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A METHOD OF PREDICTING TUNA CATCH BY USING COASTAL SEA-SURFACE TEMPERATURES[1]

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INTRODUCTION

From its start nearly 60 years ago the California tuna fishery has grown into the state's largest fishery, both in value and in pounds landed (Power, 1960). Yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*) now are the two most important species and comprise the bulk of the California tuna landings. These are tropical tunas and seldom enter California waters in commercial quantities, the greatest portion of the catch being made by large bait boats and purse seiners operating off Mexico, Central America and South America.

In contrast to the distant fishery supported by yellowfin and skipjack is the fishery for the temperate tunas, albacore (*Thunnus germo*) and bluefin (*Thunnus saliens*). During the summer and fall, both of these species occur off the California and Baja California coasts where they are taken by many boats incapable of making the long trips to the tropics. Baitfishing and trolling produce the major portion of the albacore catch, whereas the bluefin is almost exclusively a purse-seine fishery. For detailed accounts of these methods see Godsil (1938) and Shimada and Schaefer (1956) on baitfishing, Scofield (1956) on trolling, and Whitehead (1931), Scofield (1951) and Orange and Broadhead (1959) on purse seining.

The catches from the California albacore and bluefin fisheries have varied markedly from year to year. The author, and other researchers, feel that some of this variation has been attributable to changes in the ocean climate off the California coast. The present study attempts to relate fluctuations in the temperate tuna catch (bluefin and albacore) to environmental conditions as measured by sea-surface temperatures at two shore stations in southern California.

ERRORS IN ESTIMATING AVAILABILITY FROM CATCH RECORDS

The majority of the local tuna catch has been made during the summer months. The seasonal nature of the California tuna fishery indicates that fluctuations in catch due to changes in the geographical distribution of the fish are of major importance. Some of this variation may be due to changes in the behavior of the fish rather than their actual absence from California waters. Present knowledge makes it

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difficult, if not impossible, to distinguish between fluctuations caused by absence and those caused by behavioral differences. For this study, no attempt is made to separate these two causes. Instead it is assumed that two populations of tuna, one of albacore and one of bluefin, are so located that during the summer months their ranges include the waters off southern California. The degree of presence (availability) of these populations is sampled by their respective fisheries. This method of sampling is subject to errors introduced by inclement weather and changes in the economy. Both of these errors can be treated as part of the sampling error. Variations in landings due to changes in population size (abundance) can also be treated as a randomly distributed sampling error.

An additional source of variation in the landings may be attributed to changes in the size of the fishing fleet. The error from this source can not be randomly distributed for the number of boats in both the albacore and the bluefin fleets has declined since the 1940's, but variations due to changes in fleet size are assumed to be small.

DISTRIBUTION OF CATCH

According to Clemens (1955), the usual albacore season starts around the middle of June. During the three years covered in his report, 1951-1953, the first catches were made in the vicinity of Cedros and Guadalupe Islands. As the summer progressed, the fishery moved up the coast terminating in the fall with the majority of the catches being made north of Point Conception.

During the spring of 1960, the Bureau of Commercial Fisheries, San Diego Biological Laboratory, in cooperation with the U. S. Navy, initiated an offshore albacore survey. Trolling gear was placed aboard five radar picket vessels stationed about 250 miles offshore from southern California to Washington. The early season catch as reported by these ships seemed to follow the northward and inshore march of the 59 degree isotherm (Johnson, 1960). Apparently the northward movement of the fishery reported by Clemens is related to sea temperature. This concept was originally developed by Thompson (1917), who utilized mean minimum aid temperature data from maritime stations as an index of sea temperature. He observed a striking correlation between observed temperatures and the northward movement of the fishery. Recently, Radovich (1961) has pointed out that movement of the fishery is related to temperature.

It is common knowledge that the bluefin fishery develops further south than the albacore fishery, often starting in June near Cape San Lazaro, Baja California, and shows a similar northward movement later in the season. Catches are made off southern California in the late summer and early fall (Skogsberg, 1925). Schools are reported north of Point Conception, but the catch from this area is negligible.

That temperature does play an important role in the movements of these fishes was dramatically shown by changes in the catch localities for albacore and bluefin during the recent warm period 1957 to 1960. Sea-surface temperatures during these years ranged 4 degrees F. higher than the 10-year mean (McGary, 1960). The usually large fishery for albacore off Baja California failed; it developed instead several hun-

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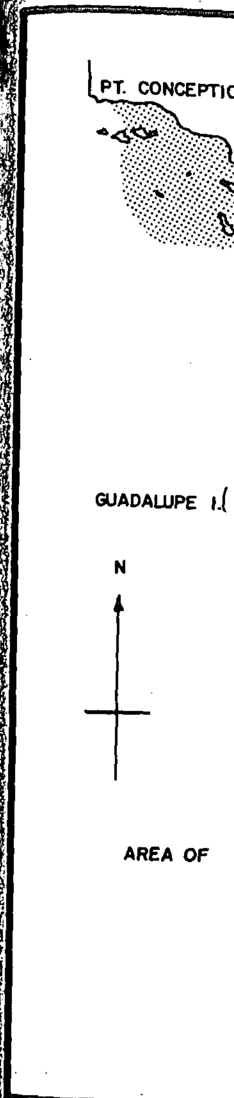

