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APPARENT ABUNDANCE OF THE PILCHARD (*SARDINOPS CAERULEA*) OFF OREGON AND WASHINGTON, 1935–43, AS MEASURED BY THE CATCH PER BOAT

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APPARENT ABUNDANCE OF THE PILCHARD (*SARDINOPS CAERULEA*) OFF OREGON AND WASHINGTON, 1935-43, AS MEASURED BY CATCH PER BOAT

By JOHN C. MARR, Aquatic Biologist

One of the basic problems in fishery biology is the formulation of estimates of abundance. Boat-catch data constitute a source upon which such estimates are based. In general, it may be stated that the amount of fish taken by a fishery depends on the quantity of fish in the sea (abundance), the accessibility of the fish to the fishermen (availability) and the amount of effort (boat-weeks or similar units) expended in the fishery. Abundance is determined by the amount of successful reproduction (which may, and often does, take place at a considerable distance in space and time from the fishing grounds) as subsequently influenced by natural and fishing mortality. Availability is probably determined by conditions on the fishing grounds at the time the fishery is being prosecuted. It includes the possibility of migration of the fish to or from the fishing grounds. The quantities of fish which may be caught per unit-of-effort by the fishermen are thus determined by the combined effect of varying availability and fluctuations in abundance. The term "apparent abundance" is introduced to represent this combined effect.

Since the start of a fishery for the pilchard or sardine, *Sardinops caerulea* (Girard) 1854, in Oregon and Washington, boat-catch data (date, location, and amount of catch, name of boat, and other information not used here) have been collected by the fishery agencies of these States. If these catch data are converted to catch per unit-of-effort, the relative changes from season to season will be a measure of the changes in the level of apparent abundance or, possibly, changes in the amount of effort expended.

The first pilchard cannery in California was in operation before 1900 and large scale commercial operations started in 1916. The industry in British Columbia also is comparatively old; the first pilchard cannery there was in operation in 1917. In contrast, the Oregon pilchard fishery began only in 1935. This fishery started as a result of modification of laws concerned with the use of food fishes for reduction purposes (Hoy 1938: 5), rather than a sudden change in the habits or distribution of the pilchard. Similarly, the pilchard fishery in Washington began in 1936 as a result of special legislation (Chapman 1936: 1). In the beginning, landings were made at Coos Bay, Astoria, and Grays Harbor; however, at Coos Bay they were discontinued after 1938.[1] The original boat-catch data for the years involved are not given because of space limitations. Data on the tons landed in each season are shown in table 1 and in figure 2.

There are marked differences among the methods of purse seining for pilchard in the several fishing areas along the Pacific Coast of North America. Catches in British Columbia are usually made during the day, "with the best results usually obtained at daybreak and dusk" (Hart 1933: 13). (This refers to catches made off the Canadian coast; in some later years the Canadian fleet has often fished off the United States coast.) The Canadian boats fish in pairs (one seine boat and one tender) whereas in all other regions the boats operate singly. Catches landed at Grays Harbor and Astoria are made during daylight hours. Catches landed at Coos Bay were made both day and night. Pilchard landed at California ports are almost always caught at night and mostly in the dark of the moon. Hart (1933: 13), with reference to the Canadian fishery, states that "Night fishing is precluded by the damage which is done to the nets after dark by the dogfish." Chapman (1936: 5), speaking of the 1936 season in Washington, states that "the fishermen say that the fish split up into small schools of 5 and 10 tons at night, for which it is not practical to set. In addition,

[1] "Since writing the above, I have been informed by D. L. McKernan of the Oregon Fish Commission that some landings were also made at Coos Bay in 1939. Actually, 6 boats made 17 landings, or about 3 percent of the Oregon landings and 1.7 percent of the Oregon-Washington landings for that year. Under the methods of season and fleet definition used, these would be reduced to 1.4 percent and 0.8 percent, respectively."

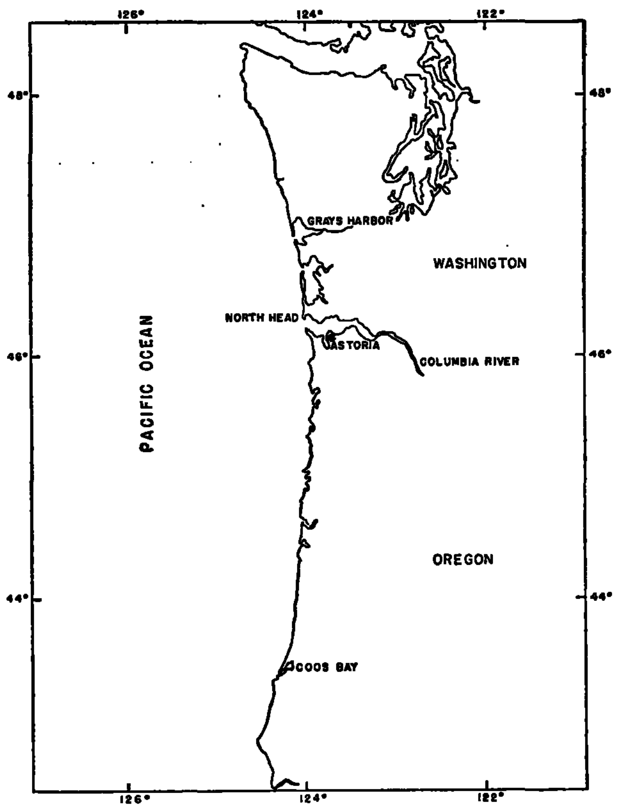

FIGURE 1.—Chart of locations mentioned in the text.

