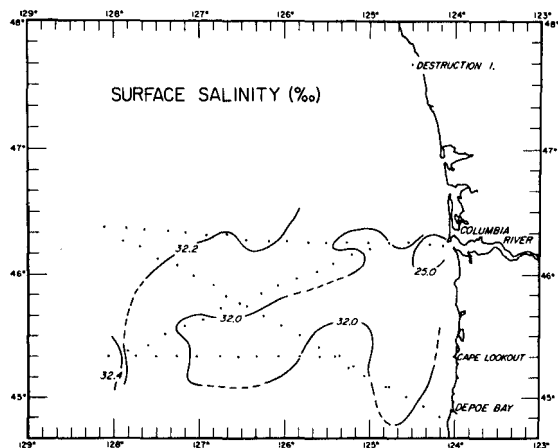


FIGURE 17.—Surface salinity measured during the cruise, 27 July-2 August 1970. Dots indicate stations.

offshore, increased in the region of the plume, and were highest along the coast (Figure 18). This agrees with Pak, Beardsley, and Park (1970) who found higher concentrations of light scattering particles in the low-salinity, warm plume waters than offshore.

Albacore Catches

The catch rates of albacore by the *Cayuse* during the cruise are shown between daylight stations in Figure 19. Highest catches were

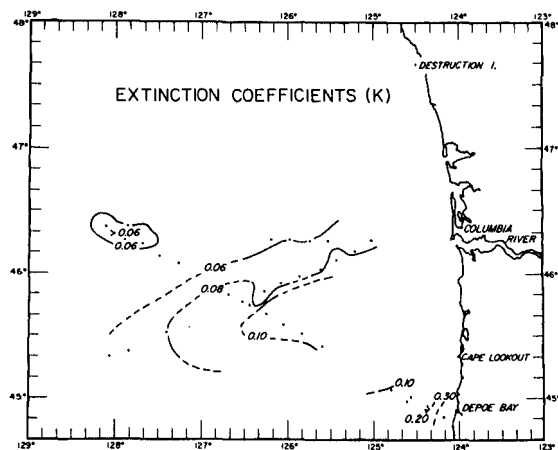


FIGURE 18.—Extinction coefficients of downwelling irradiance, $k = (\ln I_0 - \ln I_d)/d$, where I_0 is surface intensity and I_d is the intensity at depth d . Dots indicate stations where photometer casts were made.

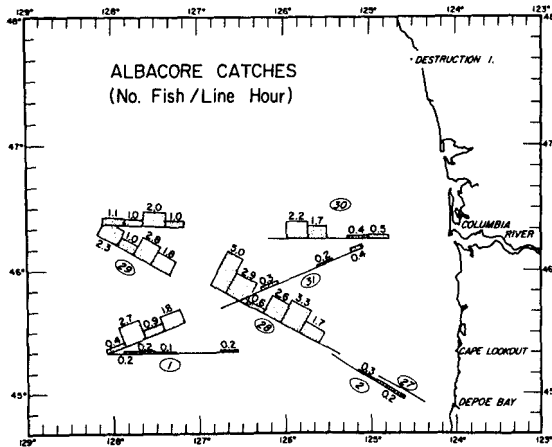


FIGURE 19.—Catch rates of albacore (fish landed per line hour) while the *Cayuse* steamed during daylight hours. Numbers above histograms indicate catch per line hour. Numbers encircled below a group of histograms denote the calendar day during the cruise (27-2 August).

made on the first half of the cruise, which corresponds to the trend of catches by commercial boats in the area (Figure 1). Fish ranged from 57 to 80 cm fork length. Catches were made along much of the cruise track and were not confined to one local area. Within individual days, however, highest catches often occurred along the offshore edge of the plume. For example, on 28 July peak catches of 3.3 and 2.9-5.0 fish/line hr were made in the vicinity of 32.0‰ and 16°C surface water (Figures 14 and 17). These were areas along the edge of the plume where the horizontal temperature and salinity gradients were more intense than in other areas (Depoe Bay Stations 85-95 and 115-135 (Figure 15)). Lowest catches on 28 July of 0.6 fish/line hr were made within the core of the plume at Stations 105-115 where salinity was 31.5‰ or lower and temperatures were above 16°C. Catches also declined along the northernmost cruise track as the ship entered a finger of 16°C and 32‰ water on 30 July.

On 31 July, after the major drop in average catches by the fleet, largest catches (2.7 fish/line hr) were not in the general area of previous high catches on 28 July but farther offshore, 160 miles off Cape Lookout. In this area the 16°C isotherm sloped to the surface (Figure

16), again indicating a horizontal thermal gradient.

A few fish were caught on 1 and 2 August, in nearshore waters, 25-50 miles off Depoe Bay. No fish were caught in the same area 6 days earlier. During the intervening time, the mixed layer depth deepened and transparency increased at the stations where fish were caught. At the station 25 miles offshore, for example, the extinction coefficient was 0.17 on 27 July compared with 0.11 on 2 August; the depth of the 15°C isotherm descended from 5 to 30 m. Thus nearshore catches late in the cruise may be correlated with increased water clarity and increased depth of favorable water temperatures.