FIGURE 1. Cl
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dred miles to the north. At the same time, the bluefin catch off southern California increased, resulting in the largest landings from California waters since the late 1940's. The striking contrast between the most productive bluefin areas in August 1952 and 1953, two years of cold water temperatures, and August 1957 and 1958, is shown in Figure 1. The data came from tuna seiner logbooks maintained by the fleet since 1952 for the Inter-American Tropical Tuna Commission.

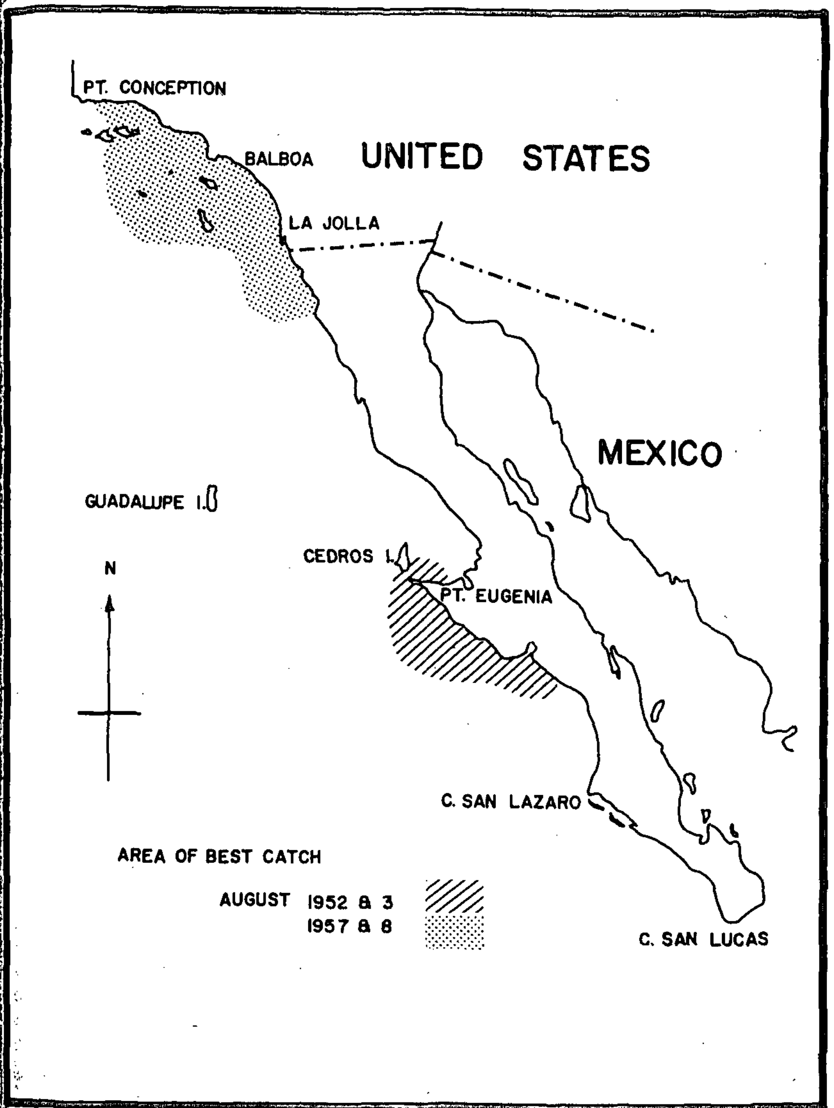


FIGURE 1. Changes in the most productive areas for bluefin fishing between August 1952 and 1953 and August 1957 and 1958.

TEMPERATURE EFFECTS

Any attempt to postulate some particular optimum temperature for albacore would have to explain the difference of several degrees in water temperature existing between our troll fishery and the Japanese pole and line fishery. The best Japanese catches occur in waters warmer than off California (Calif. Mar. Res. Comm., 1960, Murphy). The reverse seems to be true for bluefin, as the Japanese net fishery is conducted at a lower temperature than ours (Uda, 1957). In this case, however, a different population of bluefin tuna may be involved since trans-Pacific migrations have not been demonstrated for bluefin as they have for albacore (Otsu, 1960).

It is possible that temperature affects the behavior of a fish in such a way that the best catches for particular types of gear occur at different temperatures. For example, there is some indication that bait-fishing for albacore is more successful later in the season when the schools are more concentrated. This concentration of schools may be related to the higher water temperatures which occur later in the season.