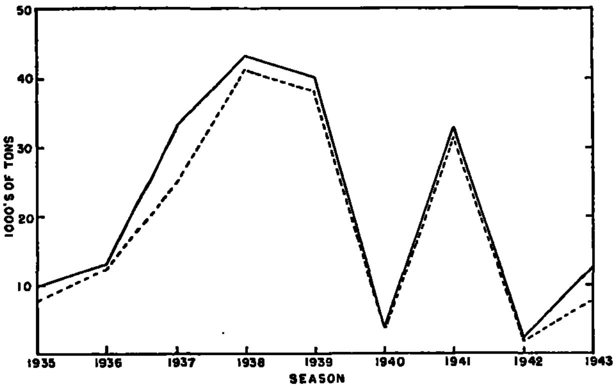

FIGURE 2.—The solid line indicates the total number of tons of pilchard landed at Astoria and Grays Harbor from 1935 through 1943; the dashed line indicates the number of tons landed by the selected fleet during the seasons as defined in the text.

in the northern area near Swiftsure Bank, the dogfish are so thick after dark that they greatly hinder fishing." California fishermen are not troubled by this shark.

The California fishery operates at night, apparently because of the presence in the water of large numbers of luminescent planktonic organisms. The mechanical stimulation of these organisms by the pilchard results in a milky glow which makes the schools easier to locate by night than by day (N. B. Scofield 1928: 250; W. L. Scofield 1926: 16) and also probably renders the gear more effective. Luminescent organisms are also present in the more northerly waters, although possibly not in such vast numbers (Sverdrup, Johnson, and Fleming 1942: 833). The presence or absence of large numbers of dogfish may determine whether pilchard are fished for in the day time or at night. However, it seems probable that there is a fundamental difference in the behavior of the pilchard on the different fishing grounds. In the south there may be a tendency for the fish to concentrate in schools at or near the surface, at night and to disperse horizontally or vertically during the daytime, or to descend without dispersing during the daytime. The reverse may occur in the more northern waters. If this situation actually obtains, Coos Bay may lie in a transition area. Observations in the several regions would be of great value and comparative studies of the northern and southern regions might well be a profitable method of obtaining information as to some of the factors that control the availability of the fish to the fishermen.

The data in this study have been made available through the courtesy of the Oregon Fish Commission and the Washington Department of Fisheries. V. E. Brock has completed a study of the first 4 years of this fishery and, although this analysis takes a different form than his, he generously made his work available. M. B. Schaefer, O. E. Sette, R. P. Silliman, and L. A. Walford have given freely of their time and advice.

CATCH PER STANDARD BOAT-WEEK

Catch per unit-of-effort might be most simply measured by the average number of tons of fish caught per boat per week. The use of such a measure would assume that the amount of effort expended per week were the same for all boats and for every year. This assumption is not valid, due to changes in sizes of boats in the fleet and related changes in nets that occur over a period of years. Further complications arise in the systematic treatment of the present data as a result of the irregular nature of the seasons each year. These are not fixed by law but are determined by the movements of the fish, by the weather, by the success of the California fishery, and probably other factors such as the economic problems resulting from processing pilchard early in the summer when the fat content usually is low.

In order to facilitate the treatment of the data certain rules had to be made. These are as follows:

1. Data for Coos Bay are omitted from this study, since no landings were made there after 1939 [2] and because catches landed there were made both day and night. A single landing during a season at Coos Bay by a boat making all of its other landings at Grays Harbor or Astoria was treated as though it had been made at the customary port. However, boats making two or more landings at Coos Bay during a season were eliminated.

2. Boats fishing out of Grays Harbor and Astoria fished in essentially the same areas and, in fact, often made landings at both ports. The percentage of boats making landings at both ports during a season ranged from 11 to 90 percent over the nine seasons covered. Therefore, in treating the data, boats from the two ports were considered to belong to one fleet.

[2] See footnote 1, p. 385.

3. In order to minimize error or possible bias due to the catches of boats which were in the fishery for a short period not necessarily representative of the season as a whole, all boats which landed fish in less than one-half the number of weeks in a season were omitted.

4. Scattered landings, which characteristically preceded and followed the period of a few weeks when the bulk of the catch was made each year, were discarded. This had the effect of keeping in the data many boats that would have been discarded under rule 3. To eliminate these scattered landings required a certain amount of arbitrary judgment, but it was done in a manner aimed at maximizing both length of season and number of boats. In no year did the landings preceding or following the season thus defined, as the period containing the bulk of the landings, amount to more than 8.1 percent of the total landings.