Albacore Food Habits

The proportion of fishes, crustaceans, and squids found in the stomachs of albacore caught from the *Cayuse* is illustrated in Figure 20. In general, albacore caught within 130 miles of shore had been feeding largely on fishes, whereas squids and sometimes euphausiids were more important constituents of stomach contents farther offshore. An "S" within the pie diagrams denotes where saury, *Cololabis saira*, was the predominant food (>50% of the wet weight biomass).

On 28 July when large catches were made by the *Cayuse* and the commercial fleet, albacore were observed jumping at the surface in pursuit of saury. On this day sauries constituted nearly all the stomach contents of albacore, many of which had full stomachs. Saury predominated only twice in stomachs of albacore examined from offshore (beyond long 127°W), on 29 July and 1 August, but composed most of the stomach contents of albacore examined off the Columbia River on 30 July. Thus saury was the main forage of albacore along the outside edge of the Columbia River plume, but usually not beyond the plume during 28-30 July. After 30 July, saury was a less important food item, and ragfish, *Icosteus aenigmaticus*, and rockfish, *Sebastes*, were more common than they were earlier. In addition, sergestid shrimp constituted all the stomach contents of two albacore caught near

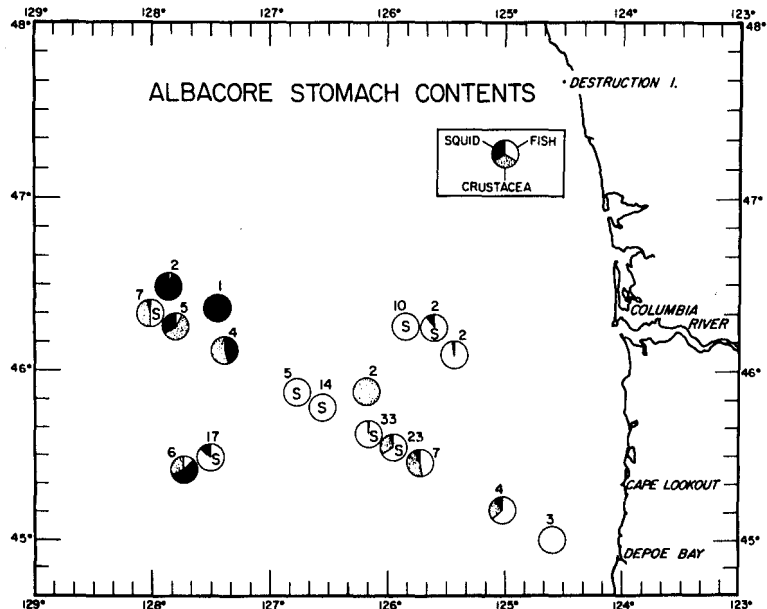


FIGURE 20.—The proportion of squids, fishes, and crustaceans (on a weight basis) in the stomach contents of albacore caught by the *Cayuse*, 27 July-2 August 1970. Numbers indicate the number of stomachs examined. "S" denotes where saury made up over 50% of the biomass of stomach contents.

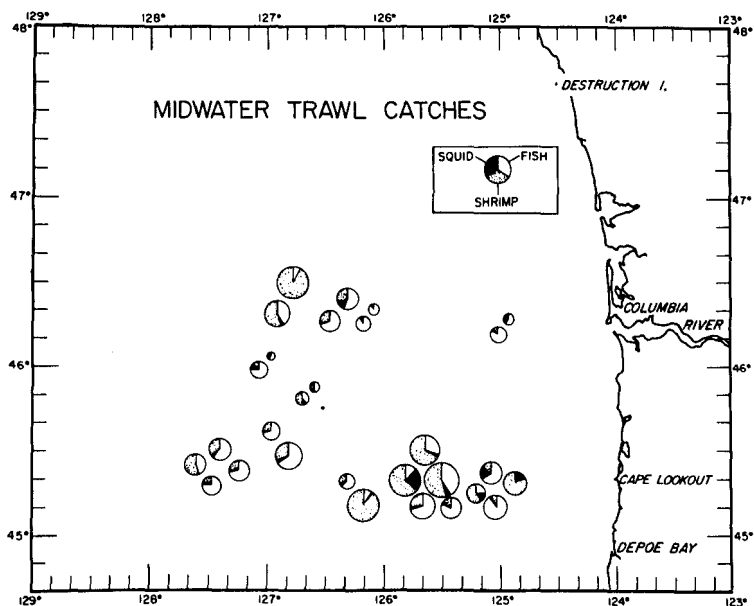


FIGURE 21.—The proportion of squids, fishes, and shrimps (on a weight basis) in 6-ft Isaacs-Kidd midwater trawl tows to 100-m depth at night, 27 July-2 August 1970. The total biomass of these groups combined for each tow is proportional to the logarithm of the diameter of the circles.

the area where saury had been eaten several days before.