Several indirect effects might influence the capture of tunas. One is the increased basic productivity found in areas of upwelling. Schaefer (1957) also points out that areas of tropical tuna concentrations appear to coincide with regions of high basic productivity. An increase in the amount of tuna food in an area could result in a temperature-tuna relationship seemingly dependent upon the cooler water associated with the upwelling.

High productivity as well as other factors which may be correlated with temperature can produce changes in water clarity and these in turn may influence fishing success. Some attempts have been made to relate fishing success to turbidity (Whitehead, *op. cit.* and Murphy, 1959). The latter relates albacore catch to underwater visibility on the assumption that troll caught albacore are sight feeding. Thus trolling success might be poor in the turbid coastal water close to shore, whereas net fishing for bluefin may depend upon poor underwater visibility resulting in better catches near shore and at night.

CHANGES IN LANDINGS

Yearly tuna landings are reported by the California Department of Fish and Game in its *Fish Bulletin* series. The catch is divided into fishing boat landings from waters north of the California state line, California waters, and waters south of the International Border. The total landings from 1945 through 1959 are given in Table 1. The cut-off date, 1945, was chosen in order to exclude some of the economic factors present during the war years. In addition to total landings, albacore and bluefin landings from south of the International Border and from California waters have been provided. An increase in the bluefin catch from California waters was coincident with the warm-water conditions in 1957 and 1958. For comparison, tropical tuna landings from California waters also have been given in Table 1. The presence of commercial quantities of these fish in California waters may be regarded as a further indication of changes in the oceanic

TABLE 1

Landings in Millions of Pounds for Bluefin and Albacore
Thousands of Pounds for Yellowfin and Skipjack[1]

Year	Total California albacore landings*	Total California bluefin landings	Landings from south of the International Border		Landings from California waters			
			Bluefin	Albacore	Albacore	Bluefin	Yellowfin	Skipjack
1945	21.77	20.59	6.45	12.26	8.78	14.14	4.96	93.08
1946	18.06	22.03	6.50	8.96	9.10	15.53	32.65	1,747.06
1947	13.14	20.83	6.07	5.76	7.40	14.76	3.32	893.05
1948	36.42	6.53	4.84	25.93	10.50	1.69	0.41	319.19
1949	44.02	4.39	2.12	23.58	20.40	2.27	9.88	26.68
1950	61.75	2.74	2.73	23.60	38.14	0.01	1.46	12.42
1951	30.68	3.86	3.02	17.62	13.28	0.84	0.00	0.59
1952	49.79	4.58	3.67	26.70	23.10	0.91	0.00	0.53
1953	33.83	9.17	5.87	20.49	13.30	3.90	0.10	1.28
1954	26.11	21.02	15.37	11.82	14.29	5.65	0.00	14.40
1955	29.00	13.61	11.13	19.69	9.31	2.48	0.00	1.24
1956	37.04	12.62	10.01	21.06	15.87	2.61	0.10	0.88
1957	43.47	20.31	9.85	20.91	22.61	10.46	70.85	353.46
1958	27.10	30.72	15.11	0.72	25.39	15.61	417.71	2,488.91
1959	32.74	15.30	2.17	0.00	32.52	13.13	81.68	1,380.96

[1] Source—Calif. Dept. Fish and Game, Marine Resources Operations.
* Includes some fishing boat landings from north of the state line.

climate off California. The data were plotted (Figure 2) using fishing boat landings reported from California waters for skipjack, yellowfin, and bluefin, and landings from waters south of the International Border for albacore. The figure indicates that a change took place towards the end of the 1940's which was reversed in 1957. This change was characterized by a decline in skipjack, yellowfin, and bluefin landings, and a rise in albacore. The rise in the albacore catch and the decline in bluefin are most interesting. Since the two fisheries are essentially independent, albacore being caught with hook and line and bluefin being netted, fluctuations due to fishermen's preference for one species over the other are eliminated.

This relationship can be explained by postulating two population centers, one for albacore and one for bluefin. These centers of abundance, which are indicated by the best catches for the two species, do not coincide, bluefin occurring south and inshore of albacore. During cold years, the center of the albacore population would move south resulting in higher catches south of the International Border. Logbook records show that substantial catches of albacore were made off Baja California during the early 1950's when bluefin were rare north of Cedros Island. During warm years, the albacore would move northward resulting in lower catches in the southern fishery. At the same time, the center of the bluefin population also would move northward resulting in increased bluefin catches in California waters. The relationship is examined in more detail in Figure 3 where southern albacore catches and northern bluefin catches have been plotted against each other. A northward movement of bluefin should be accompanied by an increase in bluefin catch and a decrease in albacore catch.