5. Within the limits of these seasons there is no way of telling whether or not a boat was fishing during periods in which it made no landings. Therefore, if a boat made no landings during a particular week, it was assumed to be fishing provided that *(a)* it made landings in the weeks immediately preceding and following that week, and

TABLE 1.—*Information on the Oregon-Washington pilchard fishery, 1935 through 1943*

Season	Dates of first and last landings	Dates of season	Number of weeks in season	Total number of landings	Landings omitted: Number outside of season [1]	Percentage outside of season	Number at Coos Bay [2]	Number less than one-half season [3]	Number with no length data [4]	Total number	Total percent
1935	June 23 to Nov. 30	July 7 to Sept. 14	10	139	9	6.5	6	23	0	38	27.3
1936	July 15 to Sept. 30	July 19 to Aug. 29	6	247	17	6.9	2	16	4	39	15.8
1937	July 9 to Oct. 13	July 18 to Sept. 25	10	455	37	8.1	0	55	0	92	20.2
1938	July 29 to Sept. 19	July 31 to Sept. 10	6	607	14	2.3	16	11	0	41	6.8
1939	July 7 to Aug. 17	July 9 to Aug. 19	6	626	6	1.0	0	18	18	42	6.7
1940	Aug. 5 to Sept. 21	Aug. 4 to Aug. 17	2	63	3	4.8	0	0	4	7	11.1
1941	June 21 to Sept. 3	July 6 to Aug. 30	8	610	32	5.2	0	18	0	50	8.2
1942	June 30 to Aug. 7	June 28 to Aug. 8	6	57	0	----------	0	13	0	13	22.8
1943	July 8 to Aug. 16	July 11 to Aug. 21	6	170	2	1.2	0	23	41	66	38.8

Season	Total tons landed at Astoria and Grays Harbor	Total tons landed at Coos Bay [5]	Percentage of Astoria and Grays Harbor landings omitted	Number of boats in fishery	Number of boats in selected fleet	Average length selected fleet	Number of boat weeks
1935	9,915	15,988	20.7	11	6	70	43
1936	13,019	7,663	13.5	33	26	69	113
1937	33,106	759	25.7	29	16	72	135
1938	43,155	554	4.4	62	57	73	288
1939	40,109	----------	5.0	64	55	73	278
1940	3,890	----------	11.9	36	33	73	38
1941	33,054	----------	5.7	30	26	74	187
1942	2,446	----------	26.7	17	6	75	29
1943	12,456	----------	40.0	19	8	75	34

[1] Landings that were made outside the limits of the season as defined in the text were eliminated.
[2] Boats that made 2 or more landings at Coos Bay during a season were eliminated; see also footnote 1, p. 385.
[3] Boats that were in the fishery less than ½ of a season were eliminated.
[4] Boats for which no information on length could be obtained had to be eliminated.
[5] See footnote 1 on p. 385.

