

AN ABSTRACT OF THE THESIS OF

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DURING SUMMER 1969 AS RELATED TO SELECTED OCEAN

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Oregon's commercial fishery for albacore tuna (Thunnus alalunga) is large, valuable, and variable. Little is known, however, about the oceanographic factors which determine abundance and distribution of albacore.

Primarily using logbook data contributed by fishermen, this study compares albacore catches with selected ocean conditions. The study is limited to troll-caught fish taken during the summer of 1969 off the Pacific Northwest. The location and success of commercial albacore catches were analyzed with respect to the sea-surface temperature field. Also examined was the relationship between fish catches and sea-surface temperature, mixed-layer depth, and water color.

The 1969 albacore season off the Pacific Northwest lasted for 67 days, from 12 July to 16 September. Nearly 30 million pounds of

albacore, worth \$6.7 million, were landed in Oregon ports, making 1969 the second best season in history.

The first commercial quantities of albacore were caught about 135 n mi west of Coos Bay. During the rest of July the fish moved north somewhat but stayed well offshore. During August the fishery spread out considerably, moving as far north as Vancouver Island. In September fishing activity shifted south and inshore.

Off the Pacific Northwest no albacore were taken from waters cooler than 54F(12.2C) or warmer than 66F(18.9C). Most fish were taken from the sea-surface temperature range of 59.5-63.5F(15.3-17.5C). July fish favored 61.5-63.5F(16.4-17.5C) water. By contrast, August fish favored 59.5-63.5F(15.3-17.5C) water while September fish favored 59.5-61.5F(15.3-16.4C) water. Catch-per-unit-effort data did not indicate as marked a decline in availability at cooler temperatures as did gross catch.

Mixed-layer depths associated with favorable albacore catches, 56-135 ft(17.1-41.1 m), were somewhat deeper than those determined by previous investigations. Water-color results showed that most albacore were caught in blue oceanic water.

Other factors associated with good fishing included favorable wind and sea conditions, areas with considerable temperature structure, plentiful food supply, presence of "tuna birds", and stable, moderately developed upwelling situation.

Albacore Tuna Catches in the Northeast Pacific
During Summer 1969 as Related to
Selected Ocean Conditions

by

Daniel Alexis Panshin

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ALBACORE TUNA CATCHES IN THE NORTHEAST PACIFIC
DURING SUMMER 1969 AS RELATED TO
SELECTED OCEAN CONDITIONS

INTRODUCTION

Albacore tuna (Thunnus alalunga) is one of several commercially important species of tuna. Each year from July into early October, albacore typically are available in the waters off the Pacific Northwest.

Oregon's commercial albacore fishery is large, economically significant, and highly variable. In 1969, for instance, Oregon landings amounted to nearly 30 million pounds, worth \$6.7 million at dockside, the result of fishing by a fleet of some 750 boats. During the 35-year history of the albacore fishery in Oregon, on the other hand, annual landings have fluctuated nearly a hundredfold from lows of less than half a million pounds to a 1968 high of 37.8 million pounds.

Despite the commercial importance of albacore, little is known about the complex oceanographic factors which determine their abundance and distribution. A need exists to learn more about albacore in relation to their ocean environment.

Primarily using logbook data contributed by fishermen, this study will compare albacore catches with selected ocean conditions. The purposes of the study are to describe the patterns of albacore catches and sea-surface temperatures which did exist during 1969, to interpret

albacore catches in terms of sea-surface and other ocean conditions, to see if quantitative relationships can be established, and to indicate some of the further work which needs to be done.

The study is limited to troll-caught albacore, taken during the summer of 1969 mainly from the region bordered by 42° N latitude on the south, 48° N latitude on the north, and within 200 n mi of the coast. Sea-surface temperature is the prime oceanographic variable which will be investigated; other variables are mixed-layer depth¹, water color, and salinity. The study will deal for the most part with a time-and-space scale on the order of one week and 250 n mi².

In order to carry out these objectives, albacore catches by location and catch success will be analyzed as a function of the sea-surface temperature field. Quantitative and semi-quantitative relationships of catches with the above-mentioned variables will also be examined.

In the data for this study, temperatures are reported in Fahrenheit because commercial fishermen use the Fahrenheit temperature scale. For similar reasons depths are reported in feet. In each instance parenthetical conversions are also shown to the conventional scientific scales of Celsius and meters.

In Appendix I and here and there through the text fishermen are

¹Mixed-layer depth is the depth to which surface waters are well mixed and nearly isothermal.

quoted. The particular fishermen are not identified since they were promised anonymity. All of those quoted are full-time, experienced, commercial fishermen from California, Oregon, or Washington.

REVIEW OF SELECTED STUDIES

This chapter reviews certain previous studies which deal with the fish itself, the commercial fishery for albacore, and oceanographic variables which influence distribution of albacore.

The Fish

Albacore tuna, Thunnus alalunga (see Figure 1), is a fast-swimming, migratory fish. Albacore inhabit the upper layer of the open ocean (Howard, 1963), generally from the surface to a maximum depth of about 150 m (492 ft) (Blackburn, 1965). They are common to the temperate and sub-tropical regions of the Pacific, Atlantic, and Indian Oceans.

In the North Pacific, albacore are found from 10°N to about 58°N on the eastern side and to 45°N in the center and on the western side; in the South Pacific they are found from 5°S to 45°S (Blackburn, 1965). "Virtually no fish are found in the equatorial zone between 10°N to 5°S . Thus, the populations in the North and South Pacific are separated from each other (Yabe, Yabuta, and Ueyanagi, 1963, p. 986)." Genetic differences between North Pacific and South Pacific albacore have been demonstrated by studies of blood group characteristics (Yoshida and Otsu, 1963). North Pacific albacore belong to a single stock (Suda, 1963).

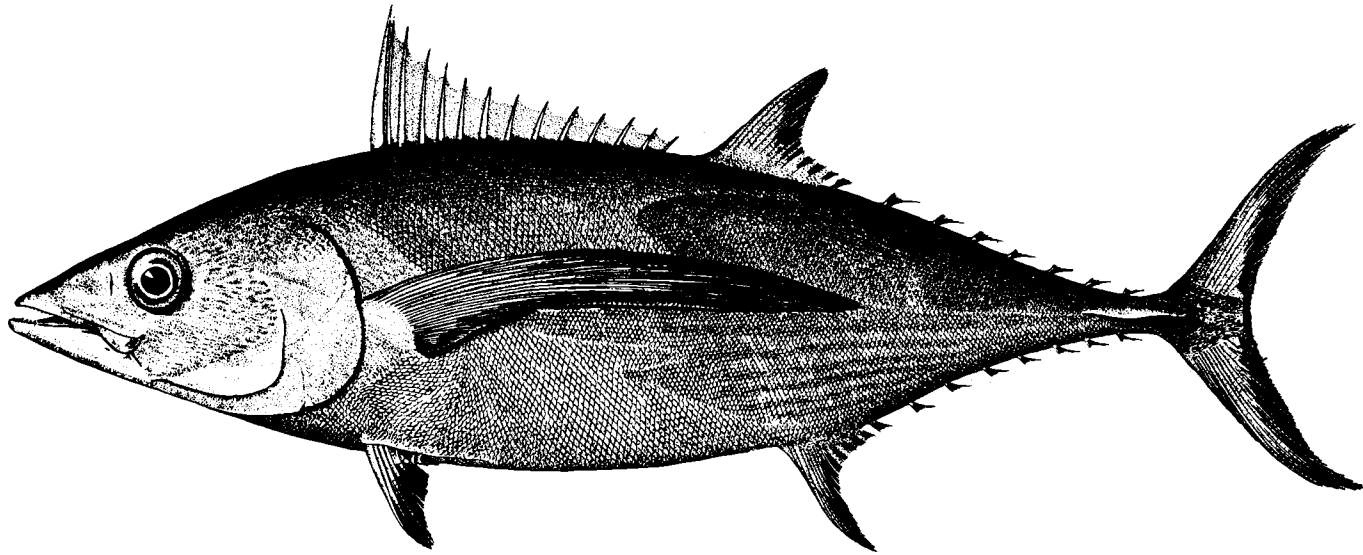


Figure 1. Albacore tuna, Thunnus alalunga. (Engraving courtesy of U. S. National Marine Fisheries Service.)

Spawning in the North Pacific takes place in western sub-tropical waters of the North Equatorial Current (Suda, 1963). "The larval and early juvenile stages are spent in these waters. When about a year old, the fish migrate into temperate waters (Otsu and Uchida, 1963, p. 43)."

The sexually immature fish then stay in the temperate waters of the North Pacific Current system for the next several years. After sexual maturity is achieved at age six or older, they move south into western subtropical waters to spawn. After spawning, at least some of the spawned-out albacore return north to temperate waters (Otsu and Uchida, 1963).

Length and weight relationships have been estimated for different ages of albacore:

Table 1. Average albacore lengths and weights by age (Clemens, 1961a, p. 95).

Age ² (years)	Fork Length ³ (cm)	Weight (lbs)
1	52	6.4
2	65	12.6
3	76	20.0
4	85	28.0
5	93	36.6
6	100	45.5
7	105	52.7

² Age estimates were based on studies of recoveries of tagged albacore.

³ Fork length is the "straight-line distance from the tip of the snout to the fork in the tail (Phelan, 1964, p. 11)."

Definite migratory patterns, which vary by age, have also been established. The most widely accepted model for the North Pacific Ocean is that of Otsu and Uchida (1963); other reasonable migratory models include those by Clemens (1963) and Nakamura (1969).

According to the model hypothesized by Otsu and Uchida, spawning takes place in the western portion of the North Equatorial Current, roughly between the Philippine Islands and Hawaii. At about age one, young albacore migrate north and east into temperate waters. In temperate waters, there are two migratory gyres in the North Pacific: east and west. The young fish join the eastern gyre and most migrate around it annually for two or three years, coming closest to North America during mid-summer.

A varying portion of each year group, and nearly all of the older fish, migrate westward into the western gyre. These albacore migrate around it annually for another two or three years, coming closest to Japan during spring. Once sexual maturity is attained, the albacore move south out of the western gyre into subtropical waters for spawning.

This model allows for transpacific migrations, but "it is postulated that albacore undertake no more than one transpacific migration within a 1-year period (Otsu and Uchida, 1963, p. 43)." In general, younger fish are found in the eastern gyre and older fish in the western gyre. The fish tend to stay in a gyre for two or three

years. While there is a constant interchange to some extent from one gyre to the other by all ages, more fish migrate from east to west than vice versa.

Net movements of the albacore at certain points within the gyre are slow. Movements through the rest of the gyres and between gyres are rapid. Tagged albacore have been recaptured nearly 4000 n mi from the place at which they were tagged, a trip which requires at least 0.53 kts (27 cm sec^{-1}) during the 287-day period between time of release and recapture (Otsu, 1960).

In terms of vertical distribution within the upper mixed layer, young albacore tend to be found at shallower depths than older albacore. Clemens (1963) has speculated that up to three years old, albacore are found at or near the surface; at about age three, they start moving deeper. He further speculates that from age three to six, albacore frequent subsurface waters of the upper layer of the ocean to a maximum depth of 100-150 m (328-492 ft).

Albacore eat an assortment of organisms. In a study conducted off California, Clemens and Iselin (1963) found albacore to be feeding on fishes of 30 different families. Most numerous were the post-larval and juvenile forms of anchovies, rockfishes, jack mackerel, sauries, and barracudinas. In their invertebrate diet, most common were squids, euphausiids, pelagic amphipods, and heteropods. In an earlier study, McHugh (1952) had found albacore to be feeding on

a wide variety of organisms; by volume, the most common items were Pacific saury, squids, pelagic decapods, and the northern anchovy. Laurs (1969) has stated that albacore are opportunists, feeding on what is available.

The Fishery

The commercial fishing methods used to catch albacore are trolling, live-bait, longlining, and purse seining:

-- Trolling is the towing of lines from outrigger poles on each side of the boat and from the stern. Albacore trolling uses barbless hooks and artificial lures, one each per line, trolled on the surface. The lures are also known as jigs, which accounts for albacore trolling frequently being referred to as "jigging" or "jig-fishing."

Typically, a troller will fish seven to twelve lines -- three to five off each pole and one or two from the stern. Trolling is most effective against surface fish (Jones, 1958).

-- Live-bait fishing requires initial location of a school of albacore. Live-bait is then released to attract and concentrate the school, which feeds in a frenzy. The fish strike readily at feather jigs with barbless hooks which are attached by short lines to stout poles. The fishermen simply heave the fish on board. Live-bait fishing is most effective for surface and near-surface fish (Rothschild and Uchida, 1963).

-- Longline gear is made up of units called baskets. Each basket consists of a mainline 200-250 m in length, which is suspended approximately horizontally between two floats and hangs with a noticeable sag in the middle. From each mainline, four to six vertical branch lines are suspended. The branch lines are each about 20 m long and carry a hook at the lower end, usually baited with fresh or frozen fish. A typical set consists of 300 baskets and will extend for more than 30 n mi. The hooks are located from near the surface to a depth of 100 m or more. Longlining is thus most effective against subsurface fish (Takayama, 1963).

-- Purse seining uses an encircling type of net. A typical net is about 800 m in diameter and has a vertical extent from the surface to a depth of about 75 m. Capture is accomplished by surrounding the fish and closing, or pursing, the bottom of the net so that the catch can be readily brought aboard the boat with huge dip nets. Purse seining is most effective against surface or near-surface schools of albacore (Johnson, 1964). In fishing for albacore most purse seining to date has been experimental.

There are three major albacore fisheries in the temperate portion of the North Pacific Ocean:

-- The Japanese live-bait fishery off the coast of Japan takes place from about April to July. The catches are composed of three- to six-year-old fish; five-year-olds are generally most abundant.

-- The Japanese longline fishery from 170°W to 130°E takes place from about October to March. The catches are composed of two- to eight- or nine-year-old fish; four- and five-year-olds are generally most abundant.

-- The United States west coast fishery takes place from about July to November. The catches are composed of two- to six-year-old fish; three-year-olds are generally most abundant (Otsu and Uchida, 1963).

The west coast fishery takes place between central Baja California and Vancouver Island, generally within 200 n mi of shore (Clemens and Craig, 1965). The season typically starts in June or July, peaks in August or September, and ends by late fall (Clemens, 1961a). Off the Pacific Northwest, the season is usually shorter, starting in July, peaking in August, and finishing by mid-October (Meehan and Hreha, 1969).

Laur (1970) has prepared a summary and analysis of the west coast albacore fishery from 1938-1969 (see Figures 2 and 3). Figure 2 shows total west coast landings for the United States and Canada. Landings range from a low of 14.6 million pounds in 1941 to a high of 74.3 million pounds in 1950.

Figure 3 pertains to the same time period and shows the percentage of total catch taken north of San Francisco. This figure graphically points out the shifts in location of the center of the fishery.

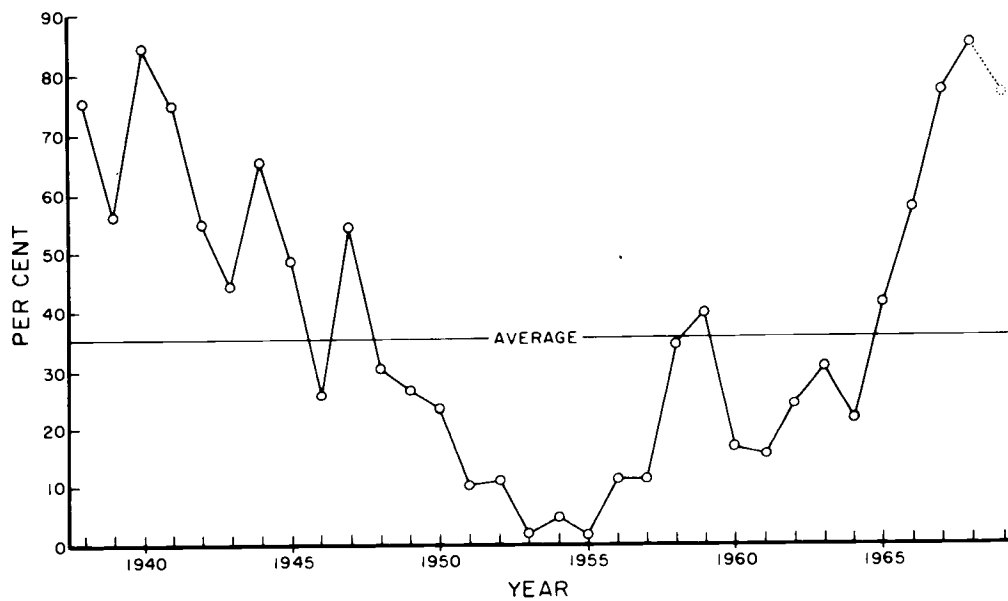
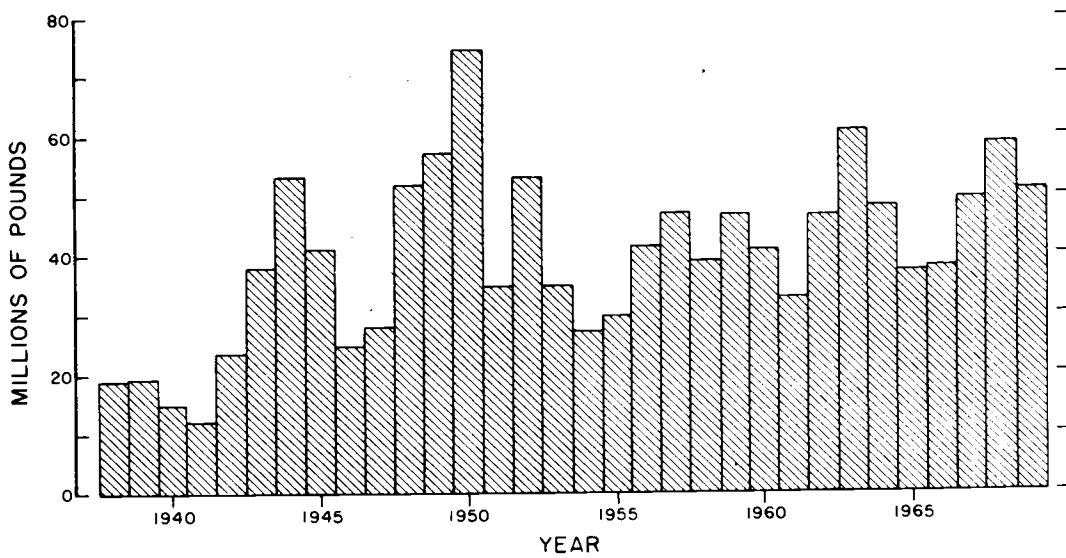


Figure 2. (upper) Total west coast landings of albacore tuna, 1938-1969, (Lauris, 1970, p. 5).

Figure 3. (lower) Percentage of west coast albacore tuna catch taken north of San Francisco, 1938-1969, (Lauris, 1970, p. 5).

The change in location from one year to the next tends to be fairly small, while the oscillatory cycles over a period of several years are obviously large. The amount of albacore taken north of San Francisco ranges from a low of less than five percent in the mid-1950's to highs of over 80 percent in 1940 and 1968.