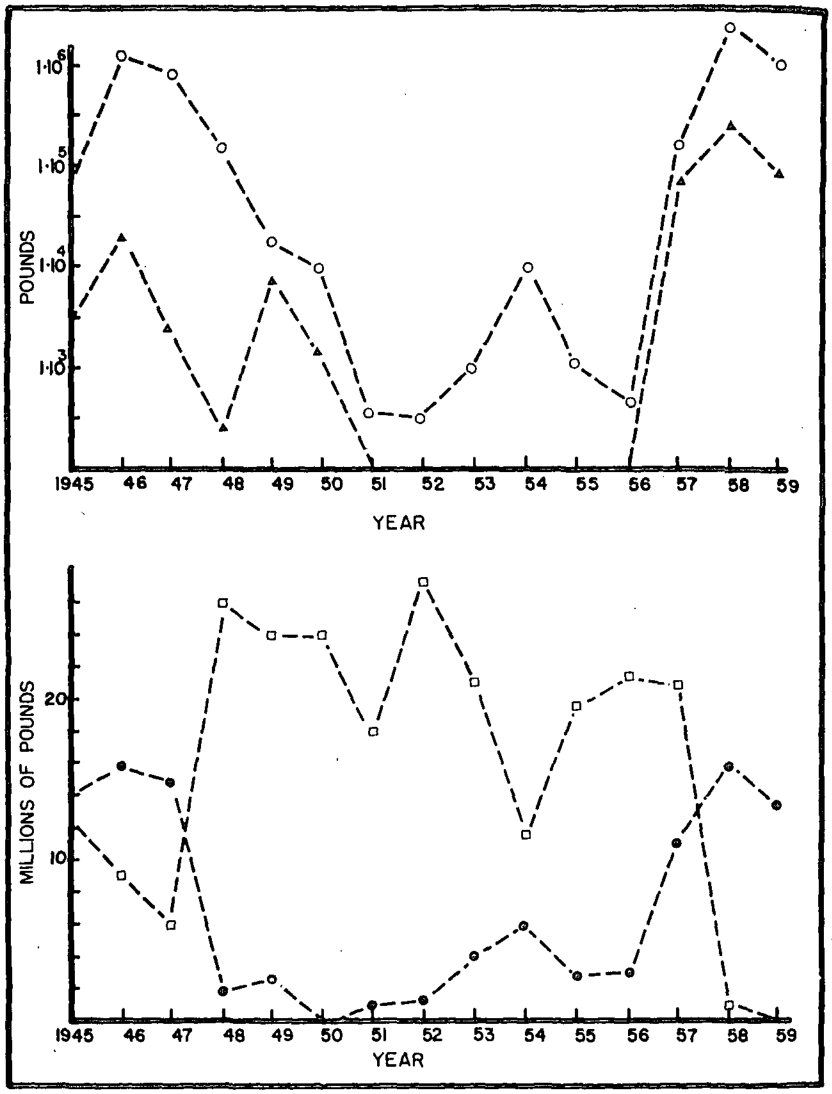
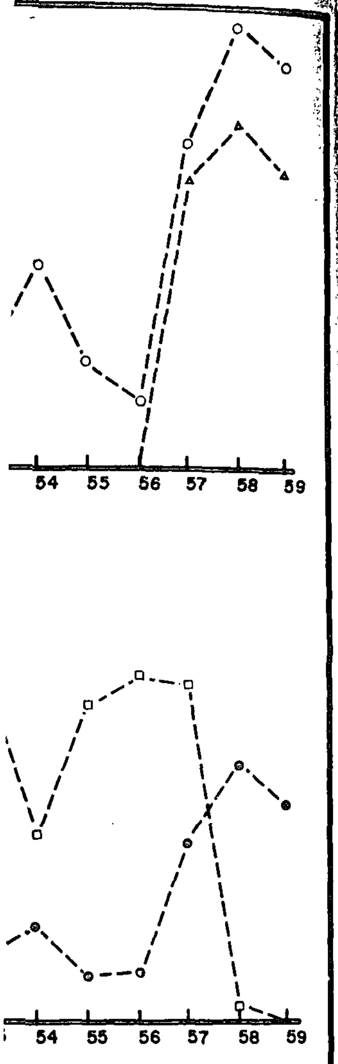


FIGURE 2. Top: Skipjack—fishing boat landings from California waters, open circles. Yellowfin—fishing boat landings from California waters, closed triangles. Bottom: Albacore—fishing boat landings from waters south of the International Border, open squares. Bluefin—fishing boat landings from California waters, closed circles.

A high inverse correlation exists between bluefin and albacore catches as is shown by a correlation coefficient of -0.84. This coefficient can be interpreted to mean that 84 percent of the fluctuations in landings between the two species are due to some common element. In this case it is assumed that the common element is movement of the fish populations due to environmental factors.