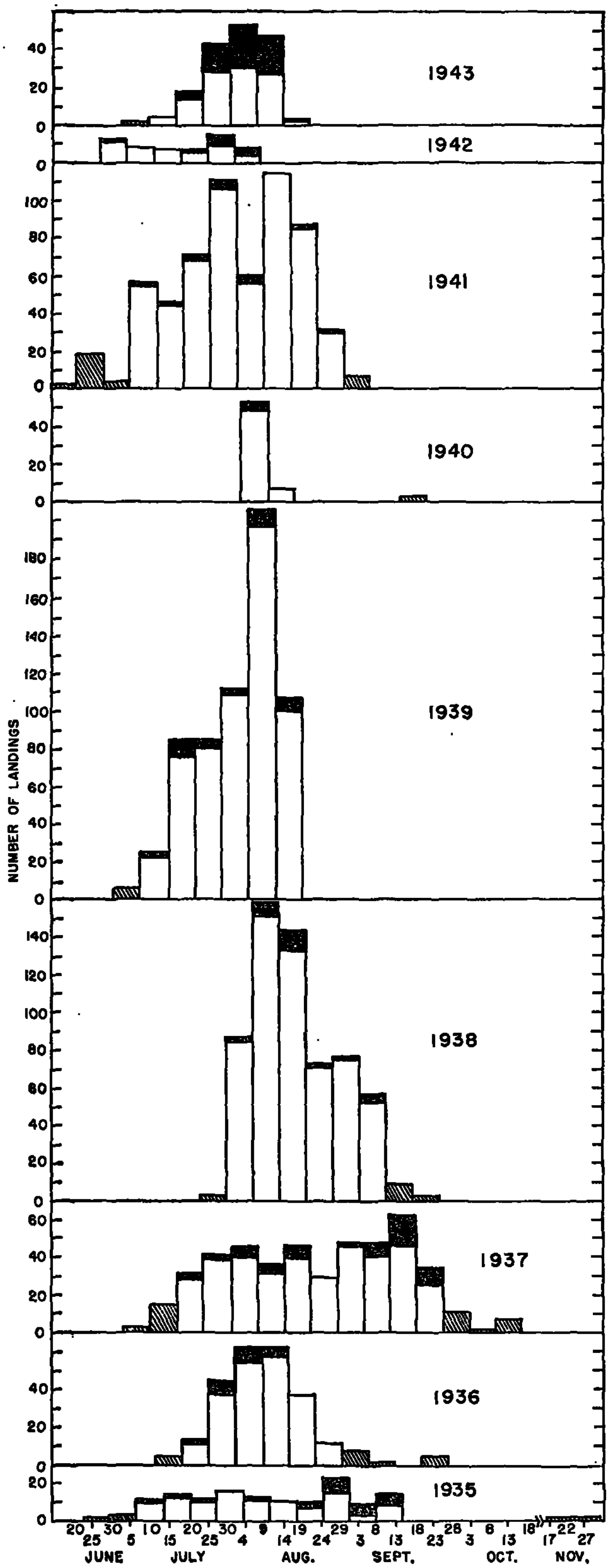

FIGURE 3.—Frequency distributions of the numbers of landings per week in each year. The hatched areas indicate landings omitted because they were outside the season as defined in the text, and the shaded areas indicate landings omitted for other reasons.

(b) one-third or more of the boats making landings during the week in question made only one landing (after Silliman and Clark 1945: 54).

The effects of the applications of the preceding rules are shown in figure 3 and table 1.

After defining the seasons and the fleet involved in the fishery each season by the above rules, it is necessary to standardize the data so that the effort units are the same from year to year. The use of the device known as linkage (where the performance of a fleet in year A is compared with the performance of the identical fleet in year B, and the performance of a different fleet in year B is compared with the performance of that identical fleet in year C, and so on) would be inadvisable, since the composition of the fleet varied widely between adjacent years and the use of such a technique would result in the loss of an inordinate amount of data.

If there is a relationship between catch per unit-of-effort and boat size (or some other attribute), it is possible to compare the performance of boats of a given size rather than the performance of identical boats. This will average out the fluctuations in individual boat success due to the fishermen's skill, just as the linkage method will, and between-season comparisons will involve similar effort units.

Theoretically, it might be expected that there is a relationship of catch per unit-of-effort and boat length (as a measure of boat size). Data on boat length are available (U. S. Department of Commerce, 1935–42). For each season separately, the tons landed by each boat in each week were plotted against boat length (by 2-foot boat-length intervals) and a straight line fitted to the points by the method of least squares. The only assumption made is that the two variables are related in an approximately linear manner over the ranges of boat sizes and catch sizes occurring in these years. In all years except 1940, 1942, and 1943, the correlation is highly significant ($P<0.01$). For the three seasons mentioned, the correlations are of doubtful, or no significance ($P=@0.10$). These latter values are probably due to the smaller number of boats in the fishery, the shortness of the season in these 3 years, or both (i. e., the small number of boat-weeks). Even though the slopes of these three regression lines do not vary significantly from zero, the levels of apparent abundance may still be accurately reflected by the levels of the lines.

By analysis of covariance it is possible to determine whether these nine regression lines differ significantly from the regression line of the pooled data for the nine seasons. They do, in fact, differ significantly.

Item	*Sums of squares*	*df*	*V*
Common	14, 550, 388	1, 143	-------
Separate lines (within)	12, 404, 161	1, 127	11, 006
Difference (between)	2, 146, 227	16	134, 139

The variance about the separate lines is significantly less than the variance between the separate lines; $Z=1.25$, P is considerably less than 0.01 (Tippett 1941: pp. 181–188). This shows that the regressions differ in slope, level, or both. The levels and slopes may be expected to vary simultaneously for two reasons. First, the smaller boats would tend to reach their capacity at relatively low levels of apparent abundance and any further rise in level of apparent abundance would not be reflected in their catch per unit-of-effort. Larger boats, however, would continue to respond through a higher range of levels of apparent abundance. Second, there is probably a minimum boat size below which, for economic and mechanical reasons, pilchard would not be caught. This is borne out by the fact that the Y-intercepts of the regression lines (using noncoded values of X) are all negative. From both of these reasons it is to be expected that the left end of the regression line would tend to be relatively fixed, while the right end would be free to move up and down in response to changes in level of apparent abundance. As a consequence, those lines at the highest level would also have the greatest slope and those lines at the lowest level would also have the least slope. Examination of figure 4 and table 2 will show that this is true for the present data.

It is thus seen that the slopes and levels of the regression lines are significantly different among the nine seasons. These differences may be interpreted as expressions of differences in levels of apparent abundance in the different seasons.