The figures show large fluctuations both in total annual landings and in location of the center of the fishery. The major reasons for fluctuations are:

- 1) variations in abundance of albacore, or absolute number of albacore in the waters off the west coast of North America in a given season (Marr, 1951);
- 2) variations in availability of albacore, or the degree to which the total number present in a given season are accessible to the efforts of the fishery (Marr, 1951);
- 3) economic factors, such as date on which price settlement is reached and price for albacore relative to other commercially important fish, especially salmon (Johnson, 1962);
- 4) changes in the amount of fishing effort (Clemens, 1961b);
- 5) advances in fishing technology (Laur, 1970);
- 6) oceanographic conditions (Clemens, 1961b);
- 7) weather and sea conditions:

for the typical trolling vessel, fishing is severely hampered by sustained winds of 22-28 knots and seas of 4-8 feet [1.2-2.4 m]; at wind velocities above 30 knots and

sea heights of 6-12 feet [1.8-3.7 m], the trolling gear ceases to fish properly, and the vessels experience great difficulty in staying on the fishing grounds (Flittner, 1970, p. 5).

Oceanographic Variables Which Influence Albacore Distribution

Several oceanographic variables are frequently cited as being important in determining distribution of albacore.

Sea-Surface Temperature

More is known about the relationship of albacore catches to sea-surface temperature than to any other oceanographic variable.

Table 2 presents published relationships between catches of surface and near-surface albacore and temperature for all oceans under different situations. In general, albacore have been found to be present within a broader temperature range than that within which successful prosecution of the fishery takes place, and the best fishing exists within an even more restricted range. As one can see, the reported temperatures may vary noticeably among and within oceans.

In addition, there are some conflicts within the temperature values cited. For instance, Laevastu and Rosa (1963) have reported that albacore occurrence worldwide is bounded by 14C(57.2F) and 23C(73.4F), but other investigators have found albacore in both colder and warmer water in particular oceans (see Table 2).

Table 2. Relationship between albacore catches (surface and near-surface) and water temperature world-wide.

Location	Temperature ranges for						Reference
	Occurrence of albacore		Successful prosecution of fishery		Best fishing		
All oceans	14-23C	(57, 2-73, 4F)	15-21C	(59, 0-69, 8F)	17-19C	(62, 6-66, 2F)	Laevastu and Rosa, 1963
Atlantic Ocean	11, 5-28, 3C	(52, 7-82, 9F)					Squire, 1963
Indian Ocean	10-28C	(50, 0-82, 4F)			18-21C	(64, 4-69, 8F)	Jones and Silas, 1963
Pacific Ocean off California			15, 6-20, 0	(60, 0-68, 0F)	17, 9C	(64, 3F)	Flittner, 1966
off Oregon-Washington- British Columbia	12, 2-17, 2C	(54-63F)			14, 4-16, 1C	(58-61F)	Alverson, 1961
Northwest Pacific	13, 9-25, 0C	(57-77F)	17, 2-22, 8C	(63-73F)			Yabe <u>et al.</u> , 1963

Similar variability may be seen for the temperature ranges listed for successful prosecution of the fishery. Part of the variability stems from differing fishery economics which serve to determine minimum requirements for a fishable concentration of albacore (Blackburn, 1965). Another part of the variability is due to other factors, such as age of the fish, time, area, and fishing gear (Howard, 1963).

For each oceanographic area, however, there is some lower temperature below which albacore are not found, as well as some upper temperature above which albacore are also not found. For the Pacific Ocean off Oregon-Washington-British Columbia, Alverson (1961) places these limits at 54F(12.2C) and 63F(17.2C) respectively.

Within the temperature limits of occurrence, some investigators hold that successful fishing takes place only within a relatively narrow band of temperatures and that fishing success peaks at some optimum value (Flittner, 1966). But others hold that within the temperature limits of occurrence temperature itself does not determine differences in abundance of albacore (Blackburn, 1965). Alverson (1961) has noted that the general relationship of albacore to temperature is one of negative rather than positive association; that is, while temperatures outside the lower and upper limits do not yield albacore, temperatures within the limits do not necessarily guarantee presence of albacore in commercial quantities. Within the temperature limits significant differences in abundance and distribution of albacore have

been noted in both time and space.

Therefore, other variables affect abundance and distribution besides just the magnitude of surface temperature. One possibility is variables other than surface temperature; another is the horizontal rate of change of surface temperature.

Areas of abrupt horizontal discontinuities in temperature, such as fronts⁴ (Howard, 1963; Yabe et al., 1963) and eddies (Laevastu and Rosa, 1963; Yabe et al., 1963), tend to favor occurrence of albacore. These areas are locations of convergences. Even though there have been few concurrent observations of albacore, micronekton, and zooplankton, these places seem to produce an aggregation of zooplankton and micronekton, and accordingly of predatory fishes such as albacore (Griffiths, 1963; Howard, 1963).

Mixed-Layer Depth

A lower temperature limit may also pertain vertically. If so, albacore should only reside above the depth at which the limiting temperature occurs (Blackburn, 1965).

For albacore caught off California, Clemens (1961) cites the depth of the 57F(13.9C) isotherm as forming a "floor" beneath which

⁴As used here, fronts (known as "edges" by fishermen) refer to surface boundaries between waters of different densities and are usually marked by temperature discontinuities.

albacore will not be found. For albacore caught off Oregon, Meehan and Hreha (1969) state that "albacore occurrence is subject to the presence of a layer of warm, mixed water of sufficient thickness to provide living space between the surface and the 57^oF(13.9C) isotherm (p. 18)."

Within the mixed layer, temperature decreases almost negligibly with depth. The lower temperature limit will thus usually occur at the mixed-layer depth or slightly below. Off the Pacific Northwest, Alverson (1961) reported good catches in areas where the mixed-layer depth ranged from 50-75 ft (15.2-22.9m) and averaged about 60 ft (18.3m).

Salinity

Several investigators have suggested the existence of a range of acceptable salinities in analagous fashion to the situation for surface temperature (Craig and Dean, 1968; Owen, 1968; Burbank and Douglas, 1969). But they cite no limiting values. In fact, Blackburn (1965) is skeptical that salinity has any direct effect at all on albacore distribution.

Water Color

Off the Pacific Northwest, blue oceanic water has regularly yielded the best albacore catches, green coastal water has yielded

poor catches, and blue-green water has yielded fair catches (Alverson, 1961). As Alverson points out, however, "water colour itself is probably unimportant (p. 1147)", as changes in water color off the Pacific Northwest usually take place coincident with changes in temperature.

Transparency

Murphy (1959) found that trolling for albacore was more successful in clear water than in turbid water, presumably because of their visual response to a lure which has been designed to resemble a living prey. (The study also showed that gill-netting, which is dependent on lack of visual response, is somewhat more effective in turbid water.) Murphy proceeds to a hypothesis that water clarity may directly influence abundance and distribution of albacore through its effect on their foraging ability. On the other hand, very clear water tends to contain little food (Laevastu and Rosa, 1963).

THE DATA

Most of the data used in this study have come from fishermen. Sea-surface temperatures, however, have been received from a variety of other sources.

Fishermen

During the spring of 1969, 421 logbooks were distributed to west coast albacore fishermen whose home ports varied from San Diego to Seattle. Of these, 123 fishermen (nearly half from California and the remainder split almost equally between Oregon and Washington) filled out logs reporting the results of 359 fishing trips and a total catch of about 325,000 albacore.

The logbook response is impressive, especially when one considers attendant factors. Some of the recipients did not fish in 1969. Others fished, but not for albacore. Some had sold their boats or had retired. And, frankly, many are skeptical of research.

Most of the logged fishing trips reported albacore which were landed in Oregon ports. Of the 2,777 commercial trips landed in Oregon, logs were submitted on 229 trips, or 8.2%. Of the 29,810,631 lbs of albacore landed, logbook data covered 4,217,704 lbs, or 14.1%. It is obvious that the fishermen who cooperated with this study were more successful than average. Further information about the

fishermen is contained in Appendix I.

The logbook format provided spaces for recording the following categories of information for each entry (see Figure 4 for sample filled-out logbook page): date, time, location, number of fish caught since last entry, sea-surface temperature, water color, estimated size of fish, and remarks (such as weather, albacore food, and birds). In order for an entry to be useful, information it had to contain at a minimum was date, time, location, and number of fish caught.

The fishermen were asked to make an entry each day when they started fishing and again in the evening when they shut down for the night. In between, if they were not moving around much and were in an area of little temperature and color change, they were asked to make at least one or two entries during the day. If, however, they were moving around quite a bit or were in an area of considerable temperature and color change, they were asked to make more frequent entries.

The number of entries per day ranged from two to more than a dozen. The average was four or five. Similarly, the quality of logs varied widely. Some fishermen provided information on just date, time, location, and fish. Others, and by far the majority, also provided information in the optional categories at least occasionally and often regularly. In addition, many fishermen generously volunteered information they regarded as important through observations,

DAILY SHEET

Boat RUBY II

1969 Date	Time	Location Loran Position		Number of Fish	Water Temp. & Color	Estimated Size of Fish	Remarks Currents, Feed, Birds, Weather, Size of Fleet, Fish Movement, Whether or Not Showing on Surface, Etc.
		2H- 4	2H- 5				
8-2	1005	2348	3118	40	62 1/2	L	NO SURFACE FISH - 6 BOATS (46)
8-2	1105	2362	3110	64	63	L	SQUID, GRASS
	1230	2400	3105	68	63	L	
	1320	2455	3100	74	63	L	FINE WEATHER
	1500	2535	3120	100	64	L	
	1540	2560	3125	115	64	L	
	1700	2620	3110	125	"		SEE FATHO PAPER. 20% AV. - 80% L. NO FEED IN FISH 6 BOATS - 62 FISH CAUGHT HERE - 4 59 MI AREA. (223)
	1730	2586	3110	135	"	V/AV	
	1840	2560	3108	146	"		
	2130	"	"	177	177		
8-3	0500	2500	3105	0	63°		
	0630	2545	3085	0	63		
	0800	2642	3088	6	"	L	CALM WEATHER
	0900	2690	3080	13	62	L	FIRST JUMPERS SEEN
	1100	2820	3070	25	62	L	SQUID
	1200	2870	3070	41	62	L/AV	75% AV. - SOUTHERLY BREEZE
	1300	2925	3081	48		L	
	1430	3042	3055	70		AV/S	1 PEANUT
	2100	"	"	306		N/S	3 PEANUTS
							10% L 60-80% AV 30-40% S (529)

Figure 4. Filled-out page from Oregon State University albacore logbook.

comments, and questions in the logsheet margins, letters, radio-telephone calls, and personal conversations.

Selected boats were further asked to take supporting oceanographic measurements. Accordingly, eleven boats received bathythermographs (eight mechanical, three expendable) with which they took a total of 421 vertical temperature soundings. Another boat collected 71 surface water samples for later salinity analysis.

Other Sources

Although much of the sea-surface temperature data came from fishermen, an important amount came from other sources. Temperatures from fishermen understandably tended to cluster in areas of good fishing. For complete coverage of the oceanic area under study, it was therefore essential to obtain additional temperatures.

The majority of the supplemental temperatures came from a series of 18 aircraft flights off Oregon and Washington, conducted between 3 July and 24 September and totalling 10,697 n mi of data collection. Three different twin-engine aircraft were used: University of Michigan C-47, National Aeronautics and Space Administration Convair 240A, and U. S. Coast Guard Grumman Albatross HU-16E.

Each aircraft was equipped with a Barnes PRT-5 infrared radiometer, filtered to measure incoming electromagnetic energy between the wavelengths of 8.0 and 14.0 microns, a range within which the

amount of reflected radiation emitted by an object is proportional to its surface temperature. The flights thus yielded continuous sea-surface temperature readings along the track lines, which were flown under the clouds at altitudes of 500 ft or 1000 ft in triangular patterns from the coast to as far as 150 n mi offshore. Accuracy of the measurements was within 0.5C(0.9F) as determined from "ground-truth" experiments (Pearcy and Mueller, 1969).

Temperatures were also obtained from cruises by research vessels. During July, August and September, the Oregon State University R/V YAQUINA and R/V CAYUSE each made three cruises in direct support of the project. In addition, the Bureau of Commercial Fisheries (now National Marine Fisheries Service) R/V DAVID STARR JORDAN and the Fish Commission of Oregon-chartered F/V SUNRISE each made one cruise.

Finally, temperatures were obtained through the Weather Bureau (now National Weather Service) from regular ship reports contributed by such sources as Navy and Coast Guard ships, merchant vessels, and foreign fishing vessels.

ALBACORE CATCH LOCATIONS AND THE SEA-SURFACE TEMPERATURE FIELD

This chapter will describe and discuss the relationship between catch locations of albacore tuna and the sea-surface temperature field.

Introductory Remarks

The ocean off the Pacific Northwest lies within the general region of the California Current, an eastern boundary current. The general features of eastern boundary currents have been well and thoroughly described by Wooster and Reid (1963).

Eastern boundary currents are common to all the major oceans of the world, occurring on the eastern sides of the subtropical gyres along the western coasts of the continents. They are equatorward currents, the source waters of which have been carried eastward in the west wind drift. The currents are slow, broad, shallow, variable, and relatively small in volume of water transported. The waters are cooler than waters of comparable latitudes in the central or western parts of oceans. The surface waters also are relatively fresh due to excess of precipitation over evaporation.

Coastal upwelling⁵ is a common occurrence in eastern boundary

⁵ Coastal upwelling occurs as a result of offshore, horizontal transport of surface water produced by equatorward winds parallel to the coast and by the rotation of the earth; it is the compensatory, ascending replenishment of subsurface water into the surface layer near the coast.

currents, at least on a seasonal basis. Because of the nutrients brought into the sunlight zone of the ocean, areas of coastal upwelling are high in biological productivity and support successful commercial fisheries.

Off the Pacific Northwest coastal upwelling is marked during summer months when winds regularly blow from the north and northwest. The other dominant oceanographic feature in summer is the Columbia River plume. The Columbia River is the major river on the west coast of North America, and provides about 14 percent of total river discharge in the United States. It reaches peak flow of about $17,000 \text{ m}^3/\text{sec}$ ($600,000 \text{ ft}^3/\text{sec}$) from May to July (Duxbury, 1965). In early summer, a large and distinct plume of relatively fresh water extends far to sea and is driven by winds towards the south and southwest.

Sharp temperature and color fronts are frequent. Such fronts are common between the colder, green upwelled water inshore and the warmer, blue oceanic water offshore. They also occur frequently between the outer edges of the plume and offshore oceanic water. The plume is often green or muddy green in color and is present as a tongue of quite warm water in early summer; because the plume has a shallow mixed-layer depth and strong vertical density gradient, it is heated more rapidly than surrounding waters (Owens, 1968).

In 1969 the basic oceanographic patterns were typical. Offshore

temperatures, however, were up to 2F(1.1C) warmer than the long-term average while nearshore temperatures in the upwelling zone were cooler than average (U. S. Bureau of Commercial Fisheries, 1969a, 1969b, and 1969c).

The west coast albacore tuna fishery in 1969 was north and successful. Nearly 30 million pounds of albacore, worth \$6.7 million⁶, were landed in Oregon ports, making 1969 the second best season in history. Another 3.6 million pounds were landed in Washington ports (most of the albacore caught off Washington and Vancouver Island by U. S. fishermen was landed in Astoria). The vast majority of albacore landed in the Pacific Northwest was made up of troll-caught fish. Baitboats accounted for perhaps 20 percent of the total catch and purse seiners for an insignificant share (Hreha, 1971).

Weekly Comparisons, 10 July - 17 September 1969

In this section the 1969 season is traced from start to finish. The traditional approach of fishery agencies is to examine fisheries using a time-and-space scale of one month and 1° latitude by 1° longitude blocks (about 2400 n mi², at the latitudes under study). In order to look at more detailed features and more rapid changes, the time-and-space scale used in this paper is on the order of one week and

⁶Oregon fishermen received from \$420-450 per ton for albacore in 1969.

250 n mi².

For each week catch success is compared with the sea-surface temperature field. Only troll-caught fish are included in the tabulation. The area of coverage is off Oregon and Washington to 200 n mi offshore.

The weekly charts present fish catch information for those boats which regularly logged two or more observations per day. The fish caught by a particular boat during a given interval were assigned to the location recorded at the end of the interval. Number of lines fished per boat varied from a low of seven to a high of twelve; most boats fished about nine lines (Hreha, 1971).

The bulk of the sea-surface temperatures used to draw the charts came from remote-sensing aircraft flights and from fishermen. Additional temperatures came from research vessels and ship reports. Temperatures are presented in Fahrenheit.

The primary navigational reference is Loran, an electronic system, because it is the method by which troll fishermen navigate. Fish catches are summarized by Loran blocks which are 100 microseconds on a side (see Figure 5). The Loran navigation system produces hyperbolic lines of reference; the 100-microsecond blocks are thus not exactly equal in area from one to another. Fish catches are therefore presented on the relative basis of fish caught per hour per boat so as to minimize the effect of unequal areas and make

comparisons between blocks more meaningful. At least one full fishing day of effort had to take place in a given block during the week of interest before fish catch information for that block was plotted on the weekly chart.

Week of 10-16 July 1969

Figure 5 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 10-16 July 1969.

Both coastal upwelling and the Columbia River plume were obvious. Upwelling extended along the Oregon coast southward from Newport and was most intense south of Cape Blanco.

The Columbia River plume, as determined by sea-surface temperature, was highly convoluted, with many eddies and fingers. The eastern edge was especially erratic and reached the beach along the northern Oregon coast; the western edge of the plume was somewhat more distinct. Aircraft flights revealed numerous color fronts within short distances; chunks of blue oceanic water appeared to be interspersed with chunks of green Columbia River water.

Offshore surface temperatures ranged from 59F(15.0C) to 64F(17.8C). Clear skies and moderate winds since 1 July had allowed rapid warming of surface waters.

The start of the west coast albacore season is determined by one or more of the following factors: price settlement, weather,

availability of fish. In 1969 the season start was determined by availability of albacore. The price settlement between fishermen and processors had been reached on 30 June. In both late June and early July weather conditions posed no major problems to troller operations.

By late June a few boats had left port on scouting trips. The first confirmed catch of the season was made on 20 June about 350 n mi west of Cape Mendocino. Scouting continued and became vigorous after 4 July. Until mid-July, however, albacore catches were intermittent and small.

The usual thumb rule for what constitutes minimum economic success for a commercial boat trolling for albacore is 100 fish/day. Using this criterion, the 1969 season started on 12 July about 135 n mi west of Coos Bay.

During this first week of the season, reporting boats caught 3,257 albacore, 1.3% of their season total. Fishing activity was centered in the region from 90-150 n mi offshore of Newport to Coos Bay, an area associated with the downstream portion of the Columbia River plume. During this week catch success was the poorest of the season, averaging 2.4 fish/boat hour or about 38 fish/boat day, assuming a standard fishing day of 16 hours.