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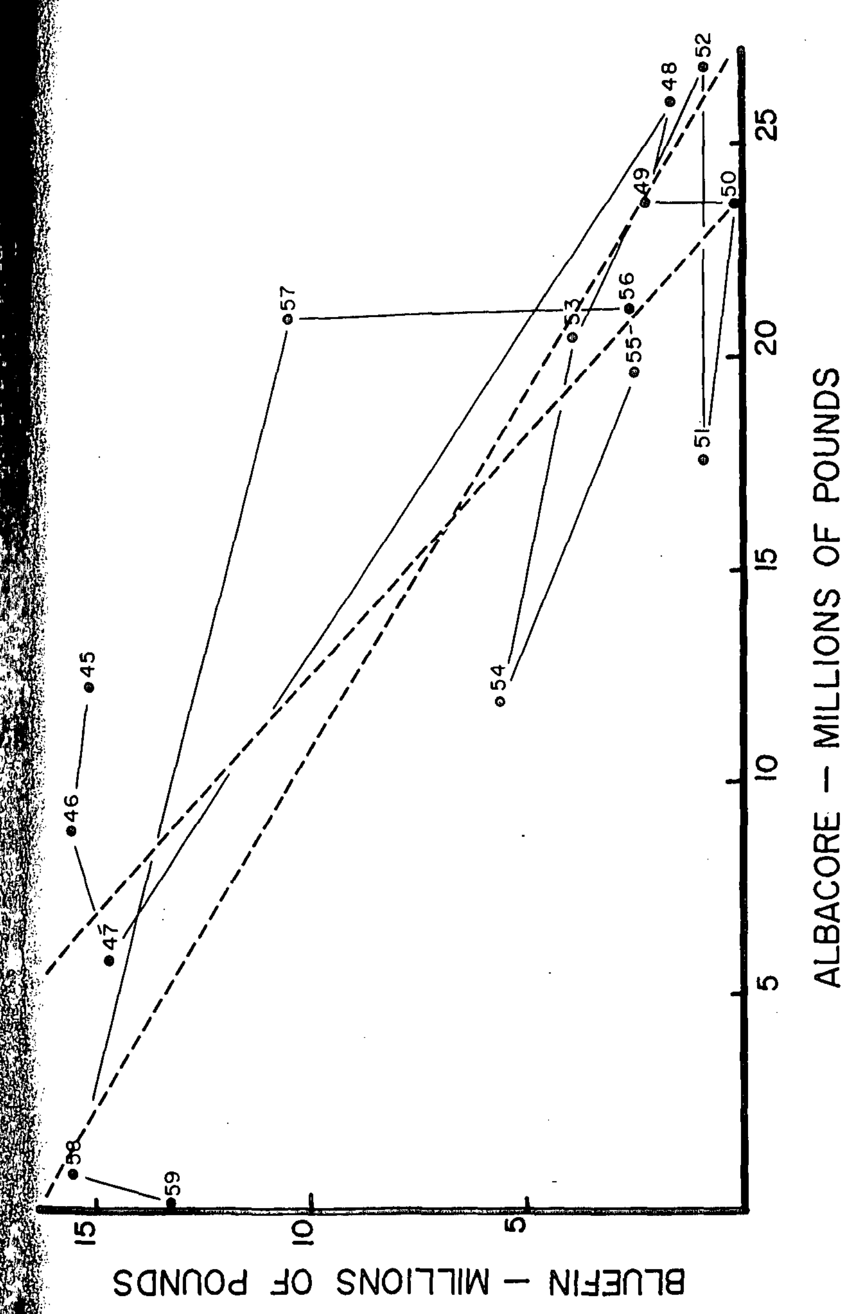

FIGURE 3. *Albacore*—fishing boat landings from south of the International Border. *Bluefin*—fishing boat landings from California waters. Numbers on graph are years 1945 through 1959.

TEMPERATURE AS AN INDEX OF AVAILABILITY OF ALBACORE AND BLUEFIN

A source for sea temperature data covering the same period and areas as the catch is difficult to find. Since 1949, California Cooperative Oceanic Fisheries Investigations (CCOFI) has run a series of station lines from San Francisco to Cape San Lucas but the coverage is missing for certain key months. Sea-surface temperatures collected by the U. S. Weather Bureau are sparse prior to 1950. However, sea-surface temperatures are available from shore stations along the California coast back to 1935. These data have been collected by the University of California, Scripps Institution of Oceanography, under a program initiated by Dr. George F. McEwen. Observations from the two stations south of latitude 34° N., La Jolla, and Balboa Pier, have been averaged for use in this study (Table 2). Although these shore stations are in the northern part of the area to be considered, they probably will provide an index to environmental changes in the sea off southern California and northern Baja California. This is due to the common circulation of the waters from Point Conception to Point Eugenia (Calif. Mar. Res. Comm., 1958).

