THE RELATION BETWEEN EFFORT AND YIELD IN THE DUNGENESS CRAB FISHERY

by

Wesley Silverthorne
Nelson E. Stewart

for
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ABSTRACT

Surplus yield models, mark-recapture data, and length-frequency data have been used to determine how the annual catch of Dungeness crab in Washington, Oregon, northern California, and central California will react as fishing effort varies. Yield curves were estimated for Washington and Oregon showing the maximum sustainable yield (MSY) at effort levels below levels which now exist in those fisheries. Analysis of effort and yield during peak harvest years in northern California indicates that the effort needed to harvest the MSY if all years were peak years is only slightly higher than recent levels of effort. No sustainable yield curve was obtained for the central California fishery because the crab population appears to have been in a steady decline for nearly two decades.

We conclude that there has been and will probably continue to be more effort applied to crab fishing than is required to harvest the maximum sustainable yield. Whether or not it would be desirable to reduce effort levels will depend on economic and equity factors not yet considered.

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INTRODUCTION

The end product of the effort management study, according to the Phase II proposal, is to be a "detailed analysis of the advantages and disadvantages" of selected effort management schemes. Each scheme may be expected to have a number of aspects giving rise to advantages or disadvantages. Chief among these is the potential any effort limitation has for changing the annual catch.

Fisheries biologists have developed several distinct techniques for predicting the impact of fishing effort and fishing regulations on fish stocks, catch rates, catch per unit effort, and related variables. The application of these techniques is referred to as fish stock assessment. The need for stock assessment is well stated by Gulland (1969, p. 99):

> The problems of stock assessment occur at all stages of the development of a fishery, with the need for accuracy and precision increasing as the fishery develops. In an undeveloped fishery all that is generally required is a rough measure, say to within a factor of two or three, of the magnitude of the resource and the potential yield from it and also a measure of the decrease in catch per unit effort likely to be caused by future increases in fishing effort. These estimates may be used as bases for determining the possibilities of expansion. Later, better estimates will be required to determine when the fishery is approaching the level beyond which further expansion of fishing will give little increase in total catch, so that further expansion can be discouraged, or some form of regulation considered. Finally, in a very intense fishery, very accurate estimates may be necessary to ensure proper regulation, e.g. in setting precise catch quotas, etc.

The situation in the Dungeness crab fishery is much like Gulland's second stage where the fishery is being examined to determine whether or not regulations to discourage further expansions should be considered. Accordingly, we have applied certain stock assessment techniques to the Dungeness crab fishery, hoping not for absolutely precise answers, but rather for precision commensurate with the need at this stage.

The basic assessment technique used here has been to fit various surplus yield models to catch and effort data. This choice of approach has been dictated by the fact that the data required by other approaches are not obtainable without undertaking an extensive sampling program. What additional data are available, such as length-frequency data from Oregon and tagging studies from Washington and California, have been examined to see whether or not they tend to confirm the implications of the surplus yield models.

TRENDS IN LANDINGS AND EFFORT

Coastwide

Crab landings for the coastal areas of Washington, Oregon, and California have varied over the past 24 years from a high of 47.4 million pounds in 1970 to a low of 7.8 million pounds in 1974 (Figure 1). Landings in 1974 were 18 million pounds less than the 24-year average of 25.8 million pounds.

The number of boats fishing crab has varied but has not increased significantly since 1952. However, the number of crab pots in use in the coastal fishery has increased from 46.4 thousand in 1951 to 137.9 thousand in 1972, which is approximately a 200% increase. The average number of pounds of crab caught per pot has varied with yield fluctuations but the general trend has been downward. The number of individual landings has also varied with yield fluctuations but otherwise has remained fairly constant (Table 1).

Since 1972 there has been a decrease in the numbers of boats and pots that were fished in Washington and California (Tables 2 and 4). Effort statistics for Oregon are not available after 1972 but it is believed that the numbers of boats and pots fished off Oregon has also decreased (C. D. Snow, personal communication).

Washington

General trends in landings and fishing effort in Washington's coastal fishery follow closely the coastwide trends (Figure 2). Annual landings have varied from a low of 3.3 million pounds in 1951 to a high of 18.4 million pounds in 1969 and since 1951 have averaged 7.8 million pounds.

The number of crab boats in Washington's coastal fishery remained fairly constant between 1951 and 1969 with an average of 90 boats per year. In 1970 the number of boats increased from 97 to 138 and by 1972 there were 152 boats fishing crab. In 1973 the number of boats had dropped back to 147.