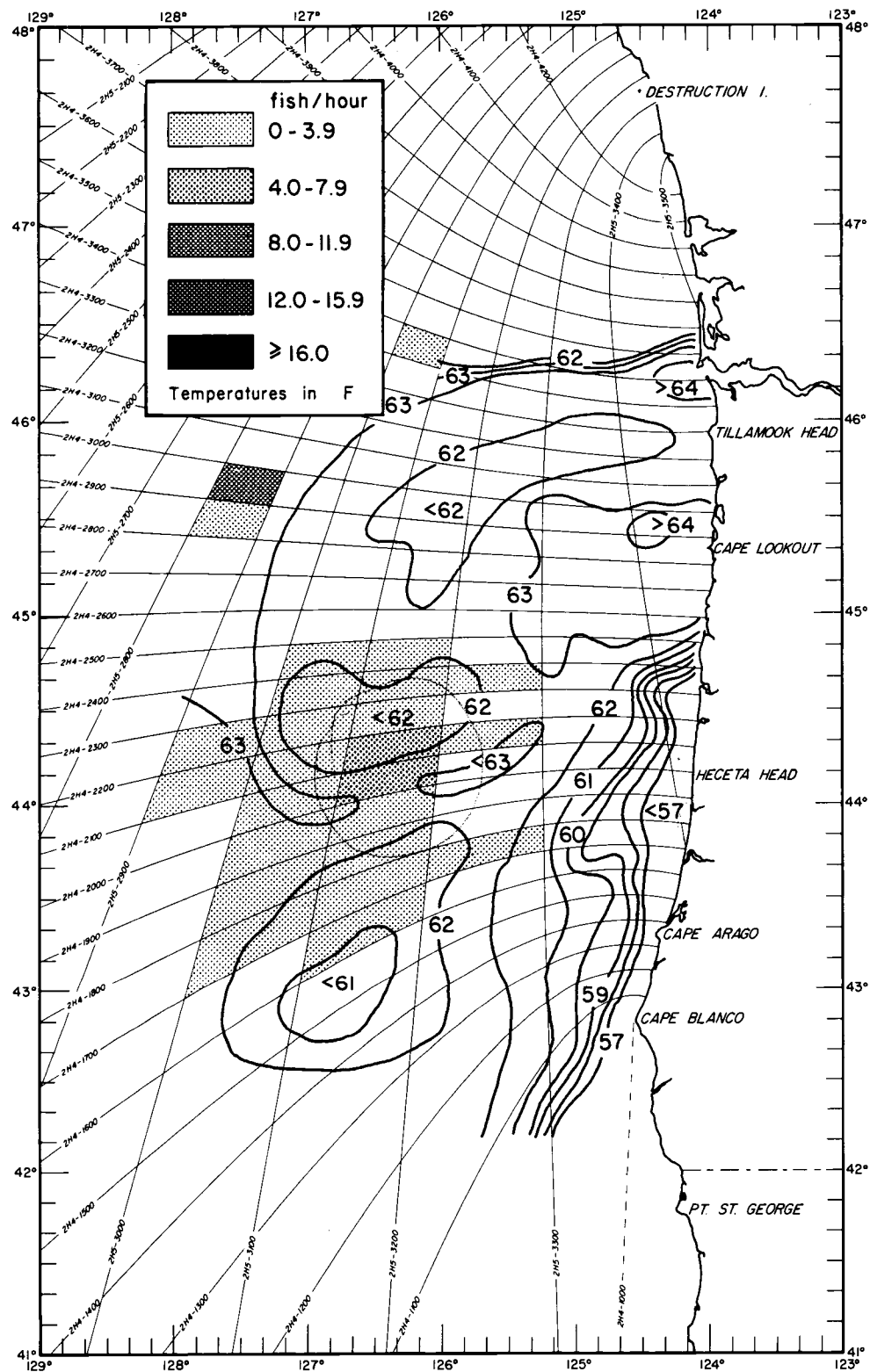


Figure 5. Albacore tuna catch data and the sea-surface temperature field, 10-16 July 1969.

Week of 17-23 July 1969

Figure 6 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 17-23 July 1969.

The most significant feature of the week was the vigorous northerly winds. Winds off Oregon were 20-30 kts and greater, while winds off Washington were somewhat less strong. The resultant heavy seas caused considerable damage to fishing vessels, and two boats were lost off southern Oregon.

The high winds affected both coastal upwelling and the Columbia River plume. Upwelling became much more pronounced than during the previous week, extending at least as far north as Grays Harbor. The horizontal extent was also greater, frequently to 30 n mi in width. And temperatures within the upwelling zone were colder, down to 46F (7.8C) off Newport. At the same time, the northerly winds broke up the offshore part of the plume into smaller patches while the extensive coastal upwelling interrupted and masked the nearshore portion of the plume. The winds also brought about a drop in offshore sea-surface temperatures of up to 1F(0.6C) and an increase in mixed-layer depths.

In spite of the rough seas and high winds, fishing was much more successful than during the previous week. Reporting boats caught 37,951 albacore, 14.7% of the season total. The center of fishing activity remained in the region from 90-150 n mi offshore of Cape Arago to north of Heceta Head. Fishing was more widespread and

further north than during the previous week. A secondary center of activity developed about 110 n mi west of the mouth of the Columbia River. Catch success improved to 8.6 fish/hour, or 138 fish/boat day, an economically favorable level of production.

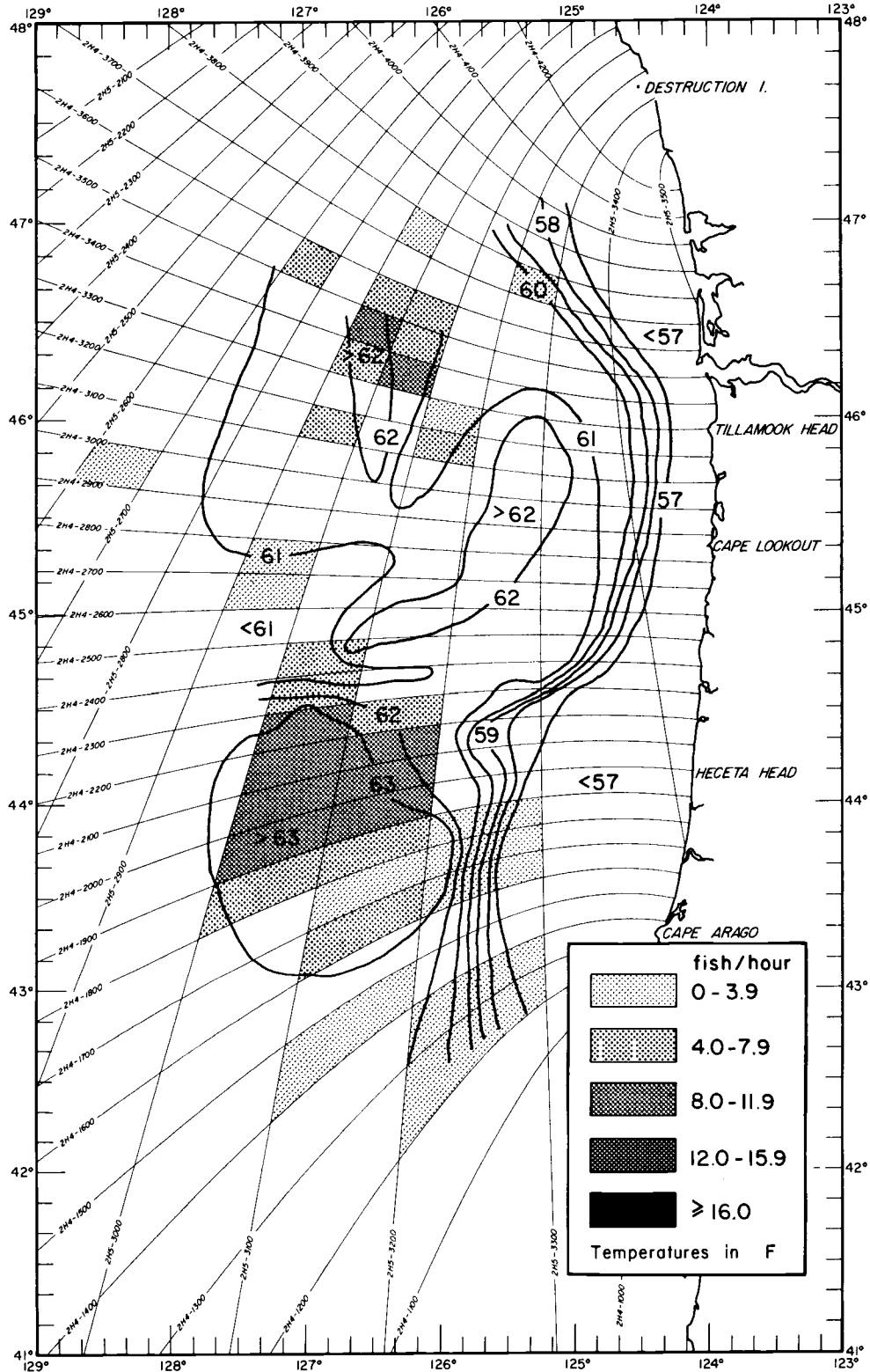


Figure 6. Albacore tuna catch data and the sea-surface temperature field, 17-23 July 1969.

Week of 24-30 July 1969

Figure 7 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 24-30 July 1969.

Persistent northwest winds and resultant strong upwelling masked the upstream, nearshore portion of the Columbia River plume, as determined by temperature. Downstream, off the central Oregon coast, a couple of patches of the plume were indicated by warm (>63F) water.

Coastal upwelling reached its most extensive development of the season during this week. Winds were unusually strong from the north during the entire second half of July. The upwelling front was commonly found 50 n mi offshore. Nearshore temperatures were among the lowest on record; off Newport, a temperature of 45.5F (7.5C) was measured.

Sea-surface temperatures offshore fell in the same range as for the previous week, although the pattern was somewhat different. Mixed-layer depths increased to the 70-100 ft (21.3-32.8m) range.

Conditions favorable to albacore and moderating weather led to another jump in albacore catches. During the week reporting boats caught 59,147 albacore, 22.8% of the season total, the most productive single week of the 1969 season. Catch success also reached a season high of 10.1 fish/hour, or 162 fish/boat day.

The albacore continued to move north, and were now found in quantity north of the mouth of the Columbia River. About one-half of the week's catch came from the area west of Heceta Head. Areas west of Cape Lookout and northwest of the Columbia River mouth also yielded large catches.

The week of 24-30 July was the first that any 100-microsecond Loran block supported a catch-per-unit-effort of over 16 fish/boat hour. It is noteworthy that blocks of high catch success frequently fell adjacent to blocks of low catch success; smooth transitions in catch-per-unit-effort did not usually exist.

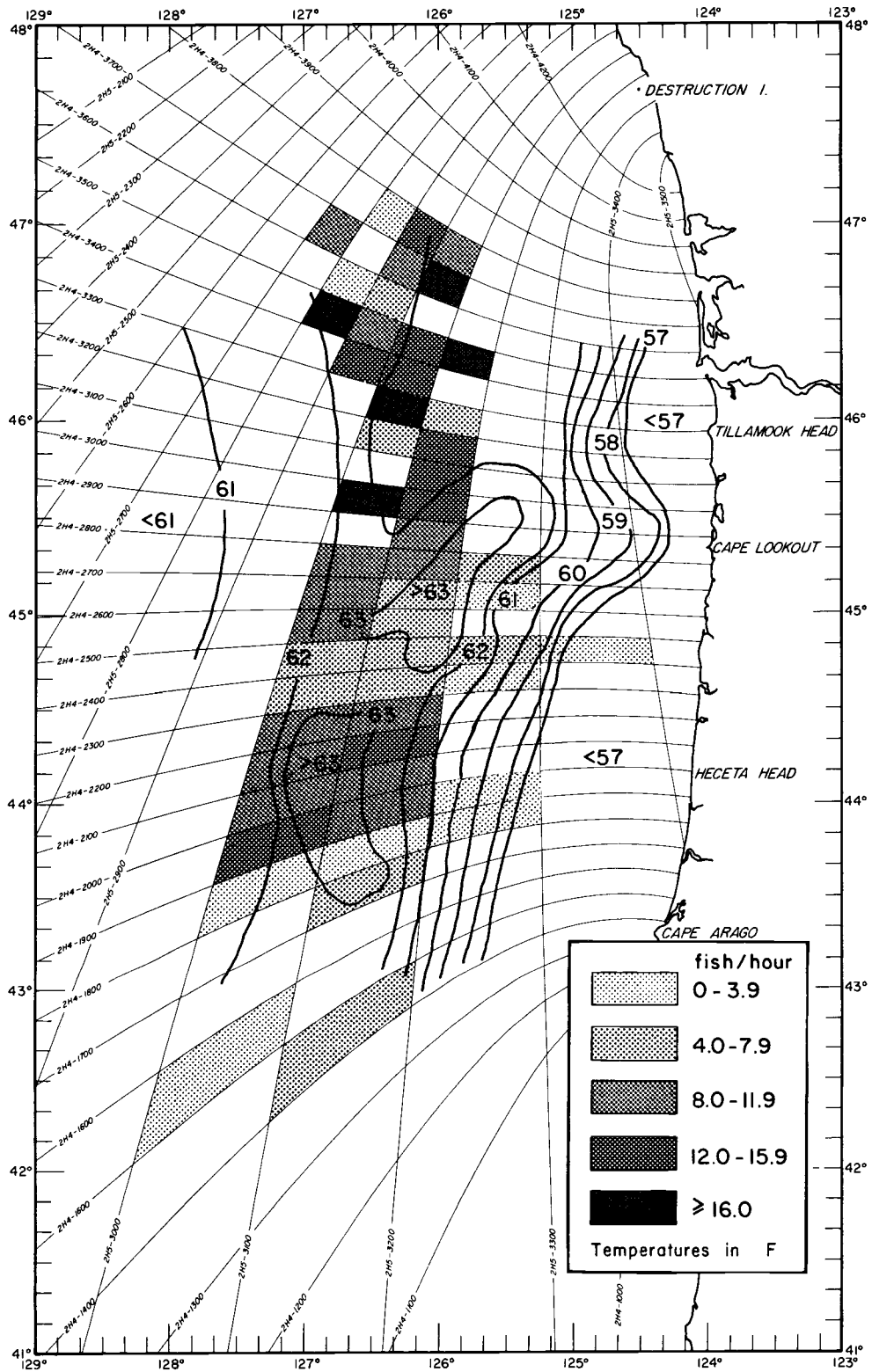


Figure 7. Albacore tuna catch data and the sea-surface temperature field, 24-30 July 1969.

Week of 31 July-6 August 1969

Figure 8 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 31 July-6 August 1969.

The most significant oceanographic event of the week was the shift of winds from northwest to southwest for 36 hours from the evening of 3 August through the morning of 5 August. This shift, coupled with moderate winds the rest of the week, brought about a dramatic relaxation in coastal upwelling. The band of upwelled water narrowed by 15-25 n mi and the coldest temperatures were about 5F(2.8C) warmer than the previous week. Upwelling no longer extended north of the mouth of the Columbia River and the upwelling front had a less intense gradient.

The Columbia River plume was not detectable seaward of the river mouth by temperature for more than a few miles. The patch of water warmer than 63F(17.2C) west of Cape Lookout was a possible offshore remnant of the plume.

Fishing continued to be excellent. Reporting boats caught 54,291 albacore, 21.0% of the season total. Catch success remained high at 8.7 fish/hour, or 139 fish/boat day.

The area of fishing shifted further north, but no fishing took place north of the area covered by the chart. Well over half of the week's

fish were caught about 100 n mi west of Cape Lookout in the area in and just seaward of the patch of water warmer than 63F(17.2C).

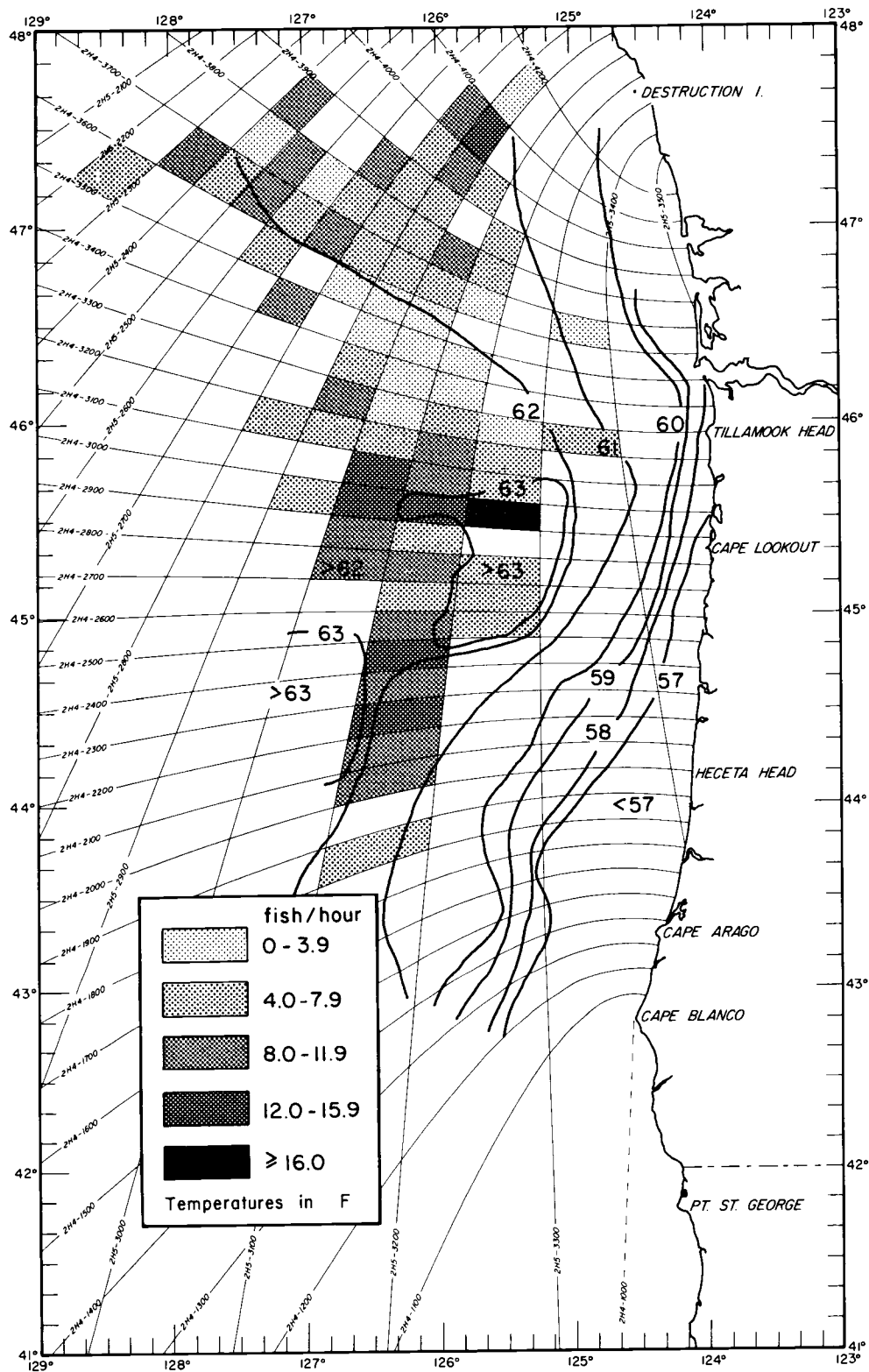


Figure 8. Albacore tuna catch data and the sea-surface temperature field, 31 July - 6 August 1969.