The bulk of the local tuna has been caught during July, August and September. A comparison has been made in Figure 4 between the annual catch of bluefin from California waters and albacore from waters south of the International Border, and the sea-surface temperatures at Balboa and La Jolla averaged together for these three months. Two lines were fitted by the method of least squares, $A\text{-}A'$ for albacore and $B\text{-}B'$ for bluefin. The equation for $A\text{-}A'$ is:

$$1)\quad A_s = 163.84 - 7.65T_s$$

where A_s is the estimated albacore catch (millions of pounds) south of the International Border and T_s is the average surface water temperature (degrees Centigrade) July through September at Balboa and La Jolla. The standard error of an estimated catch is 7.412 and the standard error of the slope is 2.68. The equation for $B\text{-}B'$ is:

$$2)\quad B_s = -112.32 + 6.17T_s$$

where B_s is the estimated bluefin catch (millions of pounds) from California waters and T_s is as above. The standard error of an estimated catch is 4.607 and the standard error of the slope is 1.66. The slope of the line in equation (1) is significant at the 5 percent level, the slope in equation (2) at the 1 percent level. The inverse relationship between the bluefin and albacore catch is apparent.

A study of year to year temperature changes indicates that warm years along the southern California coast are preceded by warm water temperatures in winter. This has been attributed to increased advection from the south during the winter months (Calif. Mar. Res. Comm., 1953) and other causes. The relationship between winter and summer temperatures provides a convenient way to predict unusually good or bad years for the local tuna fishery. In Figures 5 and 6, the southern albacore and northern bluefin catches were plotted against Balboa and La Jolla sea-surface temperatures averaged together for the months

TABLE 2

Sea-Surface Temperatures, Degrees Centigrade, for the Years 1945 Through 1959 at La Jolla and Balboa

Yearly mean	SUMMER			WINTER		
	Mean-La Jolla	Mean-Balboa	Summer mean	Mean-La Jolla	Mean-Balboa	Winter mean

TABLE 2

Sea-Surface Temperatures, Degrees Centigrade, for the Years 1945 Through 1959 at La Jolla and Balboa

Year	Yearly mean		SUMMER							WINTER								
			Mean-La Jolla			Mean-Balboa			Summer mean	Mean-La Jolla				Mean-Balboa				Winter mean
	La Jolla	Balboa	July	Aug.	Sept.	July	Aug.	Sept.	La Jolla + Balboa	Jan.	Feb.	Mar.	Apr.	Jan.	Feb.	Mar.	Apr.	La Jolla + Balboa
1945	16.61	16.20	20.02	21.39	20.31	18.78	19.77	19.36	19.94	14.17	13.99	13.09	13.82	14.27	14.31	13.34	13.94	13.87
1946	16.83	16.62	20.39	21.21	18.89	20.00	19.69	19.04	19.87	13.03	12.78	13.63	16.17	13.49	13.29	13.53	15.96	13.98
1947	16.88	16.78	19.29	20.01	19.56	19.10	20.30	19.01	19.54	13.45	13.86	14.87	15.76	13.67	14.03	15.05	15.89	14.57
1948	16.08	15.62	18.47	19.86	19.31	17.98	18.15	18.41	18.70	13.56	13.14	13.41	14.80	13.44	12.78	13.30	14.29	13.59
1949	16.52	15.97	20.15	20.86	20.19	18.95	19.24	18.62	19.67	12.28	12.66	13.42	14.40	12.13	12.31	12.96	14.37	13.07
1950	16.40	15.85	20.54	19.11	19.31	18.64	18.16	18.83	19.10	12.76	12.97	13.91	15.67	12.56	12.82	13.81	15.06	13.70
1951	16.62	15.78	20.14	19.69	17.77	18.85	17.84	16.80	18.52	13.25	13.48	13.99	15.99	13.05	13.44	13.33	15.06	13.95
1952	16.28	15.31	18.06	20.90	18.12	16.25	18.32	16.21	17.98	13.71	13.59	13.46	15.42	13.21	13.41	12.94	14.89	13.83
1953	16.24	15.51	20.57	20.69	17.63	19.17	18.60	16.36	18.84	13.97	13.18	13.65	14.60	13.74	13.01	12.86	13.75	13.60
1954	16.86	15.02	21.25	21.26	19.10	17.91	17.27	16.29	18.86	14.10	14.32	14.03	15.06	14.05	14.42	13.84	15.24	14.38
1955	16.48	15.34	19.60	21.48	20.58	18.11	17.62	17.92	19.22	13.38	12.95	14.35	14.14	13.55	12.51	14.29	12.99	13.52
1956	16.37	15.69	19.96	21.08	18.82	18.27	19.69	17.40	19.20	12.61	12.89	13.36	14.77	12.60	12.68	13.37	14.15	13.30
1957	17.36	16.48	20.87	21.55	19.15	19.87	20.75	18.44	20.10	14.81	14.34	14.83	15.29	14.56	14.06	14.83	13.75	14.56
1958	17.84	17.43	19.39	20.49	20.21	18.32	19.54	19.49	19.58	16.06	16.00	15.34	17.06	15.82	15.86	15.32	17.11	16.07
1959	18.35	17.71	21.95	21.27	21.01	20.29	18.90	20.27	20.84	16.00	15.21	16.19	17.02	15.49	15.02	15.96	16.22	15.89