TABLE 2.—*Data on the regression of catch per week on boat length in the Oregon-Washington pilchard fishery, 1935–43*

Season	$Y=a+bX$ [1]	Tons per boat-week: Boat size, 68′–69′ [2]	Boat size, 72′–73′ [3]	Boat size, 78′–79′ [4]	r [5]	P
1935	$Y=-73+18.4X$	166	203	258	0.41	<0.01
1936	$Y=37+4.8X$	99	109	123	.27	< .01
1937	$Y=12+11.8X$	165	189	224	.25	< .01
1938	$Y=-21+10.8X$	119	141	173	.25	< .01
1939	$Y=-11+9.6X$	114	133	162	.18	< .01
1940	$Y=3+5.7X$	77	89	106	.27	@ .10
1941	$Y=-12+11.5X$	138	160	195	.26	< .01
1942	$Y=-49+6.8X$	39	53	73	.26	> .10
1943	$Y=-17+14.7X$	174	203	248	.19	> .10

[1] Equation of the regression line of tons caught per week on boat length (by 2-foot boat length intervals), where Y=tons caught per week, $a=Y$-intercept of regression line, b=regression coefficient of Y on X, and X=boat length. Boat lengths were coded as follows: boat length class 44′–45′=1, 46′–47′=2, . . . , 88′–89′=23.
[2] Value obtained by substituting $X=13$ in the preceding equation.
[3] Value obtained by substituting $X=15$ in the preceding equation. This length was referred to as a "standard boat" in the text.
[4] Value obtained by substituting $X=18$ in the preceding equation.
[5] Coefficient of correlation.

A catch per standard boat-week datum may be determined, for each season, from the equation of the fitted line. It should be noted that calculating the catch per week for any particular size boat makes use of all the data going into the regressions. The numerical expression of catch per standard boat-week will depend, of course, upon the size chosen as a standard boat. For purposes of comparison with indices of abundance from other regions, the selection of a medium size is indicated, since such indices have usually been based upon the performance of a fleet of boats rather than on any standard size. (See, for example, Silliman and Clark's 1945 study of catch per unit-of-effort in California.) The modal boat-length class (72′–73′) was therefore selected as representing a standard boat. For each season the average tons per week for a standard boat were calculated from the equation of the fitted line. These values are given in table 2 and shown by the solid line in figure 5. They tend to vary around an average of slightly more than 140 tons per standard boat-week. The fluctuations around this level are rather wide and there is no significant trend during the period covered ($P>0.10$).

Selection of a different size boat will affect the numerical values obtained for the catch per boat-week. To illustrate this, there are given in figure 5 curves showing the catch per boat-week for the smallest boat size present in all seasons, 68′–69′ (broken line), and for the largest boat size present in all seasons, 78′–79′ (dashed line). The levels are somewhat different, but the relative changes