Week of 7-13 August 1969

Figure 9 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 7-13 August 1969.

The Columbia River plume still was not detectable by temperature for more than a few miles from the river mouth, and was not detectable by temperature for the rest of the season. This situation was brought about by seasonal reduction in river flow, increased wind mixing, overall warming of offshore waters, and widespread coastal upwelling. Offshore remnants of the plume persisted somewhat longer. (Columbia River water could still be traced at sea, however, by salinity.)

The winds of the week were mostly from the north and northwest but light. As a result the coastal upwelling pattern changed little from the previous week. The only exception was south of Cape Blanco where winds were much stronger due to the thermal low over the valleys of northern California; in this area, cold water extended seaward from the coast about 60 n mi and nearshore temperatures were as low as 48F(8.9C).

Extensive clouds and fog retarded the warming of offshore waters. Mixed-layer depths ranged from 50-110 ft(15.3-33.7m).

This was the last of the highly productive weeks of the 1969 season. Reporting boats caught 57,295 albacore, 22.1% of the season total. This was also the first week during which albacore were caught

north of the area covered by the chart, off Vancouver Island; 1,893 fish, or 3.3% of the week's total, were taken from this area. For the remainder of the 1969 season albacore were caught in varying quantities off Vancouver Island. Catch success for the week remained high at 8.7 fish/hour, or 139 fish/boat day.

During the week the area of active fishing spread out in both the north-south and east-west directions. The distribution of albacore was patchy. Fish were found all the way from Cape Arago to Vancouver Island but not continuously. Some of the areas where catch-per-unit-effort was high, like those west of Heceta Head, yielded relatively few fish.

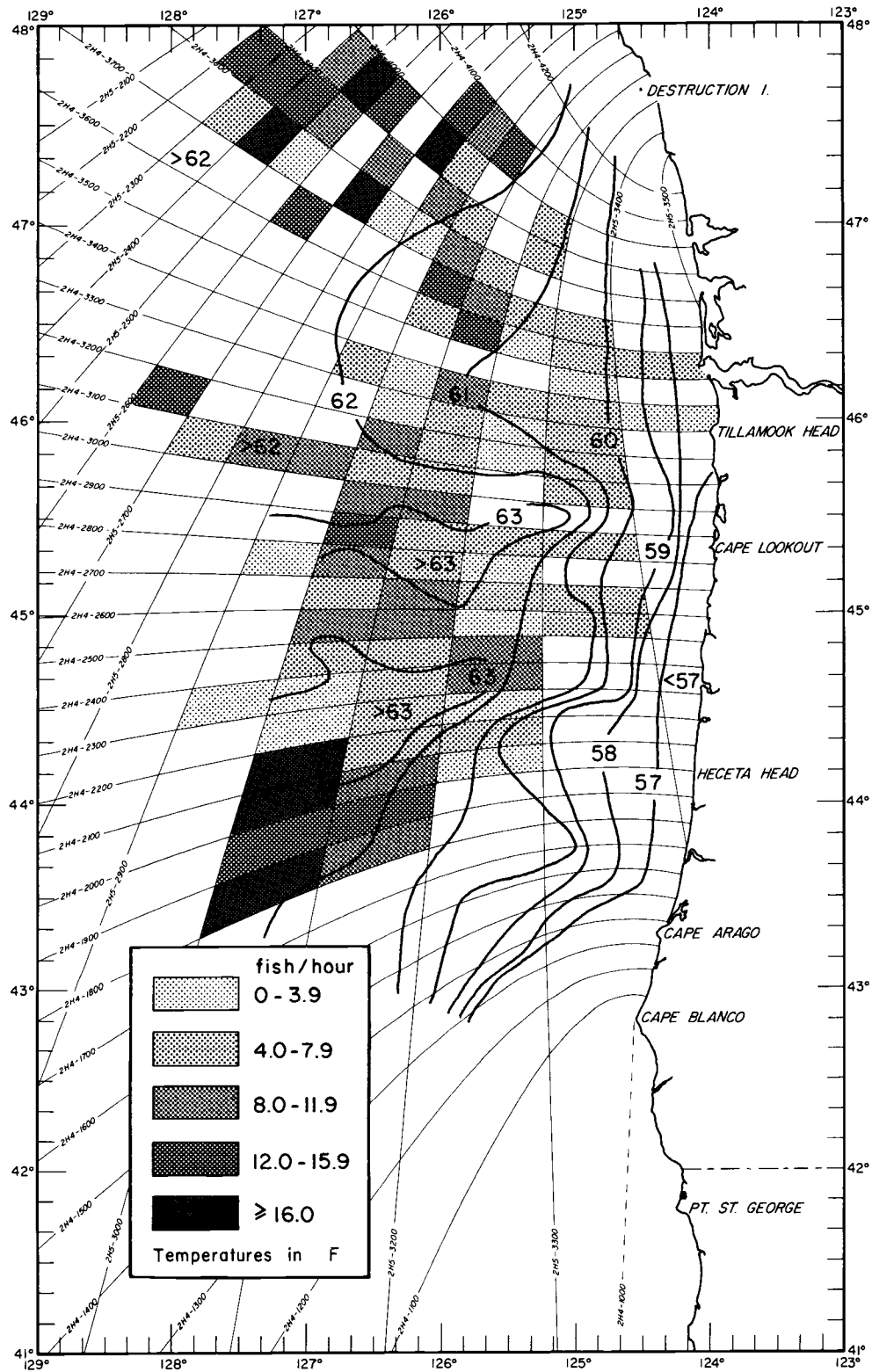


Figure 9. Albacore tuna catch data and the sea-surface temperature field, 7-13 August 1969.

Week of 14-20 August 1969

Figure 10 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 14-20 August 1969.

The winds of the week continued light-to-moderate. Occasional weak weather fronts moved through, causing a shift of winds to the west and south as they passed over the area.

The coastal upwelling pattern remained static. Upwelling was present along much of the Oregon coast, but was not well developed north of the Columbia River. Nearshore temperatures were not as cold and the horizontal extent of upwelling was not as great as in late July.

Open-ocean temperatures warmed about 1F(0.6C) during the week. Mixed-layer depths ranged from 50-80 ft(15.3-24.4 m) through most of the chart area.

Fishing activity was markedly spotty and variable. Production in a given area was unpredictable from day to day. New centers of fishing activity developed rapidly in areas considerable distances away from previous ones. Albacore were found in commercial quantities from Cape Blanco to Vancouver Island, 40-120 n mi offshore.

Weekly production for reporting boats fell off sharply to 23,746 albacore, 9.1 percent of the season total. Catch success also fell

off, but not nearly so sharply, to 7.8 fish/hour, or 125 fish/boat day.

Fishing off Vancouver Island continued to increase.

The area west of Cape Blanco reflected the catch by one boat transiting north; although albacore were present and catch success was high, the weather was too rough to allow sustained fishing.

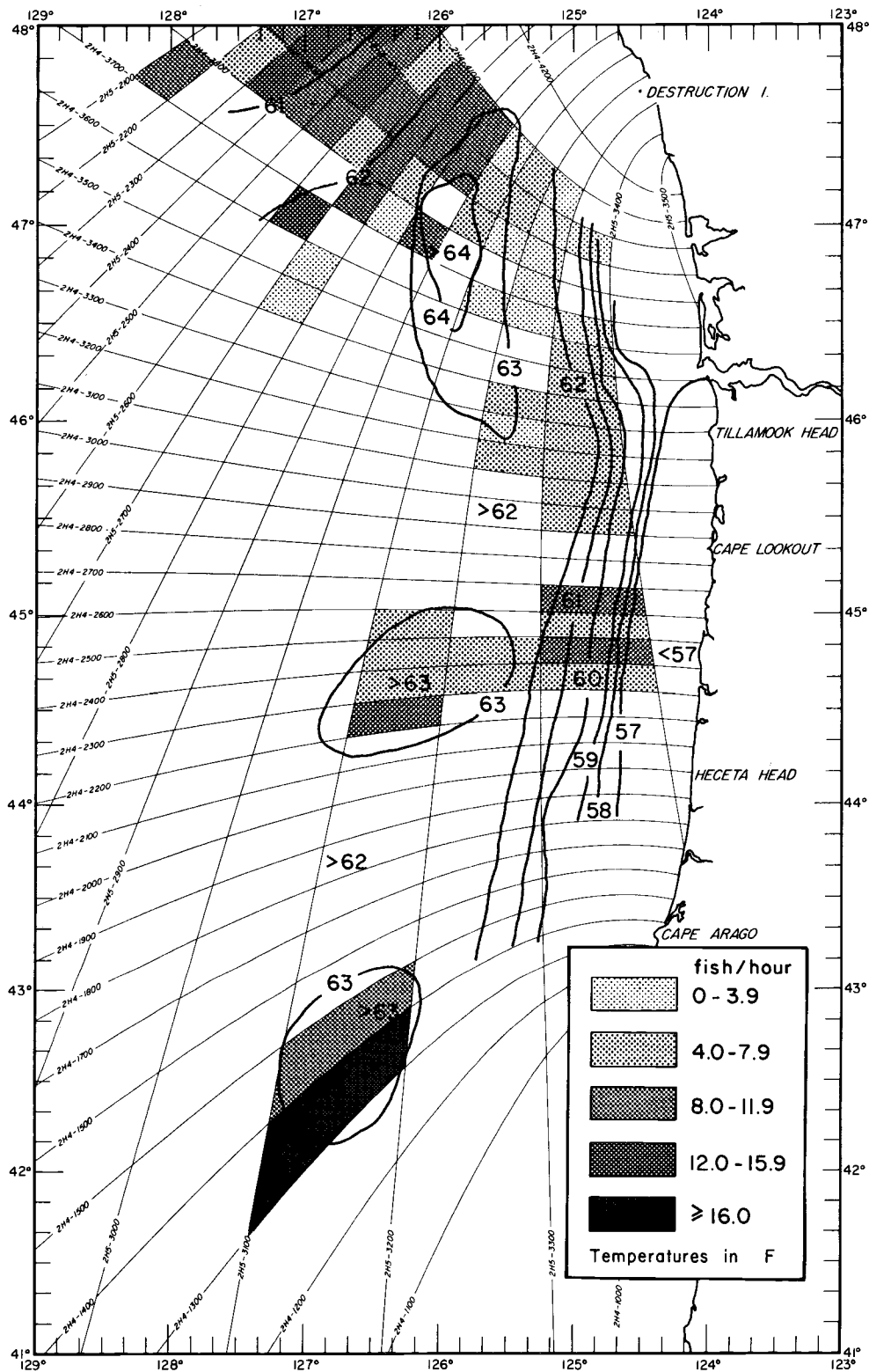


Figure 10. Albacore tuna catch data and the sea-surface temperature field, 14-20 August 1969.

Week of 21-27 August 1969

Figure 11 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 21-27 August 1969.

There was only a small amount of coastal upwelling during the week. Just a thin band existed where it was present. The passage of two weather systems produced southerly winds for the last part of the week, which in turn brought about rapid subsidence in upwelling.

Open-ocean temperatures and mixed-layer depths continued in the same general range as the previous week. Sea-surface temperatures in the offshore area were near the long-term average. The summer heating cycle had reached its peak by this week; north of the Columbia River sea-surface temperatures started to cool.

Weather conditions from Cape Blanco to Destruction Island were good. Off Vancouver Island, however, a storm passed through on 23-24 August, disrupting fishing operations and causing the loss of one boat.

Some albacore appeared to be moving offshore north of the chart off Vancouver Island as surface waters started to cool. During this week, fishing reached its peak for the season off Vancouver Island; nearly half of the week's fish came from this area.

In terms of overall production from waters off the Pacific

Northwest, the week showed another sharp drop. Reporting boats caught 8,798 albacore, 3.4% of the season total. Catch-per-unit-effort showed a slight drop to 6.8 fish/hour, or 109 fish/boat day.

The area of fishing activity was more restricted than during the week of 14-20 August. There was no fishing of consequence between Cape Blanco and Cape Lookout, and fishing did not extend as far seaward. Productive areas were scattered: off Vancouver Island, west of Destruction Island, and about 50 n mi offshore from Tillamook Head to Cape Lookout.

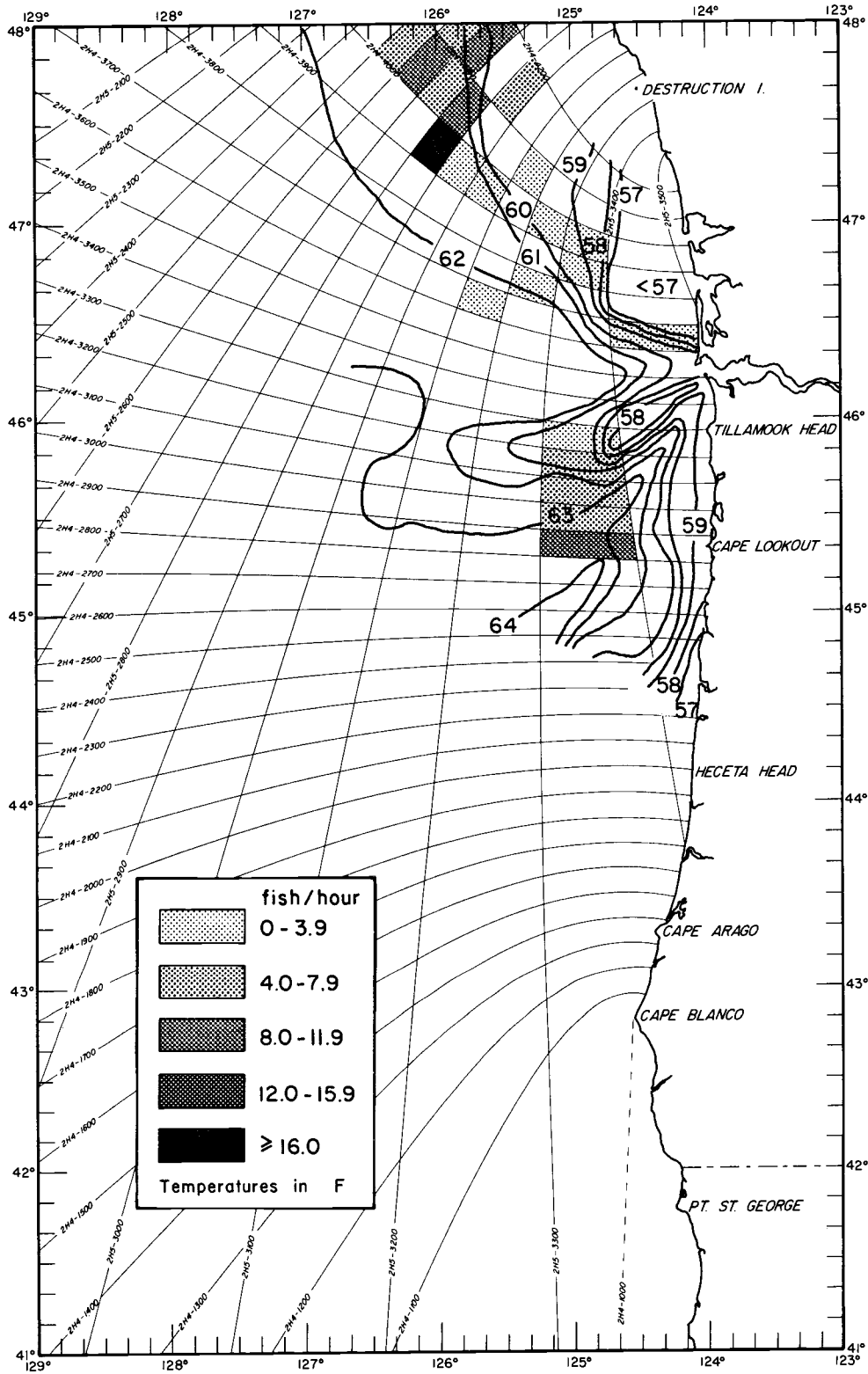


Figure 11. Albacore tuna catch data and the sea-surface temperature field, 21-27 August 1969.

Week of 28 August-3 September 1969

Figure 12 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 28 August - 3 September 1969.

The winds of the week were stronger and steadier from out of the north than for several weeks. Coastal upwelling redeveloped along the entire Oregon coast and along the southern Washington coast; the extent of cold surface water along the coast was greater than had existed since the last week of July.

Seasonal cooling of surface waters was taking place off Washington and Vancouver Island, but was not yet evident off Oregon.

Fishing declined off Vancouver Island. Fewer albacore seemed to be present. The worsening weather impeded fishing efforts for those albacore that still remained. The location of fishing activity shifted south and inshore.

During the week reporting boats caught 5,958 albacore, 1.3% of the Pacific Northwest season total. Catch success also showed a drop to 5.0 fish/hour, or 80 fish/boat day, the first week since 10-16 July that average daily production per boat had fallen below 100 fish/day.

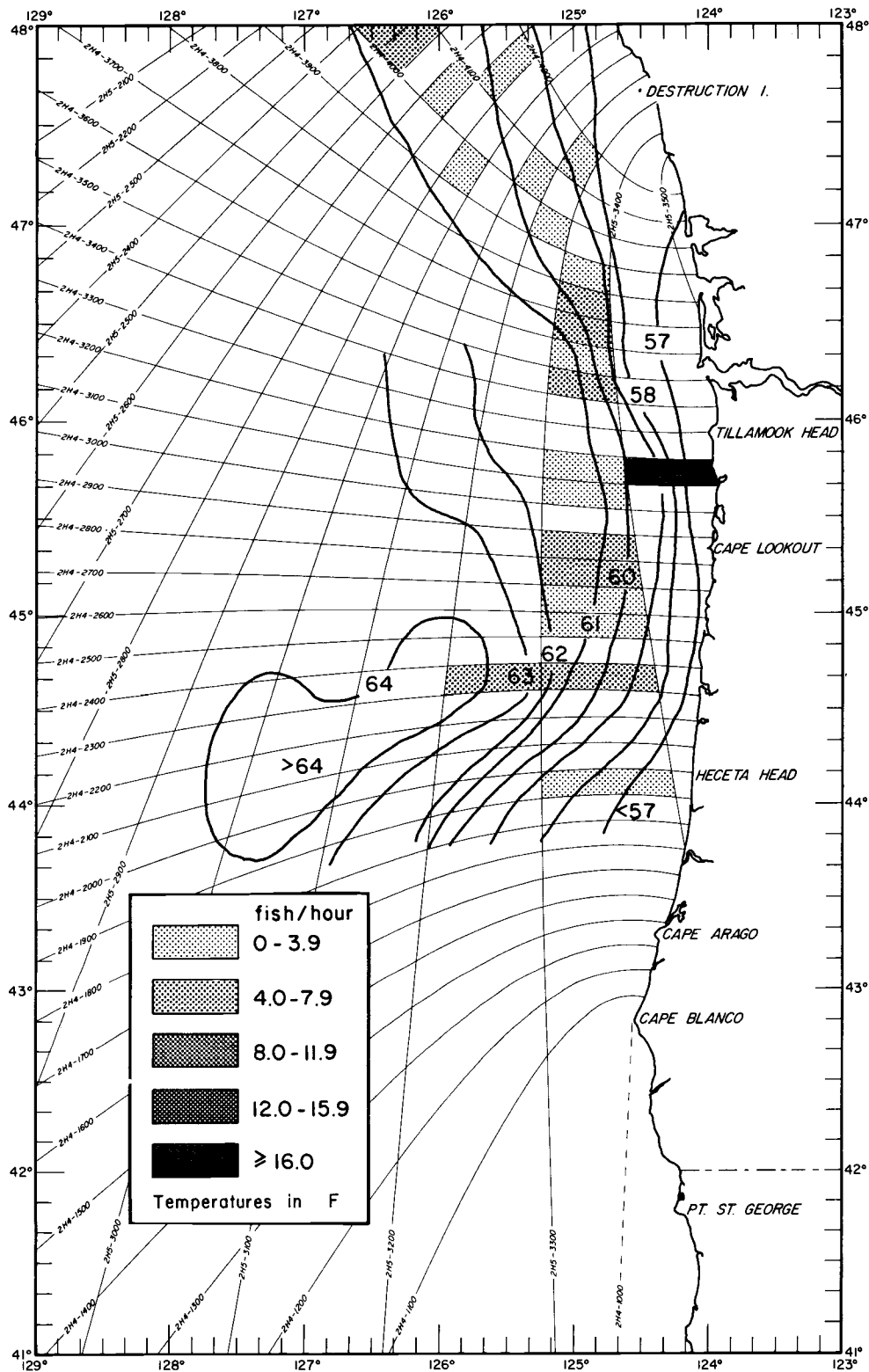


Figure 12. Albacore tuna catch data and the sea-surface temperature field, 28 August - 3 September 1969.