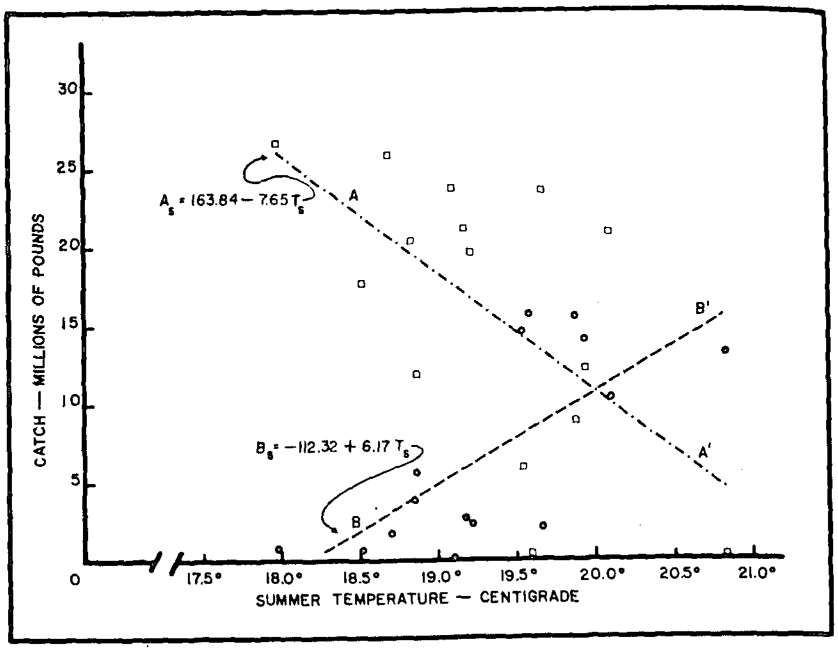

FIGURE 4. *Albacore—yearly fishing boat landings from waters south of the International Border, open squares. Bluefin—yearly fishing boat landings from California waters, solid circles. Temperature—average July, August and September sea-surface temperature, Balboa and La Jolla.*

January through April for each of the years 1945 through 1959. Lines were fitted to the data and the equations are:

$$3)\quad A_w = 135.11 \quad -8.44T_w$$

where A_w is the estimated albacore catch south of the International Border and T_w is the average winter sea-surface temperature January through April at Balboa and La Jolla. The standard error of an estimated catch is 5.324 and the standard error of the slope is 1.79;

$$4)\quad B_w = -61.41 \quad +4.84T_w$$

where B_w is the estimated bluefin catch from California waters and T_w is as above. The standard error of an estimated catch for bluefin is 4.853 and the standard error of the slope is 1.45. Both slopes are significant at the 1 percent level. Of interest is the reduction in standard error for both species, implying a closer tie between winter conditions and subsequent events than between the simultaneous events, catch and summer water temperature, shown in Figure 4.

The relation does suggest temperature as an easily measured indicator on which to base predictions. The statistical validity of the preceding is based on the assumptions that the temperatures are measured without error, that the variations in catch due to sampling by the fishery are normally distributed about some mean value, and that the standard deviations for the catch at each temperature are equal. The temperature for any year was the average of over 200 observations and errors from this source should be minimal.

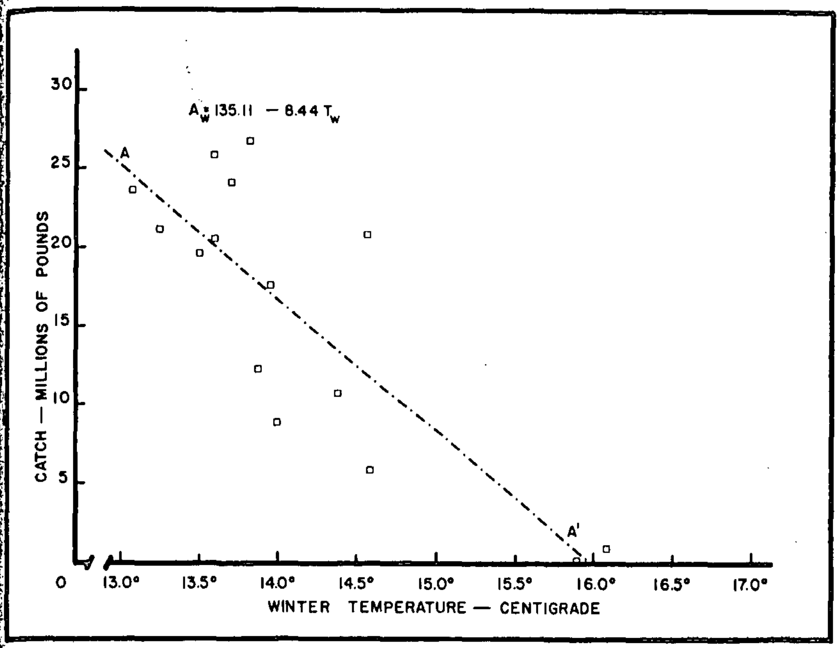

FIGURE 5. *Albacore*—fishing boat landings from waters south of the International Border. *Temperature*—average sea-surface temperature January through April, Balboa and La Jolla.