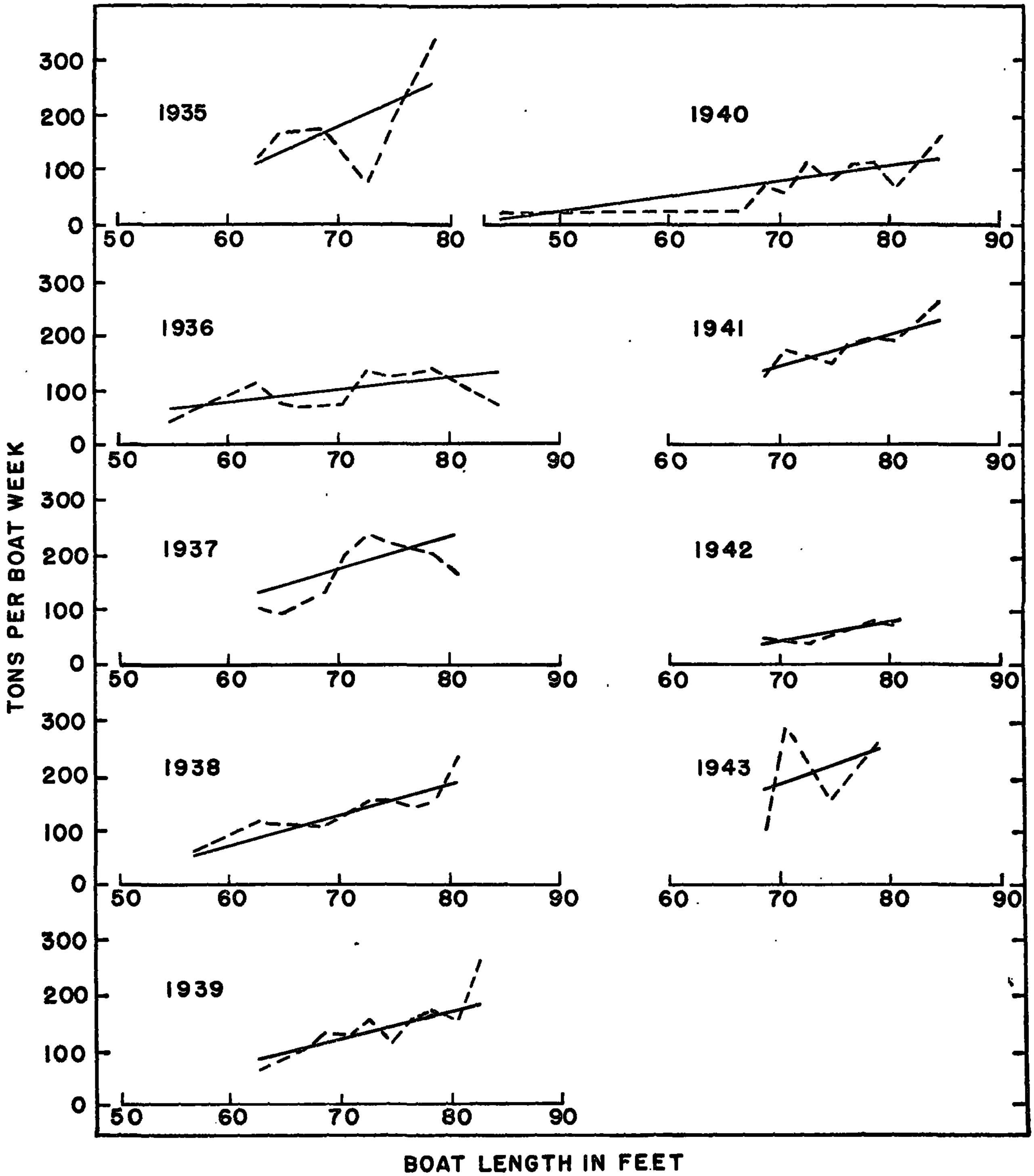

FIGURE 4.—Regression of tons landed per week on boat-length (by 2-foot boat-length intervals) for each season. The solid line was fitted by the method of least squares. The average values, for each length interval, of the points to which the solid lines are fitted are connected by the dashed line.

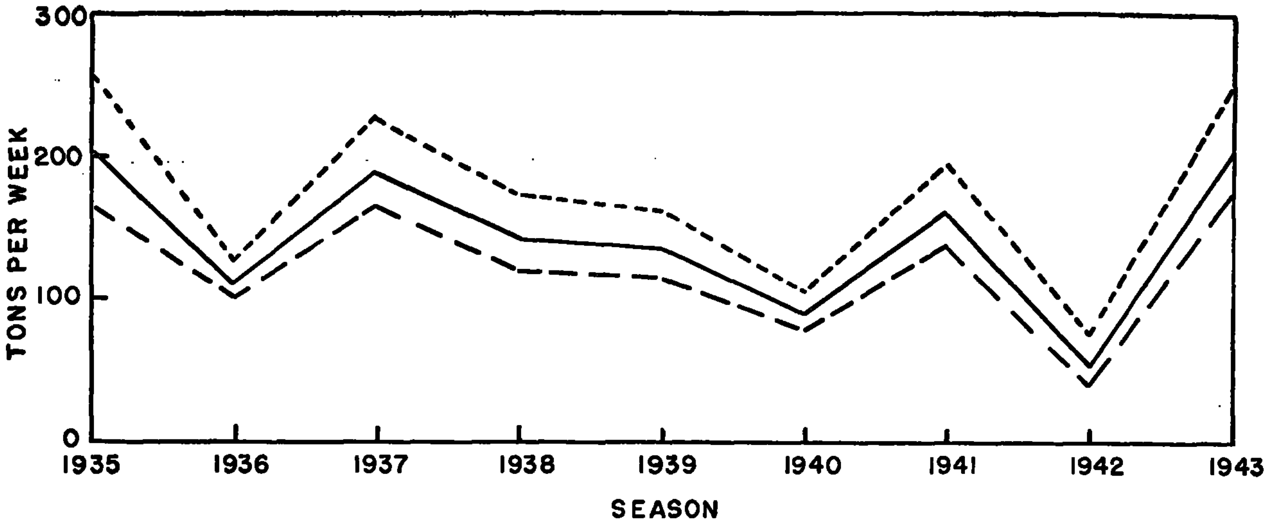

FIGURE 5.—Tons of pilchards caught per boat-week in the Oregon-Washington fishery. The broken line is based on boat-size 68′–69′; the solid line on boat-size 72′–73′; and the dashed line on boat-size 78′–79′.

are similar in all three curves. However, in contrast to the curve representing the standard boat, the curve representing the smaller boat minimizes the fluctuations, while the curve representing the larger boat accentuates them. Since boats of larger sizes are freer to respond to changes in level of apparent abundance, the dashed line in figure 5 more accurately reflects these changes than do the other two lines, although in the present instance the differences are not great. The values plotted in these lines are given in table 2.

As mentioned previously, changes in the magnitude of catch per unit-of-effort indices may be brought about by changes in the amount of effort expended, as well as by changes in apparent abundance. The former will not occur, presumably, when the intensity of the fishery is low relative to the size of the stock of fish. Records have not been kept on the number of effort units in the Oregon-Washington pilchard fishery from season to season. However, an estimate of the number of effort units in a particular season may be obtained by dividing the total catch by the catch per unit-of-effort. Comparison of the number of effort units with the catch per unit-of-effort in each season shows that, over the nine seasons covered, there is no significant correlation ($r=0.11$).

In brief, use is made of a linear relationship between average tons caught per week and boat length to obtain a catch per standard boat-week datum for each season. These data are interpreted as reflecting levels of apparent abundance; they apparently do not reflect changes in intensity. It is the variation in these levels from season to season which is of interest. No trend is apparent over the nine seasons covered; the values tend to vary around an average of slightly more than 140 tons per standard boat-week. Catch per boat-week data for larger boats more accurately reflect changes in level of apparent abundance than do data based on smaller boats.