Highest albacore catch rates also occurred where albacore were feeding on saury. All catch rates were ranked from highest to lowest for locations where food data was available (see Figures 19 and 20). The sum of the ranks was then compared for areas

where saury predominated (>50% of the stomach biomass) and where saury did not predominate stomach contents. Catch rates were significantly higher in areas where sauries predominated stomach contents than in areas where saury were not predominant. (Mann-Whitney *U* Test, $P < 0.01$, $n_1 = 9$, $n_2 = 9$). The decreased albacore catch rate after 28 July

is thus associated with a decreased availability of saury in near-surface waters where jig fishing for albacore is most effective.

The biomass of fishes, shrimps and squids per 1,000 m³ of water filtered in nighttime midwater trawl tows is shown in Figure 21. Note that the diameter of the circles is proportional to the logarithm of total biomass of the tows. The highest catches were usually composed of the shrimp *Sergestes similis* in plume waters. Fishes often predominated catches, but when they did, the total biomass was generally intermediate or low. Squids were usually present but composed a relatively small portion of the biomass.

A comparison of midwater trawl catches and tuna stomach contents reveals some obvious differences. Saury was rarely if ever caught in trawls but was common as forage especially during the first part of the cruise. Squids sometimes predominated in albacore caught offshore but were unimportant components in the trawl collections, though no trawl was towed in the offshore region where squids were common in stomachs on 30 July. Few midwater trawl and albacore catch stations coincided exactly. Nevertheless the correlation between albacore catches and midwater trawl catches sometimes appeared negative. For example, lowest biomass of micronekton (Figure 21) and euphausiids (not shown) occurred in the region of high albacore catch rates (5.0 and 2.9 in Figure 19). Perhaps such a negative relationship was caused by the grazing of albacore or their carnivorous prey.

DISCUSSION

Our present state of knowledge about the behavior of albacore and the influence of the ocean environment is inadequate to explain the drastic fluctuations of catches by jig boats that occurred off Oregon in 1970. The large concentration of albacore located by the jig fleet in July 1970 off the Columbia River was very vulnerable to surface jigs and record catches were made. In contrast, boats that trolled through this same area, and Oregon waters that had been productive in past years, often reported "no fish days" in August.

Oceanographic changes that correlate with these catch variations were not obvious. Winds were variable during the entire summer with the prevailing northwesterlies being interrupted occasionally by weak frontal systems and concomittant southerly winds (Figure 3). The first large peak in catches per day was during a period of strong northerlies; the second peak, during calm sea conditions. Sea-surface temperatures remained within the "preferred" thermal range, 14.4°-16.1°C (Alverson, 1961), over much of the region during August, usually the best month for albacore fishing. Mixed layer depths also did not change appreciably and 15°C water was usually found to 20-40 m offshore of coastal waters.

The fact that bait boats had good fishing after the demise of the jig fishery suggests that albacore were present off Oregon but not susceptible to capture by jig fishing from August through mid-October. This can be explained by changes in the vertical distribution and behavior of albacore. Surface-towed jigs are most effective on fish feeding near the surface, whereas bait boats, by chumming an area, are better able to attract fish from subsurface schools.

Because albacore was feeding mainly on surface schools of saury during the second peak in jig boat success and because a significant positive relationship existed between albacore catches and feeding on saury, it is postulated that the collapse of the jig fishery was related to a change in the availability of the saury, the major prey of the albacore during the preceding period in 1970, and usually the most important food of albacore off Oregon in other years (Pearcy, unpubl. data). Saury could have been grazed down, emigrated out of the area, or descended into deeper water. Any of these could have induced the large concentration of albacore to migrate into deeper water where better feeding conditions existed and where they would be relatively inaccessible to surface trolled jigs.

During late August we repeated a cruise in the same region as the 27 July-2 August cruise, off northern Oregon and the mouth of the Columbia River. Nineteen albacore were caught on jigs. Anchovy larvae, small rock-

fishes, and *Sergestes* were the most common organisms in their stomachs. Only one saury was identified. Examination of the feeding habits of bait-caught albacore during the late summer would be of particular interest. Absence of saury from these fish would suggest that saury was not available to albacore for the remainder of the season in this region off Oregon, and albacore fed on alternate food organisms from subsurface waters. These changes in the behavior of albacore show similarities with the schooling and foraging behavior of bluefin tuna, *Thunnus thynnus*, schools off Baja California noted by Scott and Flittner (1972). They found that the occurrence of jumping and boiling schools on the surface was related to foraging on baitfish, whereas subsurface schools, which produced the largest purse seine catches per set, fed more on red crab, *Pleuroncodes planipes*.

A major conclusion of this paper is in accord with the hypothesis that the geographic range of tuna is established by temperature but food supply is largely responsible for distributions within this range (Blackburn, 1964; 1969 Nakamura, 1969). If this hypothesis is correct, it follows that accurate predictions of albacore concentrations in time and space must consider abundance and availability of forage organisms. Moreover, the depth distribution of the preferred albacore food will have pronounced influence on the relative successes of jig and bait fisheries, as the 1970 season off Oregon demonstrated.

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