Week of 4-10 September 1969

Figure 13 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 4-10 September 1969.

Winds were moderately strong during the week, but did not restrict fishing. Coastal upwelling remained well developed.

Fall cooling was noticeable throughout the area. During the previous week the warmest surface temperature measured was 64.6F (18.1C); during the present week, by contrast, the warmest temperature was 62.8F (17.1C). Mixed-layer depths varied from 30-90 ft (9.1-27.4 m).

The favorable weather allowed fishing to take place over a relatively widespread area. Some fishing still continued off Vancouver Island, and did persist through much of September, although operations were restricted increasingly by deteriorating weather associated with a succession of Gulf of Alaska storms.

For the week fish catches rebounded somewhat to 6,480 albacore, 2.5% of the season total. Catch-per-unit-effort similarly improved to 6.7 fish/hour, 107 fish/boat day. The most productive fishing took place west of Destruction Island and west of Heceta Head.

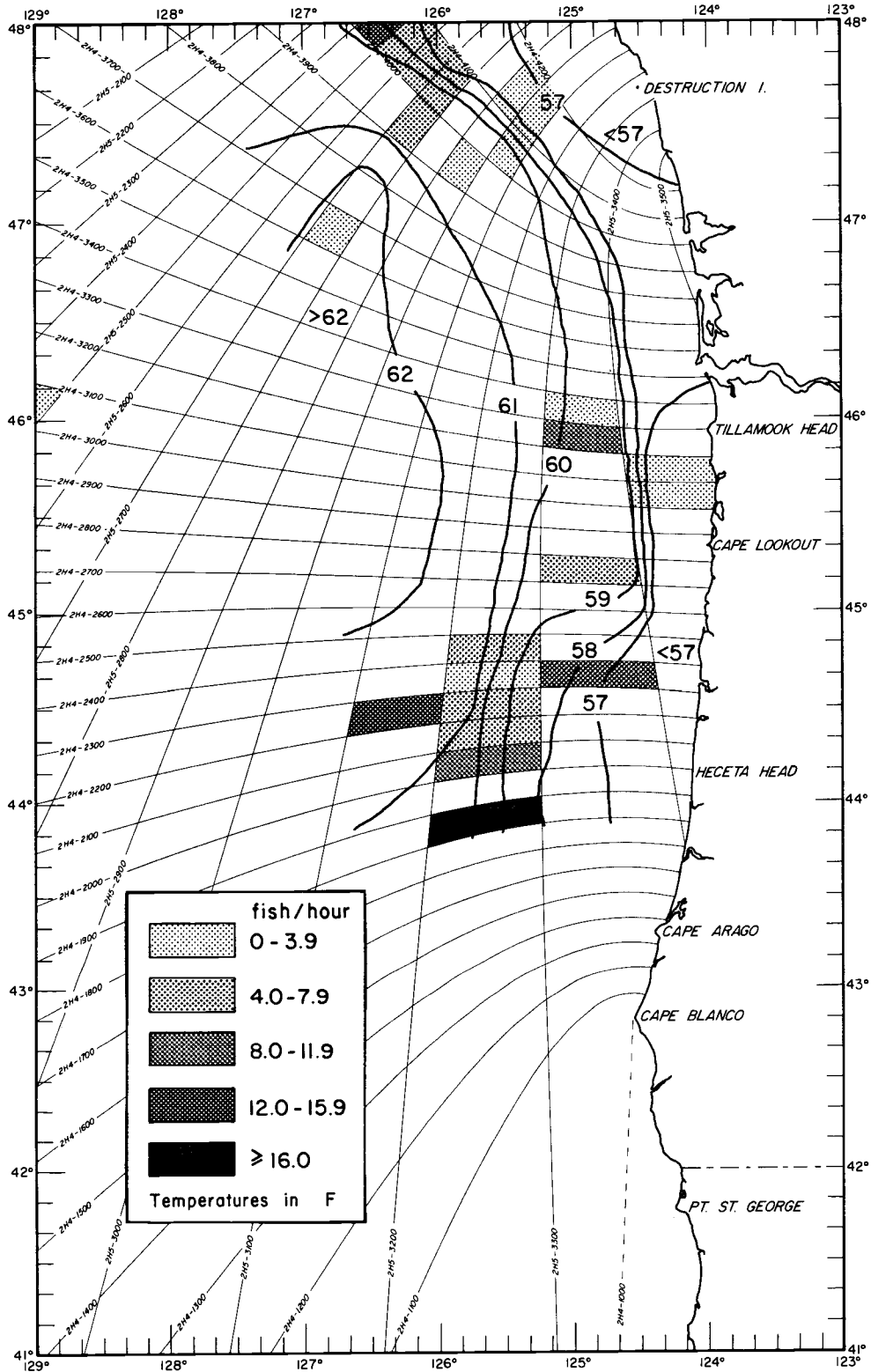


Figure 13. Albacore tuna catch data and the sea-surface temperature field, 4-10 September 1969.

Week of 11-17 September 1969

Figure 14 presents the weekly chart of albacore catch success compared with the sea-surface temperature field for 11-17 September 1969.

The 1969 commercial albacore season off the Pacific Northwest ended during the week. On 16 September the first major fall storm hit the area. Winds from the south of 30-40 knots brought high seas and heavy swells. Surface temperatures were rapidly lowered and the albacore were scattered.

Before the storm albacore were found in small, quickly moving, widely separated schools. About half of the week's fish were caught in the area relatively close to shore off Tillamook Head to Cape Look-out. Reporting boats caught only 146 fish off Vancouver Island.

Many boats completed their season during the week. Other boats headed south to California to pursue late-season albacore there. Reporting boats caught just 2,169 albacore, 0.8% of the season total. Catch efficiency for the week was 4.0 fish/hour, or 64 fish/boat day.

In late September and early October moderating weather allowed some resumption of fishing nearshore off Oregon for a few days at a time. Results by individual boats were occasionally favorable but sustained efforts were not possible.

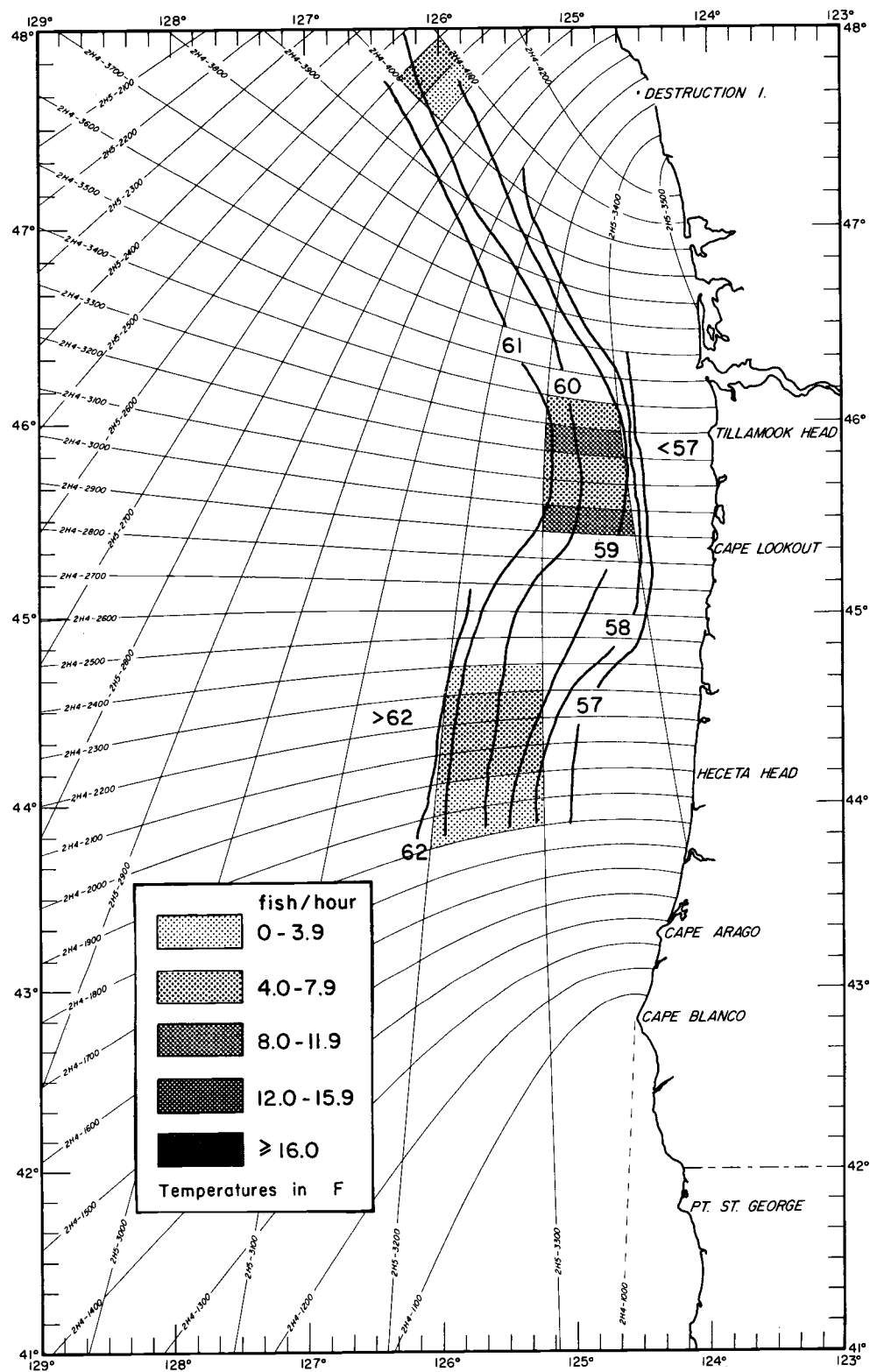


Figure 14. Albacore tuna catch data and the sea-surface temperature field, 11-17 September 1969.

Daily Comparisons, 5 and 7 August 1969

The frequent flights made it worthwhile to see if comparisons between albacore catch success and the sea-surface temperature field could be made for single days.

Flights were basically planned to fill in needed temperatures. The fishing fleet was scattered and fast-moving. As a result, flights took place over a sufficient concentration of the fleet for daily comparisons on only two days, 5 August and 7 August.

The aircraft track lines, sea-surface temperatures measured, and fish catch results (within 10 n mi of the aircraft lines) are shown for 5 August on Figure 15 and for 7 August on Figure 16.

During this period of time winds were blowing from the north. From 3-5 August, however, winds had blown from the south so that upwelling is not so extensively developed as it had been earlier in the season.

An active center of fishing had developed west of the mouth of the Columbia River and Cape Lookout in early August. It was thus decided to make the two flights over this area in a specific attempt to investigate microscale features in temperature and in albacore distribution and abundance.

Coastal upwelling was clearly evident on all four flight lines. With travel offshore sea-surface temperature warmed considerably

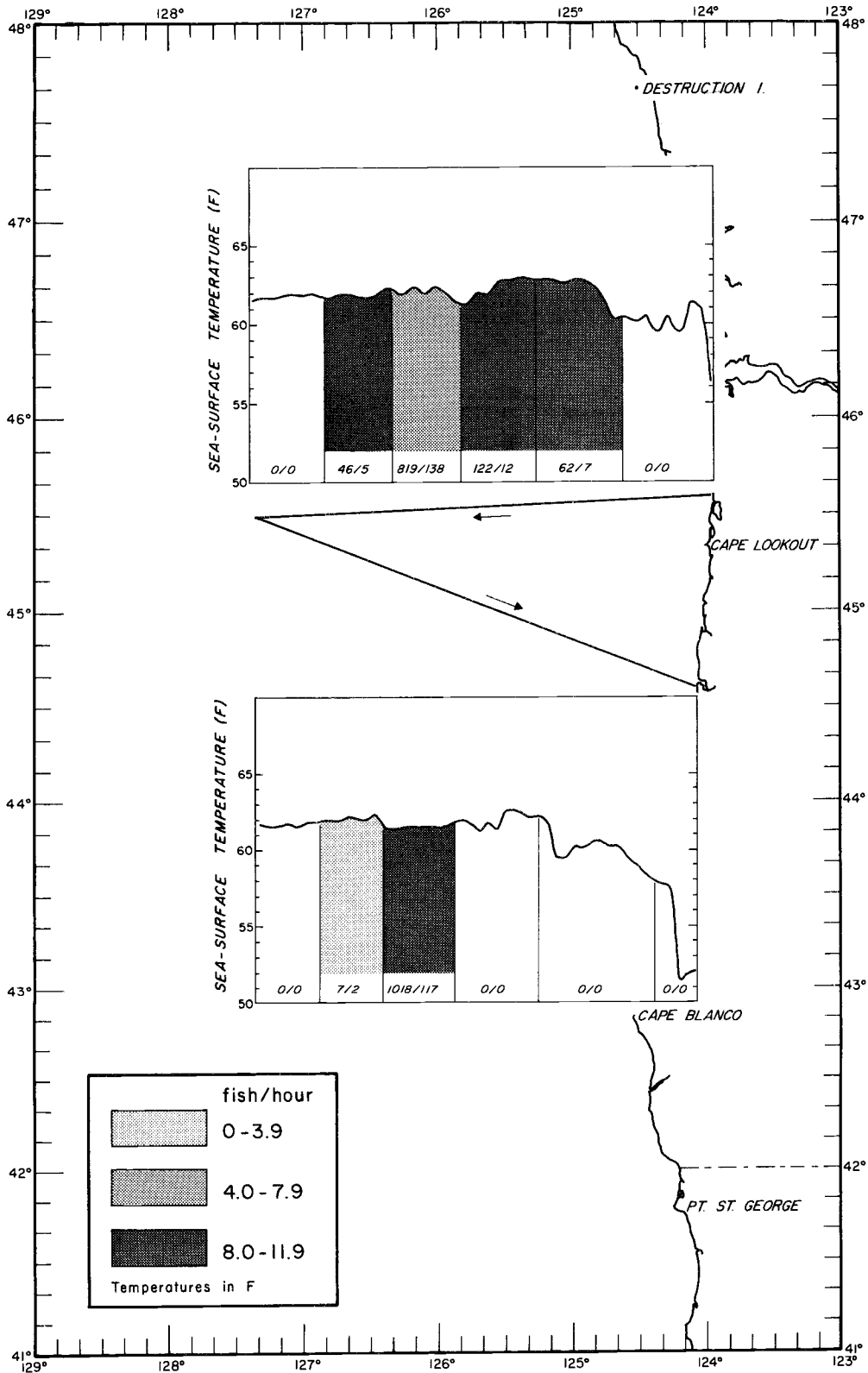


Figure 15. Aircraft flight lines, sea-surface temperatures, and albacore tuna catch data (within 10 n mi of the flight lines) for 5 August 1969. For each navigational subdivision, albacore caught are shown to the left and hours fished to the right.

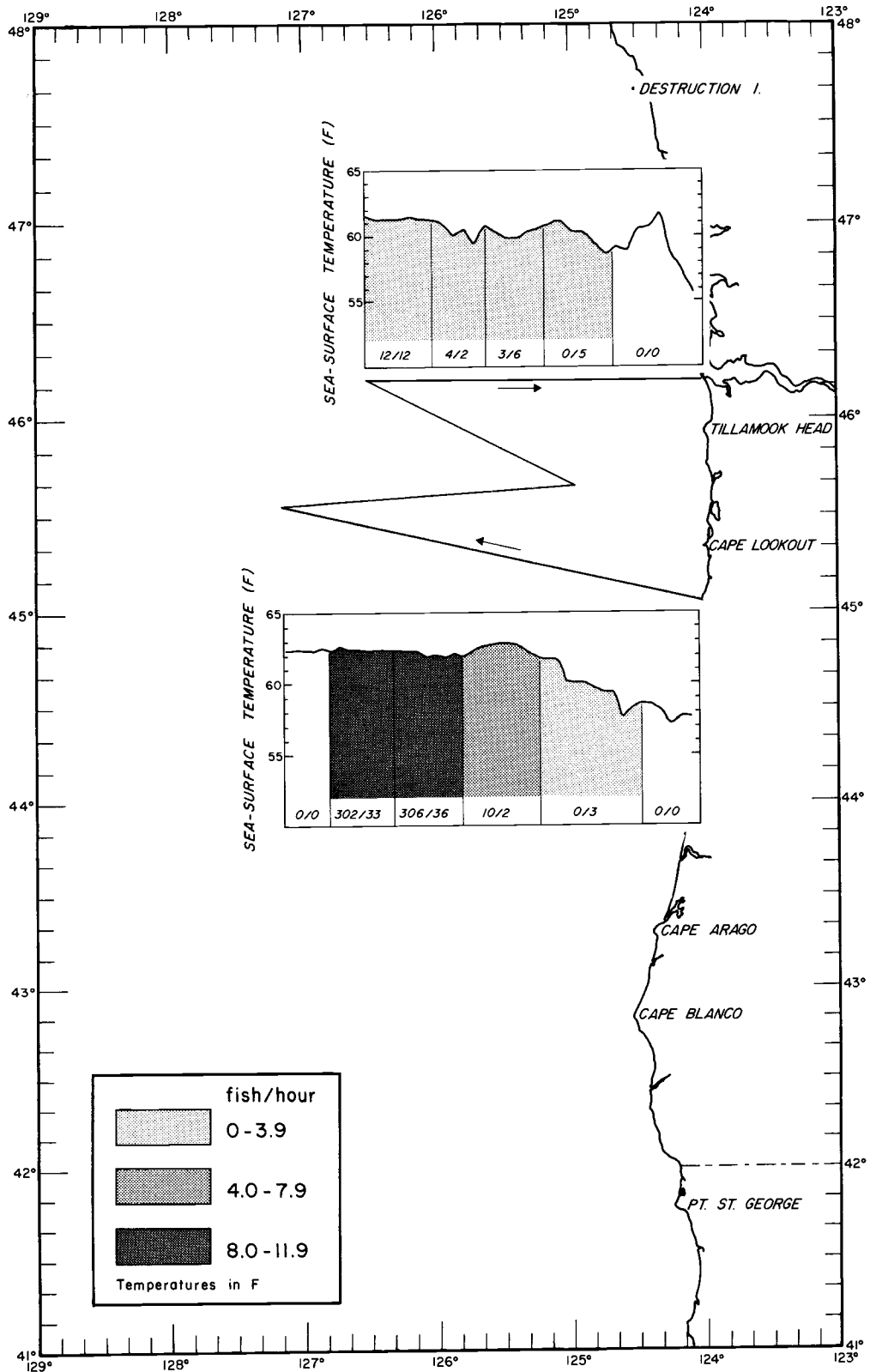


Figure 16. Aircraft flight lines, sea-surface temperatures, and albacore tuna catch data (within 10 n mi of the flight lines) for 7 August 1969. For each navigational subdivision, albacore caught are shown to the left and hours fished to the right.

in the first few miles and then stabilized at about 62F(16.7C). The fluctuations in temperature nearshore may represent intermixing between upwelling water and Columbia River water; numerous and complex color fronts were noted. Further offshore, for the seaward half of the flight lines, temperature was a little cooler than closer inshore, but the temperature structure was also less complex and color fronts were infrequent (except for the northern flight line on 7 August).