AVAILABILITY

As indicated, these data are affected by the availability of the fish to the fishermen as well as by the actual abundance of the fish. It is known, on the basis of circumstantial evidence from size-composition of the catch and other information (summary of references in Clark 1935) and direct evidence from tagging (Clark and Janssen 1945: 41), that there is an exchange, in both directions, of fish between the northern and southern fishing grounds. A spawning area of this species is known to lie off southern California south of Pt. Conception (E. C. Scofield 1934; Ahlstrom 1948). More northern waters have not been adequately surveyed and their importance as spawning areas is unknown. It is known that important spawning took place in them in 1939 (Walford and Mosher 1941; Hart 1943). If information were available that would permit the removal of the effects of varying availability from measures of abundance in the Oregon-Washington fishery and in the California fishery, it would be possible to examine the relationship of abundance in Oregon-Washington with abundance in California.

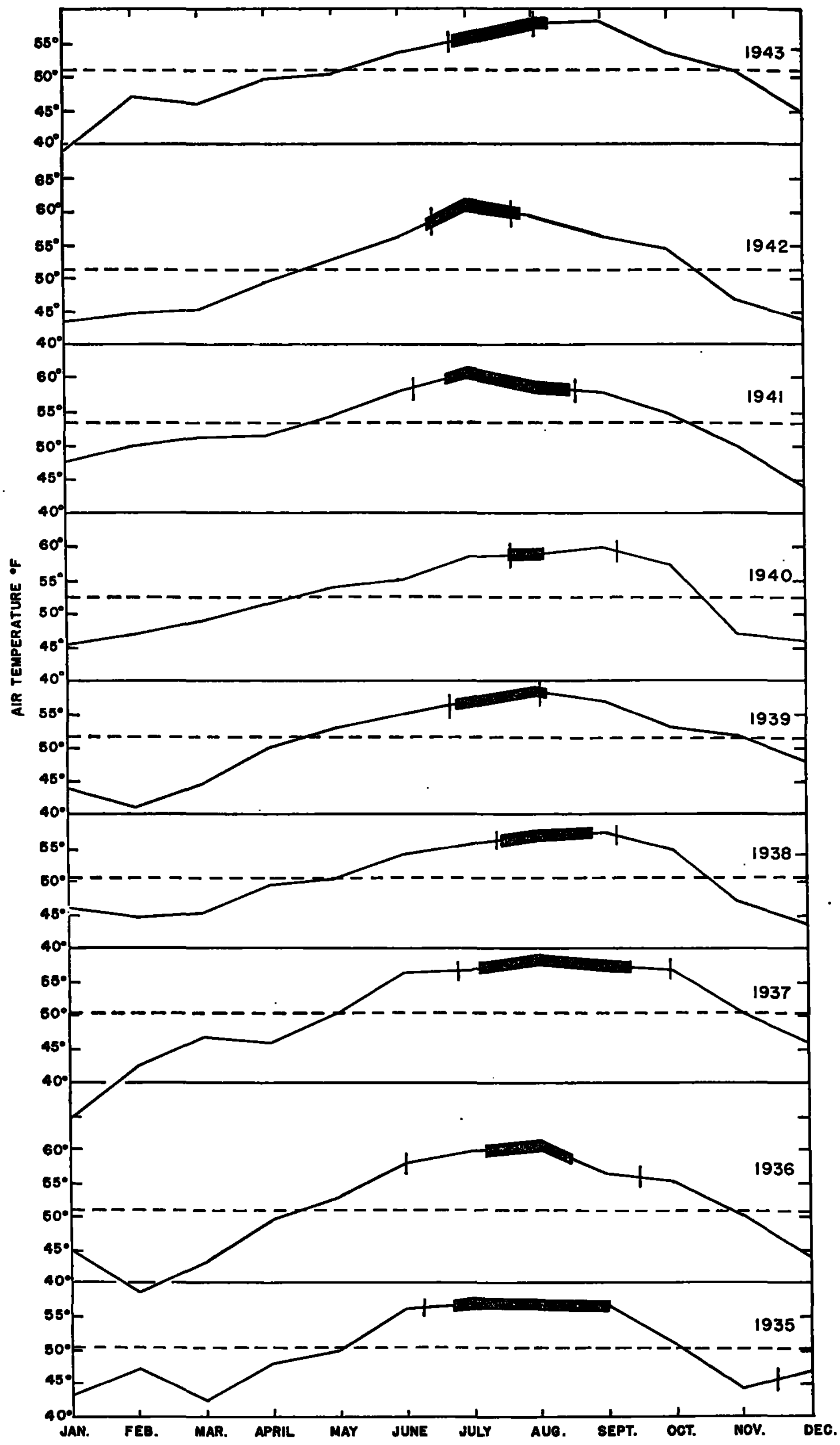

FIGURE 6.—Average monthly air temperatures, ° F., at North Head, Wash., for the years 1935–43. Vertical lines indicate the dates of the first and last landings in each year, and the solid bars the time and duration of the seasons as defined in the text. Horizontal broken lines indicate average annual air temperatures.