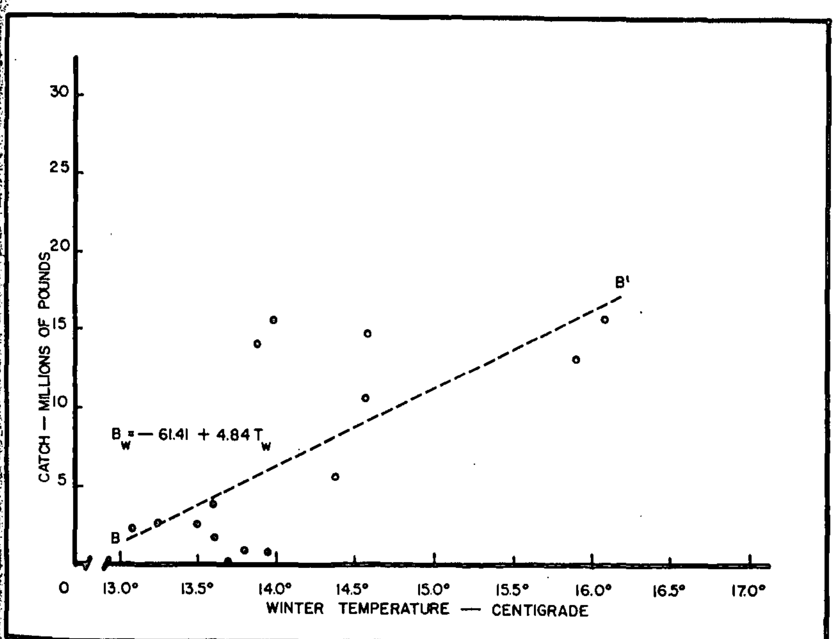

FIGURE 6. *Bluefin*—fishing boat landings from California waters. *Temperature*—average sea-surface temperature January through April, Balboa and La Jolla.

By accepting the preceding assumptions, it now should be possible to make catch predictions based on temperature. For example, the four-month average winter water temperature for Balboa and La Jolla during 1960 was 14.35 degrees C. From equation (4) we would then estimate the 1960 California bluefin catch to be 8.0 million pounds and from (3) we would estimate the albacore catch south of the International Border to be 13.9 million pounds. Fiducial limits at about the 66 percent probability level would be 3.2 to 12.8 million pounds for bluefin. Similarly, we can estimate that the 1960 albacore landings from waters south of the International Border will lie between the 66 percent confidence limits of 8.5 and 19.3 million pounds. The actual landings for 1960 are not yet available from the California Department of Fish and Game, so it is not possible to check our forecast. Preliminary reports, without regard to area of catch, indicate that the bluefin figure should be close. An early season tie-up by the albacore fleet will probably result in an over-estimate for the albacore prediction. However, since the equations were derived from data that were uncorrected for economic factors, the source of error due to the tie-up should be already included in our confidence limits.

FORECASTING TOTAL CATCH

So far only catches from limited areas have been considered. An attempt to predict total California landings from sea-surface temperatures is more involved. Total California albacore landings (Table 1) are made up of fish from south of the International Border, fish from California waters, and fish from north of the California state line. Although temperature might influence the movements of the fish in the latter two areas, the errors, which before could be treated as random sampling errors, become large north of the International Border. This is primarily due to large changes in fleet size depending on the success of the salmon troll fishery and the southern albacore fishery. The effect of weather probably is important too and would produce greater variability in the size of the catch north of Point Conception. For this reason an average of the 15-year landings is probably the best available estimate for the landings from California waters for any year. This average is 17.60 million pounds. Until a pre-season measure of changes in effort is available for the albacore fishery, a closer estimate of total catch cannot be made.

Total bluefin landings closely follow the trend of the landings from California waters. The relationship between total bluefin landings and winter water temperature is given by:

$$5)\ B_t = -76.52 + 6.40T_w$$

where B_t is total bluefin landing in millions of pounds and T_w is the winter sea-surface temperature previously described. The standard error of an estimated catch is 6.947. The standard error of the slope is 2.08. The slope is significant at the 1 percent level. The total estimated California bluefin catch for 1960 is 15.32 ± 6.9 million pounds at the 66 percent confidence level.

SUMMARY

1. Tuna landings from southern California waters fluctuate from year to year both in quantity and area of capture.

2. A correlation has been shown between sea-surface temperature (July, August, and September mean) at two southern California shore stations and bluefin and albacore catch from selected areas.

3. This correlation holds when winter water temperatures are used permitting a forecast of bluefin and albacore catch before the season begins.

4. Equations have been given for predicting any year's bluefin and albacore catch in selected areas and limits of confidence are set.

5. Landings from the selected areas have been compared with total California landings.

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