On 5 August, most of the albacore were caught in blue water offshore of the warmest zone. By 7 August many boats had headed north for Vancouver Island and effort off northern Oregon was much reduced from two days earlier. Still, most of the fish came from blue water, offshore of the area where the warmest water and most complex temperature and color structure occurred (Pearcy and Mueller, 1969).

The results from 5 August and 7 August are a disappointment. No new insights were gained into a more detailed knowledge of albacore, but several points were clearly demonstrated. First, navigational accuracy is as important as accuracy of temperature measurements; at the seaward extremities of the flight tracks, uncertainty in position was on the order of 10 n mi. Second, for comparisons on the scale of a day or less, there were data from too few boats and the reporting intervals were spaced too widely. Finally, the matter of intra-day variability in fish catch should be recognized; Appendix II

presents an investigation into this point and shows that fish catch was significantly uneven in its distribution within the fishing day.

RELATIONSHIP BETWEEN ALBACORE CATCHES AND SELECTED OCEANOGRAPHIC VARIABLES

The previous chapter emphasized the relationship between albacore catches and the sea-surface temperature field. In the course of the discussion, mention was made descriptively of the relationship between albacore catches and other oceanographic variables. The present chapter will present quantitative and semi-quantitative results of investigations into the relationship between albacore catches and sea-surface temperature, mixed-layer depth, water color, and salinity.

Sea-Surface Temperature

1969

In 1969 cooperating fishermen reported concurrent sea-surface temperature and fish catch data for 275,172 albacore taken from waters off the Pacific Northwest. The data are summarized by month of catch in Figure 17.

The three monthly distributions are significantly different one from another. Using the χ^2 test and testing the distributions by pairs against the hypothesis that both came from the same population, in all three cases the hypothesis was overwhelmingly rejected at the 0.01 level.

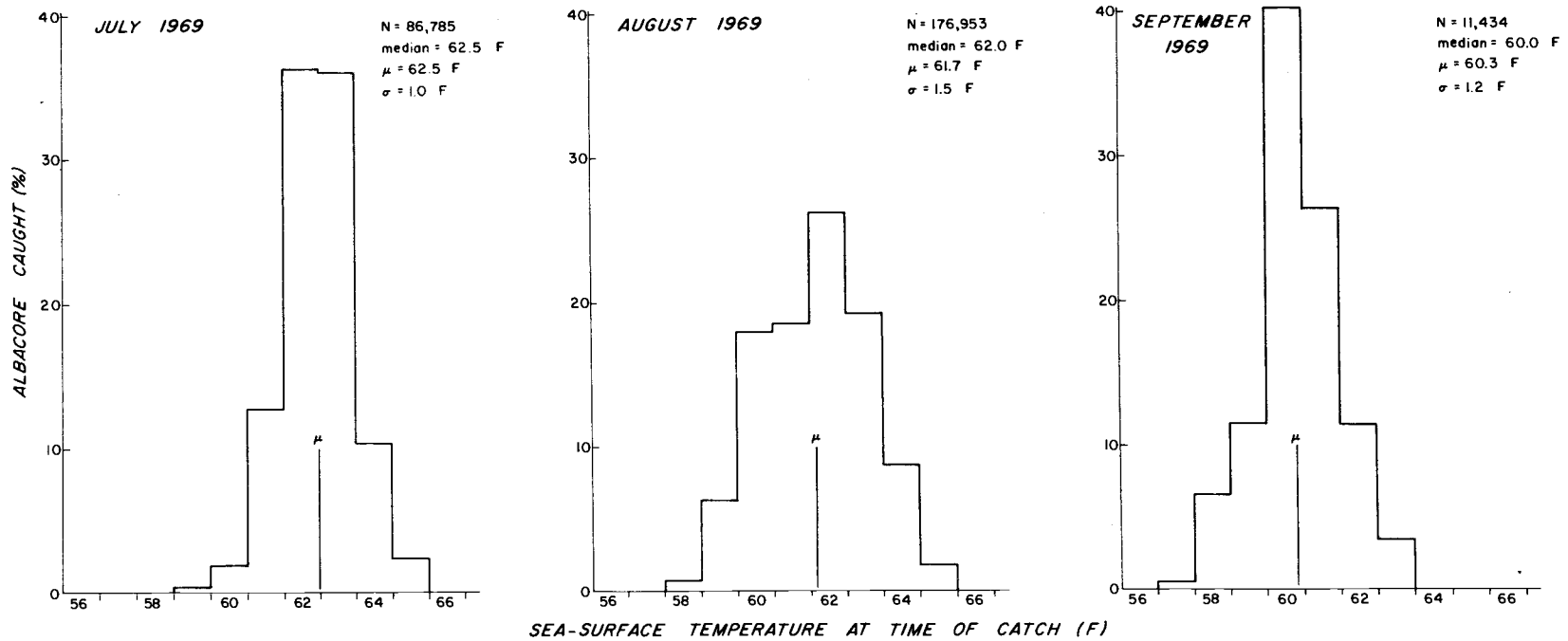


Figure 17. Monthly distributions of albacore caught in 1969 off the Pacific Northwest by sea-surface temperature (F) at time of catch.

The mean temperature for albacore caught in July was 62.5F (16.9C), the warmest mean of the three months. The standard deviation for July was 1.0F(0.6C), smallest of the three. The mean temperature for albacore caught in August was 61.7F(16.5C), while the standard deviation was 1.4F(0.8C), largest of the three months. The mean temperature for albacore caught in September was 60.3F (15.7C), coolest of the three months, and the standard deviation was 1.2F(0.7C).

1954-1958

The only other west coast data of comparable extent to the 1969 data are those collected by the California Department of Fish and Game for the years 1954-1958 (Clemens 1961a). During these five years cooperating fishermen reported concurrent sea-surface temperature and fish catch data for a total of 1,297,915 albacore, ranging by year from a low of 57,087 fish in 1954 to a high of 438,692 fish in 1956.

There are noteworthy differences in the nature of the data between 1969 and 1954-1958. The 1969 data are for albacore caught off the Pacific Northwest, regardless of where they were landed. The 1954-1958 data, on the other hand, are for albacore landed in California, regardless of where they were caught. As a result, the 1954-1958 data cover albacore which were caught from central Baja California

to Vancouver Island. Additional differences are that the 1954-1958 data report both troll-caught and bait-caught albacore and were recorded once a day to the closest whole degree F.

The 1954-1958 data are presented by year in Figure 18; for comparison, the 1969 data have been pooled for the season and are displayed at the bottom of the figure. The distributions for the six years are significantly different from each other at the 0.01 level, as determined by the χ^2 test. Still, some generalizations seem appropriate and these are attempted in Table 3.

For the 1954-1958 period no albacore were caught from waters cooler than 54F(12.2C) or warmer than 77F(25.0C). While the temperature ranges for the different categories of fishing success varied from year to year, there was greater variation at the warm end of the ranges than at the cool end.

By comparison, the temperature ranges for the 1969 data do not disagree with the ranges established by the 1954-1958 data. While the 1969 data came from cooler temperatures and a narrower temperature range, this situation is to be expected from more northerly waters, a more limited geographical area, and troll-caught albacore only.

The 1954-1958 data were also examined for trends within the season but it was not possible to make as detailed an analysis as with the 1969 data. Table 4 summarizes by month the relationship between sea-surface temperature and albacore catches.

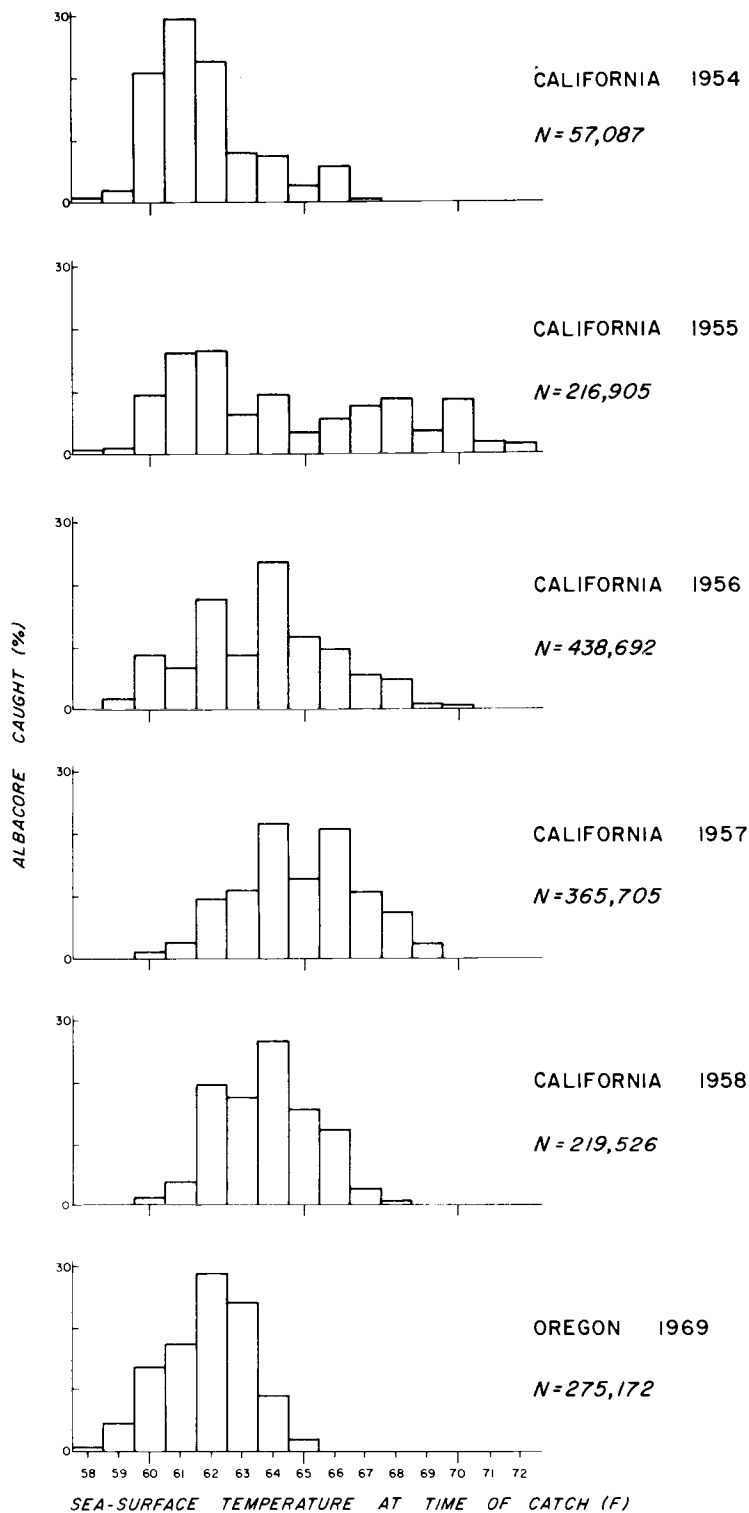


Figure 18. Annual distributions of albacore caught during the years 1954-1958 and 1969 in the northeast Pacific by sea-surface temperature at time of catch.

Table 3. Relationship between albacore catches (surface and near-surface) and water temperature in the northeast Pacific Ocean.

Source of data	Temperature ranges for		
	Occurrence of albacore	Successful prosecution of fishery	Best fishing
California 1954	55-72F (12.8-22.2C)	59.5-66.5F (15.3-19.2C)	59.5-62.5F (15.3-16.9C)
California 1955	55-77F (12.8-25.0C)	59.5-70.5F (15.3-21.4C)	
California 1956	54-71F (12.2-21.7C)	59.5-68.5F (15.3-20.3C)	
California 1957	57-76F (13.9-24.4C)	60.5-69.5F (15.8-20.8C)	63.5-66.5F (17.5-19.2C)
California 1958	54-70F (12.2-21.1C)	60.5-67.5F (15.8-19.7C)	61.5-66.5F (16.4-19.2C)
Oregon 1969	54-66F (12.2-18.9C)	58.5-65.5F (14.7-18.6C)	59.5-63.5F (15.3-17.5C)

Table 4. Basic statistics for 1954-1958 California albacore with respect to sea-surface temperature at time of catch (calculated from data reported in Clemens 1961a).

	<u>Year</u>					
	1954	1955	1956	1957	1958	
July-mean (F)	64.5	63.3	64.8	65.7	63.5	
std dev (F)	1.6	2.0	1.7	1.9	1.5	
Aug-mean (F)	62.5	66.9	63.9	65.5	64.7	
std dev (F)	1.6	3.5	2.7	2.5	1.5	
Sept-mean (F)	61.3	64.5	62.6	64.1	63.8	
std dev (F)	1.3	4.0	1.7	1.3	1.6	
Oct-mean (F)	60.6	61.5	61.7	63.1	62.7	
std dev (F)	1.1	1.9	2.2	1.4	0.9	

In general, early-season fish were caught in relatively warm water, mid-season fish were taken from a fairly wide range of temperatures, and late-season fish were caught in cooler water.

Catch-Per-Unit-Effort as a Function of Sea-Surface Temperature

Earlier investigators have pointed out that catch-per-unit-effort data do not indicate as marked a decline in availability at sea-surface temperatures cooler than the most productive band of temperatures as does gross catch (Alverson, 1961).

Some of the present data are of a sufficient detail to permit investigation of this point. For the analysis which follows, fishing days for a given boat which contained only one or two observations were excluded. For the remaining data, a computation of catch-per-unit-effort was made for each observation; the number of fish caught and number of hours fished were then assigned to the appropriate catch-per-unit-effort category for the sea-surface temperature at which the fish were caught.

The detailed results of this analysis by month are shown in Figure 19. For each degree of temperature the percentage of fish caught within each catch-per-unit-effort category is indicated graphically. Noteworthy is the wide scatter of observations among the various catch-per-unit-effort categories for all temperatures and all three months. None of the distributions approaches normality.

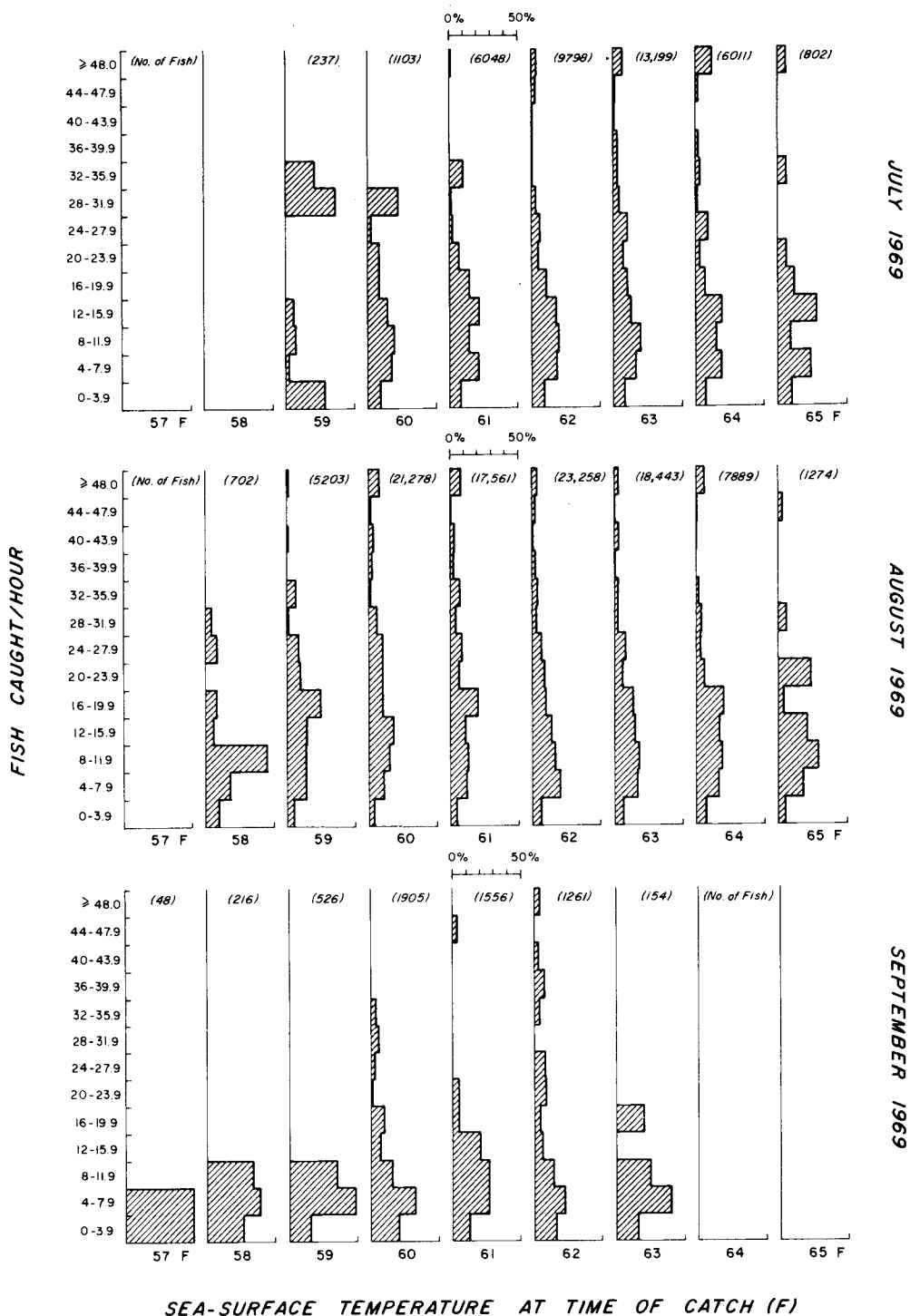


Figure 19. Catch-per-unit-effort as a function of sea-surface temperature by month.