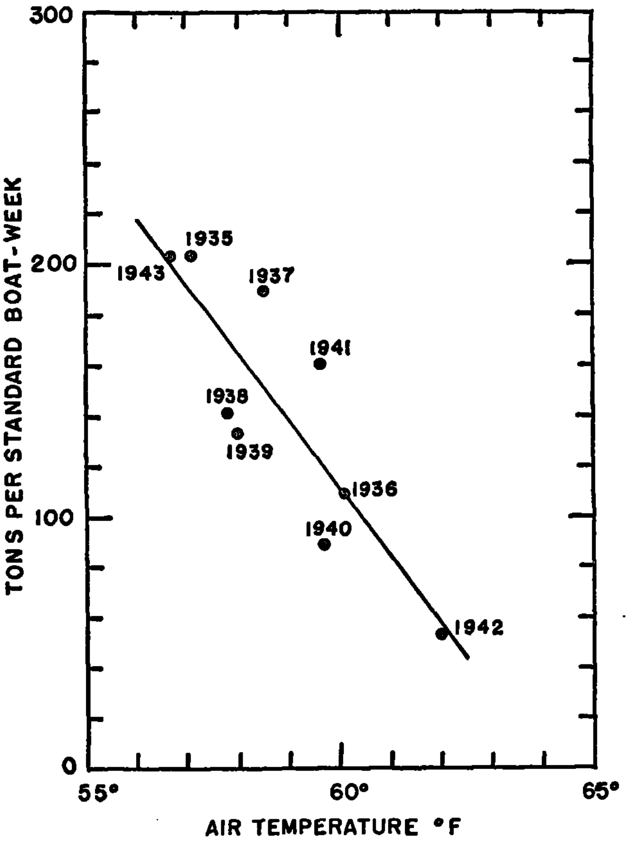

FIGURE 7.—Correlation diagram showing the relation of tons caught per standard boat-week with average daily air temperatures, ° F.. during each season (as defined in the text) at North Head, Wash.

In this connection, figures 6 and 7 are of interest. In figure 6 there are shown for each year, 1935–43, the average monthly air temperatures in ° F. at North Head, Wash. (U. S. Weather Bureau, 1935–43). (Air temperatures at a land station are used in place of appropriate water temperatures, as the latter are not available.) The vertical lines indicate the dates of the first and last landings each year and the solid bars indicate the duration of the season as limited in this study. The period of the fishery in each year seems to be associated with the period of highest temperatures. To examine this seeming relationship more critically, the regression of the time of the pilchard season each year on the time of the highest weekly average of daily air temperatures in ° F., at North Head, was determined. The time of the season was expressed in terms of the number of days after June 30 on which the mid-date of the season fell. The time of the period of highest temperatures was expressed in terms of the number of days after June 30 on which the mid-date of the week having the highest average daily temperature fell. The coefficient of correlation was found to be 0.58; $P=0.10$. By commonly accepted standards, a probability value in this range neither substantiates nor invalidates the hypothesis that there is a correlation between the time of highest temperatures and the time of the fishery. This is especially true when the crudity of the methods employed is taken into consideration. Judgment must therefore be reserved for the present.

In figure 7 are shown the tons per standard boat-week plotted against the average daily air temperatures during the season at North Head, Wash. The line was fitted by the method of least squares. For this regression, the correlation is negative ($r=-0.80$) and highly significant ($P=0.01$). If the tons per boat-week data for the larger boats are used, the coefficient of correlation has the same value; the slope of the fitted line is increased. If the regression of tons per standard boat-week on average daily air temperatures during the months of July and August is considered, the coefficient of correlation is found to be -0.75 ($P=0.02$). The best catches per standard boat-week tended to be made in the seasons of lowest average daily temperatures and, conversely, the lowest catches per standard boat-week tended to be made in the seasons of highest average daily temperatures. In other words, it has been demonstrated that the return per unit-of-effort expended in the Oregon-Washington pilchard fishery, 1935–43, has been considerably influenced by an environmental condition or conditions. Of course, the effects of water temperature (as reflected by air temperature) on the habits and life history of the pilchard are unknown. These effects might be direct or they might be the result of the effects of some unknown factor upon both water temperature and the fish. Conceivably, the effect could be on the habits of the fishermen rather than upon the habits of the fish. The subject is introduced here to emphasize the need for studies of the biology of this species.

SUMMARY

1. Boat-catch data covering the years 1935–43 in the Oregon-Washington pilchard fishery are used. The relationship between boat length and tons caught per week is used to obtain catch per standard boat-week data.

2. The catches per standard boat-week showed no significant trend over the nine seasons and varied around an average of slightly more than 140 tons per boat-week.

3. It is pointed out that catch per standard boat-week is a measure of apparent abundance. On the basis of present knowledge, it is impossible to separate the effects of availability from abundance and only the combined effects of the two, or apparent abundance, can be measured.

4. Two ways in which the Oregon-Washington pilchard fishery might be affected by temperature are pointed out.

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