Almost every temperature reflects a skewing towards high catch-per-unit-effort. With this type of presentation, however, trends within a month and between months are difficult to see.

Therefore, a summary graph has been prepared and is presented as Figure 20. In this figure the medial number of fish caught per hour is shown by month for each degree of temperature within which more than two percent of the fish for the month were caught. Differences in catch efficiency between months are more marked than are differences within months. No substantial decline in catch-per-unit-effort can be noted at temperatures cooler than those at which the bulk of the fish for the month were caught (for comparison, the mean temperature and standard deviation for all fish caught during the month are indicated).

Mixed-Layer Depth

Eleven fishermen agreed to allow bathythermographs to be installed on their boats for the 1969 season. Eight of these were of the older, mechanical type while the remaining three were new, expendable models. The eleven boats took a total of 420 vertical temperature soundings.

Many of the vertical temperature soundings were taken at the same time as a regular logbook entry was made. Table 5 presents the results of albacore catches as related to mixed-layer depth.

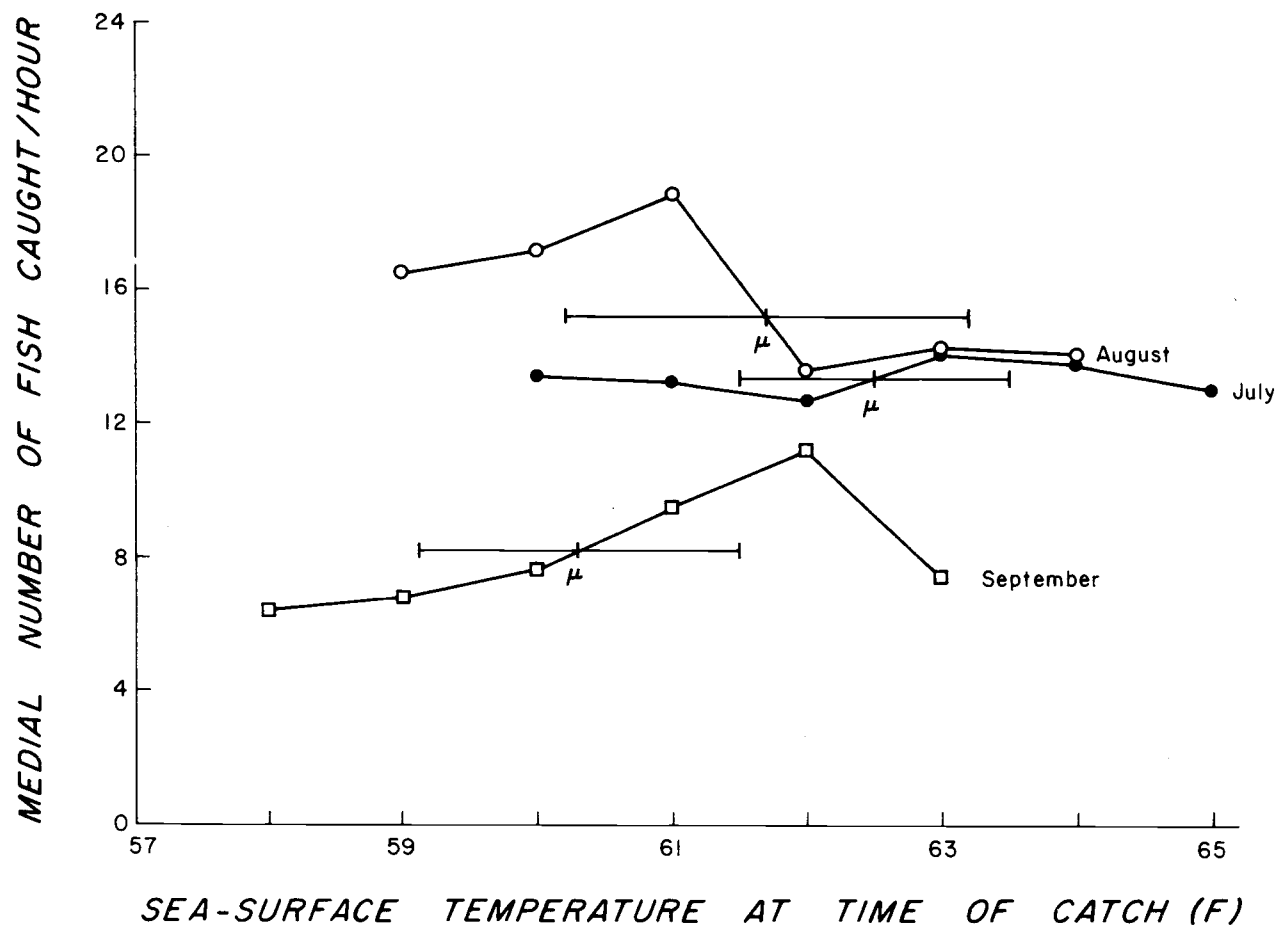


Figure 20. Medial catch-per-unit-effort by month as a function of sea-surface temperature at time of catch. For comparison, the mean temperature and standard deviation for all albacore caught during each month are shown.

Table 5. Albacore catches as related to mixed-layer depth.

Mixed-layer depth (ft)	July			August			September		
	Nr caught	Percent	Fish/Hour	Nr caught	Percent	Fish/Hour	Nr caught	Percent	Fish/Hour
16-25	18	1.4	4.5	1	0.05	0.7			
26-35	105	8.2	3.4						
36-45	145	11.3	5.6	16	0.8	1.8	26	17.0	7.4
46-55	165	12.8	5.2	157	7.7	12.0	4	2.6	0.8
56-65	85	6.6	5.8	291	14.3	10.2			
66-75	136	10.6	4.3	279	13.7	7.0	1	0.7	1.0
76-85	40	3.1	2.6	680	33.4	7.5			
86-95	307	23.9	9.7	253	12.5	5.3	5	3.3	3.3
96-105	281	21.9	6.5	186	9.2	6.5	34	22.2	7.5
106-115	3	0.2	6.0	154	7.6	9.6	7	4.6	1.6
116-125				16	0.8	8.0	43	28.1	14.3
126-135							33	21.6	14.6
Total	1285			2033			153		

The monthly distributions of albacore caught as a function of mixed-layer depth are uneven, particularly so in July and September. Nonetheless, the trend of fish catches as the season progressed is towards deeper mixed layers. The median value of mixed-layer depths for July, as determined by total number of fish caught, was about 70 ft(21.3 m); for August the median was about 80 ft(24.4 m) and for September about 110 ft(33.5 m).

In July appreciable numbers of albacore were caught in mixed-layer depth ranges of 36-75 ft(11.0-22.9 m) and 86-105 ft(26.2-32.0 m). In August most fish were caught in a range from 56-105 ft(17.1-32.0 m), and in September most were caught from 96-135 ft(29.3-41.1 m). Analysis of mixed-layer depths from a catch-per-unit-effort approach yielded no clear-cut trends, although somewhat higher catch efficiencies were associated with the more productive depth ranges noted above.

It is sometimes difficult to determine the mixed-layer depth unambiguously from a given trace. No particular problems, however, were encountered with interpreting the 1969 data. A check showed that the 57F(13.9C) isotherm regularly occurred 10-20 ft(3.0-6.1 m) deeper than that read as the mixed-layer depth.

Water Color

About half of the cooperating fishermen logged observations of water color at the time of catch. They used three color categories: blue, blue-green, and green.

The results of albacore catches as related to water color by month are presented in Table 6.

Table 6. Albacore catches as related to water color.

	July		August		September	
	No. Fish	%	No. Fish	%	No. Fish	%
Blue	36,071	79.1	57,958	65.6	3,419	51.7
Blue-Green	7,088	15.5	20,830	23.6	2,812	42.5
Green	<u>2,423</u>	5.3	<u>9,455</u>	10.7	<u>385</u>	5.8
	45,582		88,144		6,616	

By month, the highest percentage of fish caught in blue water occurred in July. A smaller percentage was taken from blue water in August, and still smaller in September. But in each month a greater percentage of fish were taken from blue water than from blue-green and green water together.

With blue-green water a trend also exists, but in the opposite direction. That is, blue-green water yielded the smallest

percentage of albacore in July. A higher percentage was taken from blue-green water in August, and still higher in September.

The amount of albacore caught in green water varied less regularly by month, reached its peak in August, but was relatively small throughout the season.

Salinity

One boat collected 71 surface water samples between 15 August and 21 September for later salinity analysis. During this time the boat was fishing off Washington and Vancouver Island.

The lowest salinity measured was $31.66^{\circ}/\text{oo}$, and the highest was $32.16^{\circ}/\text{oo}$. The vast majority of salinities fell between $31.87^{\circ}/\text{oo}$ and $32.07^{\circ}/\text{oo}$. During periods when salinity samples were taken the boat caught 1,803 albacore in water averaging $60^{\circ}\text{F}(15.6^{\circ}\text{C})$ and varying from a low of $58^{\circ}\text{F}(14.4^{\circ}\text{C})$ to a high of $63^{\circ}\text{F}(17.2^{\circ}\text{C})$.

The range of salinities was much too narrow to be able to say whether distribution and abundance of albacore are or are not related to salinity.

GENERAL DISCUSSION

The 1969 albacore season off the Pacific Northwest began on 12 July and finished on 16 September. On the basis of Oregon landings of 29,810,631 pounds, 1969 was the second most successful season in history. July finished in second place, when compared against previous Oregon landings for that month, August in first place, and September in fourth place.

During the 67-day season, neither effort nor success was evenly distributed. Most of the fish were caught during a fairly short period of time. The three-week period from 24 July to 13 August produced more than 65 percent of the albacore caught during the 1969 season. By contrast, the last four weeks of the season produced just 10 percent.

Total west coast landings in 1969 were 51.3 million pounds, somewhat greater than the 1960-69 average of 46.4 million pounds. More than 75 percent of this production came from waters off the Pacific Northwest (some fish caught off the Northwest were landed in California ports). More boats fished for albacore than average, and the catch was distributed more unevenly than usual among participating fishermen (Flittner, 1969).

Throughout the season a patchiness in albacore distribution was noted. The albacore apparently moved quickly from place to place

in small concentrations. Contributing factors may have been frequently shifting winds and a relatively sparse food supply.

The Columbia River plume was a dominant oceanographic feature in early and mid-July when river discharge was high and moderate northerly winds directed the plume to the southwest. By late July, because of reduced river flow and vigorous winds, the plume was breaking up, as determined by sea-surface temperature. In August the plume was no longer clearly delineated by temperature⁷.

Coastal upwelling was present on and off throughout the season. Upwelling was usually more intense south of Cape Blanco due to stronger winds and topographic effects.

The structure of sea-surface temperature off the Pacific Northwest was more complex than previously supposed, and changes were more rapid and substantial. In particular, there was ample confirmation of extensive changes of upwelling within short periods of time. Upwelling developed more slowly than it subsided. While it took moderate winds from the north for a period of 48-72 hours to produce appreciable upwelling, winds from the south brought about a dramatic subsidence of upwelling within as short a period as 24 hours.

⁷ Temperature is not an effective indicator of the Columbia River plume. Salinity is much more satisfactory; by salinity, the plume was detectable until mid-August (Evans, 1970).

In an earlier chapter the progress of the 1969 fishery was documented in some detail on a week-by-week basis. Table 7 is a summary of the general location and movement of the fishery during the season.

During July the fish were concentrated in the southern portion of the chart area and well offshore. The fish seemed to make their July entry into waters associated with the Columbia River plume. Some albacore were caught near the upwelling front but many more were caught near the western edge of the plume.

During August albacore spread out considerably, both in the north-south and inshore-offshore directions. By the week of 7-13 August albacore were found off Vancouver Island, a situation which persisted to some extent for the remainder of the season. Albacore were frequently caught closer to shore in the upwelling front and just seaward of it.

During September the center of fishing activity shifted south and further inshore. The September location of catches reflects the typical development of a nearshore, late-season fishery and is a consequence of fall cooling and the onset of fall storms which preclude extensive offshore fishing activities.

The present study confirms sea-surface temperature as an important variable in determining the limits of albacore distribution. (Sea-surface temperature also happens to be the easiest oceanographic

Table 7. General albacore catch locations by week for 1969 off the Pacific Northwest.

	Number of Fish Caught	Inshore ¹ (%)	Offshore (%)	North ² (%)	South (%)
10-16 July	3,257	2.1	97.9	4.2	95.8
17-23 July	37,951	2.3	97.7	4.5	95.5
24-30 July	59,147	0.8	99.2	9.2	90.8
31 July - 6 Aug.	54,291	3.8	96.2	26.0	74.0
7-13 Aug.	57,295	12.0	88.0	26.5	73.5
14-20 Aug.	23,746	22.4	77.6	71.9	28.1
21-27 Aug.	8,798	15.7	84.3	88.6	11.4
28 Aug. - 3 Sept.	5,958	46.4	53.6	67.2	32.8
4-10 Sept.	6,480	42.8	57.2	55.0	45.0
11-17 Sept.	2,169	82.0	18.0	17.0	83.0

¹"Inshore" refers to the area inshore of Loran line 2H5-3200 (which is located roughly 70 n mi offshore); "offshore" refers to the remainder of the chart area.

²"North" refers to the area north of Loran line 2H4-3500 (which runs approximately east-west off of the mouth of the Columbia River), plus the area off Vancouver Island; "south" refers to the remainder of the chart area.

variable to measure quantitatively so that more is known about it than about any other oceanographic variable.)

In the case of the 1954-1958 California data both the low and high temperature limits by season seem to reflect a preference of the fish. At one time or another, albacore were found in water as cold as 54F (12.2C), as warm as 77F(25.0C), and continuously in between. The wide temperature range notwithstanding, the best fishing was found in a narrower band tending towards the cool end of the range, from a low of 59.5F(15.3C) to a high of at least 66.5F(19.2C), and perhaps as high as 68.5F(20.3C). No one optimum temperature was found. Part of the explanation for the broad range of temperatures is that both troll-caught and bait-caught fish are included and that the fish were taken from a wide geographical area.

The 1969 Oregon situation, on the other hand, was somewhat different. The low temperature limit was the same as for the California data, 54F(12.2C), and probably reflects a preference of albacore, since in all six years surface waters substantially cooler than 54F (12.2C) were present. But the high temperature limit was 66F(18.9C) and was a function of the ocean, since in 1969 the ocean off the Pacific Northwest did not warm beyond 66F(18.9C). Again, the best fishing was found in a narrower band, this time tending towards the warm end of the range, from a low of 59.5F(15.3C) to a high of 63.5F(17.5C). And again, no one optimum temperature was found.

Alverson (1961) had previously cited a temperature range of 58-61F (14.4-16.1C) as yielding the best albacore fishing off the Pacific Northwest from within a range of occurrence of 54-63F(12.2-17.2C). Much of the contrast between Alverson's results and the present results may be due to the anomalous warming in 1969; the ocean off the Pacific Northwest was up to 2F(1.1C) warmer than the long-term average (U. S. Bureau of Commercial Fisheries, 1969).

The results from the 1969 Oregon data are in good general agreement with the earlier California data. Most of the differences may be attributed to method of capture and to the geographical range from which the fish came.

The 1969 Oregon data show a temperature trend within the season. July albacore were caught mostly in 61.5-63.5F(16.4-17.5C) water. Most August albacore were caught in 59.5-63.5F(15.3-17.5C) water. September albacore were taken from predominantly 59.5-61.5F(15.3-16.4C) water.

The within-season temperature trend in all six years was similar. In general, early-season albacore were found in relatively warm water. Mid-season albacore were present within a wide temperature range, while late-season albacore were found in cooler water.

Throughout the investigations, it was clear that albacore catches as related to sea-surface temperature varied considerably within the favorable temperature ranges from season to season, from place to

place, and within seasons.

Total albacore catches in 1969 suggest a more rapid decline in availability at cooler temperatures than do the catch-per-unit-effort results. Alverson (1961) pointed out that this situation is not surprising, stating that "by concentrating in areas where albacore are most available the catches of commercial fishermen are strongly weighted to the temperature interval existing in areas of high availability (p. 1151)."

The association of albacore catches with the other variables examined could not be established in as great detail. An obvious factor was that only a relatively few measurements were made of each of the other variables.

Mixed-layer depths associated with albacore catches were somewhat deeper than those indicated by previous investigations. There were too few vertical temperature soundings and these were too widely scattered for conclusive results. More soundings are needed and especially more from areas where fish catches are small.

Water color generally confirmed what was already known from sea-surface temperature, since blue water was associated with the open ocean and green water with the coastal upwelling area. The water-color results were in agreement with previous work (Alverson, 1961) for the Pacific Northwest. While water color is not especially useful to the scientist because of the small number of categories, the

subjectivity of determination, and duplication of results with sea-surface temperature, it is of great practical use to commercial fishermen.

The salinity results were inconclusive, perhaps because of the small range of salinities encountered. Another variable into which the logbook data allowed partial investigation was albacore food. The results of the investigation are reported in Appendix III; the great bulk of albacore food during the periods examined consisted of squid, shrimp, and saury. Some of the answers to distribution and abundance of albacore may come from a more thorough knowledge of the animals on which albacore feed.

The present study has shown the importance of the magnitude of sea-surface temperature in determining limits of distribution for albacore. Other factors were also operating concurrently.

In an attempt to seek out some of the quantitative relationships and interdependences, multiple regression analysis was tried. The time period selected was the three weeks from 24 July to 13 August during which over 65 percent of the season's fish were caught. Observations were selected which reported fish catch, sea-surface temperature, mixed-layer depth, and water color simultaneously; 50 such data sets were obtained. The resultant calculations considered first-order, second-order, and interaction terms, fish catch being the dependent variable and the remaining items being the

independent variables.

No statistically significant results emerged from the multiple regression analysis. With all independent variables considered, only 16 percent of the variation was explained. The calculations, however, were severely hampered by the small number of mixed-layer depth observations and by the inadequate water-color data (from a quantitative point of view).

There still remains much uncertainty about which variables determine abundance and distribution of albacore and what the quantitative relationships are. Perhaps a fisherman said it best, "None of these indications are always true indications."

SUGGESTIONS FOR FURTHER INVESTIGATION

The present study has provided information from a single season in an area where relatively little was formerly known about the relationship between albacore tuna and oceanographic variables. Whether the results of this study have general pertinence remains to be demonstrated. Certainly more questions have been raised than have been answered.

In the course of carrying out this study several suggestions warranting further investigation have emerged. These suggestions deal with improved ways of approaching the same variables considered here, other variables deserving of consideration, and other work with albacore which needs to be done.

Further Work with Variables of Present Study

A variety of west coast agencies work with albacore fishermen. At present, the National Marine Fisheries Service, Washington Department of Fisheries, Fish Commission of Oregon, Oregon State University, and California Department of Fish and Game all have albacore projects. Each agency from time to time requests fishermen to record data in its own logbooks which vary in format and in information requested one from another.

Fishermen are frequently faced with the decision of which logbook

to keep -- and frequently decide to keep none. The agencies conducting albacore projects need to decide on a common logbook which requests the essential information needed by all agencies. More fishermen might be willing to keep logbooks if they saw these agencies working together toward similar ends rather than much of the apparently uncoordinated duplication existing at present, and if they were confronted with just one logbook and a standardized format.

Fishermen want to be more involved in research which is intended to benefit them. They want to participate in the design and conduct of the investigation, and are obviously useful in oceanographic data collection as well as in reporting details of fish catches. A fisherman who has pursued his trade successfully for 20 years has proven himself to be a skilled practitioner and keen observer. While fishermen may not be accustomed to speaking the language of the scientist and may not communicate in what the scientist regards as the standard way (that is, through professional journals and society meetings), nonetheless much of the information which the fisherman may regard as trivial or inconsequential or take for granted is in fact extremely valuable scientifically. As fishermen begin to identify with a project, they start to volunteer information, observations, and questions. As several fishermen get enthused, a synergistic effect begins to take place. Threads of continuity start to emerge; discovery of new and significant truths can be the outcome.

Some useful answers can be found out at the traditional time-and-space scale of one month and 1° latitude by 1° longitude. Further answers can be found out at the intermediate time-and-space scale at which the present study was primarily conducted: namely, one week and 100 Loran microseconds-by-100 Loran microseconds. Many of the answers, however, will need to come from a microscale approach: that is, a time scale of one day or less and a space scale of 5 n mi - by - 5 n mi or less. Admittedly, a microscale approach also introduces new complexities in navigation, frequency, and quality of log-book entries, and in handling intra-day variations in fish catches. Probably, successful scientific work at the microscale level is more likely with selected, key fishermen of unusual motivation and competence.

In carrying out further studies off the Pacific Northwest, one must also face up to a geographical imbalance in the thoroughness with which the oceanography of the region is known and regularly conducted. For instance, knowledge of the ocean off Oregon is far more advanced than anywhere else in the region. It is important that the oceanography of the rest of the region be studied in the same detail so that background and supporting information is available.

Much of the work of the present study has concentrated on the magnitudes of temperature values which exist horizontally at the surface and vertically in depth. Besides considering the absolute

value of temperature, more consideration must be given to rates of change, both in time and space. In particular, fish catches need to be more rigorously examined against the details and structure of vertical temperature soundings. To be sure, more vertical temperature soundings are needed, both concurrently with fish catch observations as well as from areas where fishing is not taking place; the first kind of measurement can probably be best taken by a cooperating fisherman and the second from an aircraft or research vessel.

If water color correlations are to be useful, a simple, reliable, and quantitative means of measuring water color must be developed. If salinity correlations are to be useful, more salinity observations concurrent with fish catch observations are necessary.

More observations of albacore food would be useful. The value of this information, however, will depend on learning more about those organisms which albacore eat and about the feeding habits of albacore.

Work With Variables Not Examined in Present Study

Several other variables, not looked at in this study, are worth investigating.

Little work has been done in relating water clarity (transparency) to albacore catches, even though it is an important oceanographic variable. In 1969 only a few widely-scattered measurements of water

clarity were made off the Pacific Northwest. Unfortunately, the resultant data were of questionable quality, and no comparisons were available between water clarity and albacore catches.

In 1970, however, a number of water clarity measurements were made during the peak of the troll fishery. Basically, turbid water was found inshore (and might be associated with upwelled water) and clearer water was found offshore (and might be associated with open ocean water). In addition, a patch of relatively turbid water was found offshore (and might be associated with the Columbia River plume). Preliminary evaluation indicates some positive correlation between clear water and favorable fish catches. More work seeking out the relationship between water clarity and albacore catches would be definitely worthwhile.

Another potentially productive area of investigation is that of air-sea interaction. The National Marine Fisheries Service Fishery-Oceanography Center (1970) has been conducting studies into the dynamic features of the 700 mb atmospheric pressure pattern over the Northeast Pacific. Their early results show that in years with a major northern fishery a ridging of the 700 mb isobars was present over the eastern Gulf of Alaska and western Canada during June and July, and as a result there were more frequent high pressure systems off the Pacific Northwest, decreased winds, clear skies, and rapid warming of surface waters. The early-season warm water

in the northern region may serve to attract the albacore in that direction upon their yearly migrational entry into waters off the west coast of North America. Besides conducting further studies into the 700 mb atmospheric pressure pattern, sea-level atmospheric pressure and local wind stress also deserve examination.

Other Research Work With Albacore

Migration of albacore tuna in the North Pacific is still inadequately known. The study of albacore migration by Otsu and Uchida (1963) was based on fish tag recoveries, age and growth information, and length-frequency distributions from the various North Pacific fisheries.

Fish tagging may be viewed in the same way as drift bottle studies. All that is known is when and where a tagged fish was released and when and where that same fish was captured; a straight-line course is assumed between the two points, and on this basis speed is computed. Such studies are capable of yielding only the most general patterns and depend for their validity on large sample sizes.

Unfortunately, over the years just a few fish have been tagged and returns have been low. For instance, the study of Otsu and Uchida was based on 35 tag returns. Most tagging to date has been conducted on troll-caught fish taken by research vessels; numbers of fish caught are low and mortality is high. One of the cooperating fishermen in

the project, a successful baitboat owner and captain, recommended chartering a baitboat for a season. He averages 10,000 fish a season and indicates tagging of bait-caught albacore could be accomplished with low mortality. Tagging on this scale would offer hope of learning much more about the details of albacore migration.

SUMMARY AND CONCLUSIONS

In the present study the relationship between troll-caught albacore tuna and selected oceanographic variables has been examined for the Pacific Ocean off the Pacific Northwest during the summer of 1969.

The 1969 data indicate that the best albacore fishing took place under the following conditions:

- 1) Sea-surface temperature range of 59.5-63.5F(15.3-17.5C),
- 2) Mixed-layer depth range of 56-135 ft(17.1-41.1 m),
- 3) Blue sea-surface water color.

Although weather and sea conditions may not directly determine abundance and distribution of albacore, they are nonetheless clearly associated with the ability of boats to fish and therefore prompt the addition of another favorable factor:

- 4) Sustained winds of less than 22-28 kts and seas of less than 4-8 ft (1.2-2.4 m) (Flittner, 1970).

Still other factors are suggested by observation, subjective interpretation, and experience of fishermen. These factors, also associated with good fishing, include:

- 5) Surface fronts, both color and temperature (albacore frequently being concentrated on offshore side),
- 6) Eddies or shoaling of subsurface isotherms,
- 7) Plentiful supply of food,

8) Presence of "tuna birds" (probably Leach's petrel),

9) Stable ocean conditions under moderately developed upwelling conditions.

Most studies to date have associated albacore with the magnitude of sea-surface temperature. In 1969 off the Pacific Northwest, the magnitude of sea-surface temperature was unquestionably a major factor, but other factors quite obviously were also operating concurrently.

Temperature structure, both horizontally and vertically, and its changes in time and space, may well prove to be the prime determinant of abundance and distribution of albacore. Other variables, especially water clarity, deserve further study. The goal of subsequent research needs to be to seek quantitative relationships between these variables and albacore tuna.

In closing, a cautionary note needs to be struck. The status of the albacore tuna resource in the North Pacific is unknown. Vigorous and substantial harvesting is presently taking place. Rothschild and Uchida (1968) consider that larger catches of albacore tuna from the North Pacific are unlikely. On the other hand, Ahlstrom (1968) foresees a possible increase in the share of United States fishermen.

Man is skilled technologically. As he learns more about albacore tuna, he may acquire the ability to exploit this fish in excess of its maximum sustainable yield. The challenge will be to direct his

expertise towards wise and effective use of the sea.

Man must learn to balance aggressive and thorough exploitation of the ocean and its inhabitants with enlightened management and stewardship.

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APPENDICES

APPENDIX I

Albacore Fishermen and Their Comments

In mid-November 1969, a questionnaire was mailed to all fishermen who had received logbooks. Of the 421 questionnaires mailed out, 163, or 38.7%, were completed and returned.

The questionnaires yielded a variety of information about the fishermen and about albacore. Some of the information emerged directly from their answers, while other information came from voluntary, marginal comments of elaboration which the fishermen contributed with some frequency. Those excerpts which seem pertinent, important, and insightful appear in the remainder of this appendix.

Questionnaire Results

Some of the questions are listed below, accompanied by a tabulation of fishermen's responses and interspersed with amplifying remarks. In the case of all questions except the last one, the percentages are based on the number of fishermen answering the question; in the case of the last question, the percentages are based on the total number of questionnaires returned.

How many years have you been fishing commercially?

1-5 years	11	6.7%
6-10	23	14.1
11-15	26	16.0
16-20	10	6.1
more than 20	93	57.1

How many years have you fished commercially for albacore?

1-5 years	41	25.2%
6-10	31	19.0
11-15	16	9.8
16-20	11	6.7
more than 20	64	39.3

Over half the fishermen answering the questionnaire have been fishing commercially for more than 20 years. Many of these, however, have been fishing for other species much of this time, and have shifted over to fishing for albacore more recently. The shift reflects the increased availability of albacore off the west coast of the United States during the 1960's.

Did you fish for albacore this summer?

Yes	143	88.8%
No	18	11.2

Did you fish north of the California-Oregon border?

Yes	133	91.7%
No	12	8.3

Have you been told enough about the albacore-oceanographic research project?

Yes	61	50.0%
No	61	50.0

Would you like to be kept informed of albacore research results?

Yes	141	96.6%
No	5	3.4

Response to the last two questions shows the desire and interest of fishermen in being involved in all stages of planning and carrying out research which affects them.

Which information do you use in locating and catching albacore?

153	94.9%	Sea-surface temperature
134	82.2	Location of the fleet
119	73.0	Water color
101	62.0	Fronts (temperature or color)
100	61.3	Albacore feed
46	28.2	Marine weather
35	21.5	Depth of thermocline (mixed-layer depth)
16	9.8	Echosounder traces

The answer to this question confirms the importance fishermen place on sea-surface temperature and location of the fleet. It also indicates the relative lack of familiarity with depth of thermocline and echo-sounder traces.

Even though marine weather ranks rather low in terms of locating and catching albacore, questionnaire comments repeatedly emphasized the importance of adequate forecasts to safety, to prevention of boat damage, and to decisions on leaving port.

Four fishermen wrote in "birds" and one fisherman wrote in "jumpers" (fish jumping at surface).

Additional Comments

In addition to the questionnaire answers, many fishermen volunteered supplementary comments of different kinds. Some of the more significant comments appear below.

Difficulties of log-keeping. One comment captured the spirit of the real difficulties and extra burden involved in trying to keep a log:

"We were so busy this trip simply holding on while our lines flew through the air like kites and the boat leaped from one wave to another that our record keeping fell by the wayside. Our next report will be more complete."

Compliments. Some of the fishermen had compliments for the project:

"Let me thank you for what I felt was an honest effort to do a good job. Hope you will be there again next season."

and:

"Any help or effort we get from your program and others are used and appreciated more than you might think. Keep up the good work."

Criticisms. Finally, several fishermen offered up brickbats of disapproval:

"I believe that . . . the effort would be better for us if spent on a program for tariffs or quotas."

and:

"Government interference with any fisheries always leads to fishing limits, licenses, and gear limitation."

and:

The scientist ... doesn't know a damn thing as to where albacore will appear in commercial quantities. And neither do I. All either of us can do ... is point to an area as 'likely'. And I can do that from my rocking-chair; without any spectrographic overflights of the Pacific or multi-thousand dollar cruises by research vessels to assist me.

APPENDIX II

Albacore Catches as a Function of Time-of-Day

So long as one is examining albacore catches on a time scale of days, weeks, or months, intra-day variations are of minor consequence. But as soon as one starts making comparisons on a time scale of hours, variability of catch with time of day must be examined and taken into consideration.

Fishermen talk of "morning bites" and "evening bites". From a statistical viewpoint, do these exist, or is catch relatively constant through the day? The detailed logsheets which were submitted allow investigation of this point for 1969.

The records of five selected fishermen were examined. These five fishermen kept unusually complete records. The average number of log entries per day was eight, or one observation about every two hours of the fishing day.

Figure 21 presents monthly distributions of their albacore catches by the hour of the day during which the catch was taken. If a fishing interval covered more than a single clock hour, the fish from that interval were assigned uniformly to the component hours of the interval during which they were caught.

Visual inspection shows relatively low catch success in the morning, relatively high success in the evening, and a somewhat

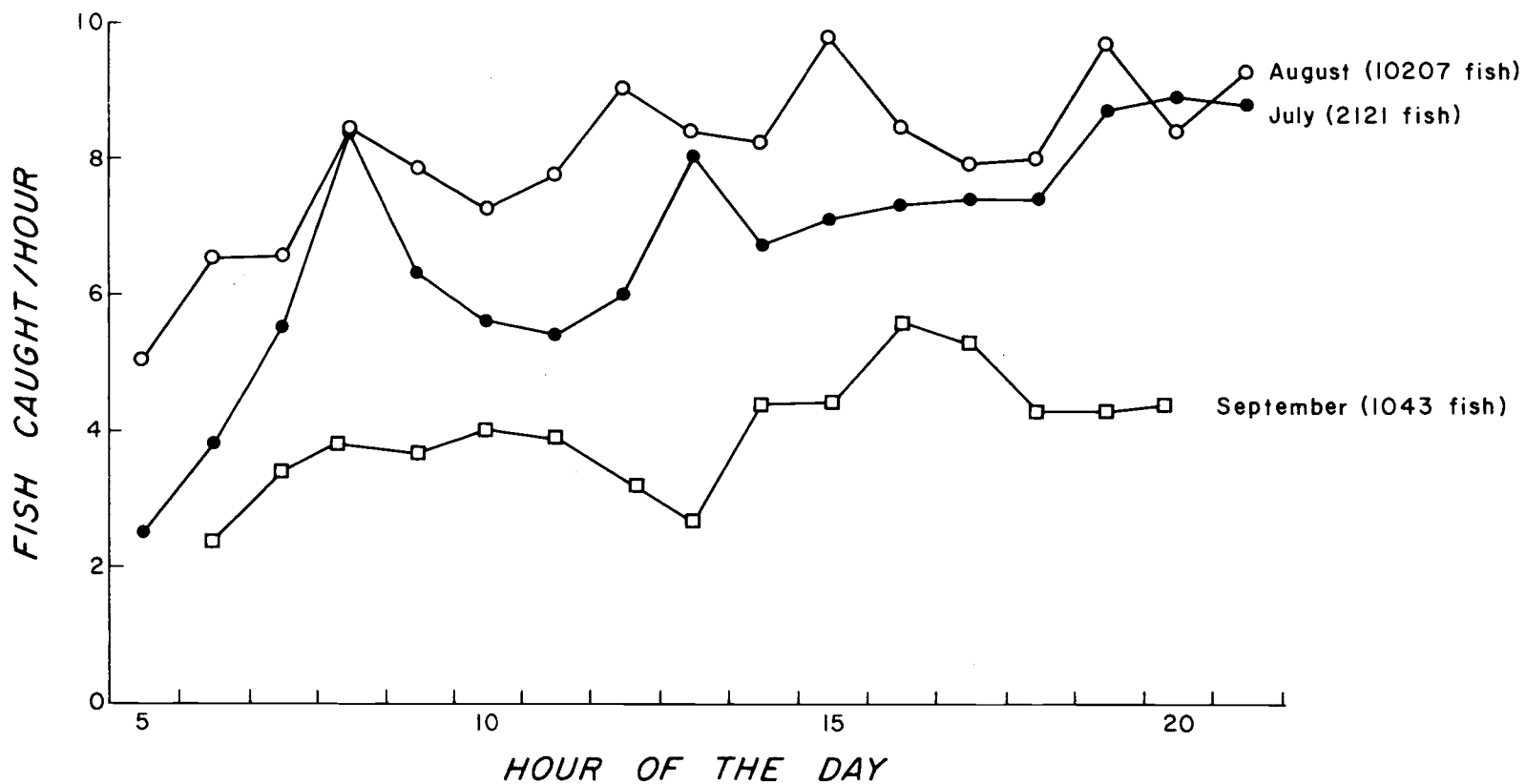


Figure 21. Average number of fish caught per boat hour by month -- for five selected boats keeping detailed logs -- as a function of hour of day during which catch was taken. (If interval covered more than a single clock hour, fish were assigned uniformly to component hours of interval during which they were caught.) Numbers of fish in parentheses indicates total number of fish caught by the five boats during that month.

irregular trend through the day from low morning success to high evening success. χ^2 tests were conducted to see whether these differences were significant.

For the χ^2 tests, the actual numbers of albacore caught during each hour were tested against the hypothesis that mean catch success prevailed throughout the fishing day. That is, the expected number of fish for each hour was determined by multiplying the actual number of hours fished during that hour of the day for the month by mean catch-per-unit-effort for that month. For all three months, the χ^2 values obtained were large (July -- 126.56; August -- 185.21; September -- 43.39) and the hypothesis was rejected for each month at the 0.01 level.

The conclusions of the investigation are that, for the five boats studied, catch success was not constant with time of day. A strong evening bite was present throughout the season. Catch success was lower during the early morning hours (but a morning bite of short duration and moderately high success was present during the 0800 hour in July and August).

Catch success does vary with time of day. This variability must be taken into consideration when making intra-day comparisons in order to avoid biasing the conclusions.

APPENDIX III

Albacore Food

Observations of albacore food were not one of the logbook data items specifically requested. Even though optional, a number of fishermen entered food observations occasionally; that is, they recorded what the fish regurgitated on being landed.

In the following analysis, food observations have been summarized for two different fishing periods. The first period is the three weeks from 24 July - 13 August during which over 65 percent of the season total was caught. The second period was the three weeks from 28 August - 17 September during which about five percent of the season total was caught. During the first fishing period, 46 boats contributed observations while during the second fishing period 19 boats contributed observations. The results of the analysis of food observations are presented in Table 8.

Table 8. Observations of albacore food during two fishing periods.

	1st Fishing Period ¹		2nd Fishing Period ²	
	No. obs	Percent	No. obs	Percent
Squid	112	54.6	14	31.8
Shrimp	67	32.7	25	56.9
Saury	12	5.9	3	6.8
"Small Fish"	7	3.4	2	4.5
Anchovies	4	2.0	0	0.0
Mackerel	3	1.5	0	0.0
	<u>205</u>		<u>41</u>	

¹ 24 July-13 August 1969² 28 August-17 September 1969

During the first period squid was most common, followed in order by shrimp and saury. During the second period, by contrast, shrimp was most common, followed in order by squid and saury. In both periods the combination of squid, shrimp, and saury made up over 90 percent of the albacore food.

In comparing the two periods, squid was more common during the first fishing period than during the second period, while the reverse situation held for shrimp and saury. During the first fishing period (when more productive fishing was taking place) both a greater variety of food and more frequent observations of food were reported.

Since food observations were optional, it is difficult to interpret logbook entries which did not contain food observations. Absence of food observations can thus mean that the albacore stomachs were empty, that the stomachs were not empty but that the fish did not regurgitate anything (or everything) on being landed, or that the stomachs were not empty but that the data were not recorded.