The trend in number of pots has been one of a steady increase of about 5% per year up to 1968 when 19.5 thousand pots were fished. In 1969 the number of pots increased to 26 thousand and by 1972 over 45 thousand pots were being fished. Since 1972 the number of pots has been declining. The average pounds of crab caught per pot has ranged from 115 to 800 pounds per pot and averaged 408 pounds per pot. The number of individual landings has fluctuated between 3.7 and 7.4 and averaged 4.9 thousand (Table 2).

Oregon

Annual landings of crab in Oregon since 1951 have varied from a high of 15 million pounds in 1971 to a low of 3.1 million pounds in 1973 and averaged 8.2 million pounds. Landings in Oregon from 1951 to 1961 have fluctuated more frequently than landings in Washington (Figure 3). Since 1961 fluctuations in Oregon's landings have followed a pattern similar to that in Washington and that occurring coastwide (Figures 1 and 2).

The number of boats fishing crab in Oregon varied between 68 and 121 from 1951 to 1969. In 1970 the number of boats increased to 143 and by 1972 the number of boats had increased to 205. The number of boats fishing crab since 1972 is not known, but as was pointed out earlier it is believed to have decreased.

The number of crab pots fished in Oregon increased steadily up to 1969 when 29.2 thousand pots were being fished. Then in the next three years the number of pots increased to nearly 55 thousand. The average pounds of crab caught per pot has declined during this period to a low of 124 pounds per pot in 1972 (the last year for which data are available). The number of individual landings increased from 5.7 to 10.7 thousand from 1953 to 1971. Since 1971 the number of landings has been dropping (Table 3).

California

Statewide trends in landings and fishing effort for California since 1951 have not followed those occurring in Washington and Oregon. When the peak yield years and the low yield years are compared the trend has been a decrease in annual landings in California (Figure 4). The number of boats fishing crab has dropped from 473 boats in 1952 to 243 boats in 1973. The number of crab pots fished increased from approximately 20 to 40 thousand between 1951 and 1957, dropped to 28 thousand by 1963, and then increased to nearly 49 thousand in 1969. Since 1971 the number of pots has declined. There has also been an overall decline in the average pounds of crab caught per pot and in the number of individual landings (Table 4).

Trends in landings and fishing effort in northern and central California have differed markedly. Catch and effort statistics for northern California follow patterns similar to those in Washington and Oregon (Figure 5). Annual landings have varied from a low of 0.9 million pounds in 1963 to a high of 14.1 million pounds in 1970 and averaged 7.3 million pounds since 1951. The number of boats fishing crab has fluctuated between 117 and 250 and overall increased slightly up to 1971. The number of crab pots fished increased from 6.3 thousand pots in 1955 to 32 thousand pots in 1971. Since 1971 the number of pots has been declining. There has been a general downward trend in the average catch per pot. The number of individual landings has varied with yield but otherwise has changed little in the past 23 years (Table 5).

In contrast to northern California and the rest of the Pacific coast the Dungeness crab fishery in central California has experienced a serious decline since 1957 (Figure 6). Landings dropped from 9.3 million pounds in 1957 to 0.7 million pounds in 1962 and have remained less than 1.5 million pounds since 1962. Along with the decline in landings there has also been a significant decrease in the numbers of boats and pots used in the central California fishery. The number of boats has dropped from 265 in 1960 to 90 in 1973 while the number of pots has dropped from 21.4 to 9.7 thousand over the same time period. The average pounds of crab caught per pot dropped from 482 in 1957 to 47 in 1971. There has also been a substantial decline in the number of individual landings since 1957 (Table 6).

ESTIMATION OF SUSTAINABLE YIELD CURVES

Sustainable yield curves were estimated for Washington, Oregon, northern California, and central California with the use of three different surplus yield models. The distinctive feature of each model is the form of the estimated curve. In the Schaefer model logistic growth is assumed, making the yield curve a parabola. The exponential model assumes a Gompertz growth function, giving the relationship between fishing effort and population size an exponential form. The yield curve using the exponential model is asymmetrical. The generalized production model assumes a growth function proposed by Richards (1959). The yield curve may be skewed to the right or left or may be identical to the Schaefer curve, depending on the estimated parameter values.

In addition to the three models used, four separate estimation techniques were used. The Schaefer model parameters were first estimated by linear regression using catch and catch per unit effort for the period 1939-1971 for each of the three states. These estimates have been previously reported in "Excess Effort in the Dungeness Crab Fishery: A Preliminary Analysis". The same linear regression method has now been used to estimate Schaefer and exponential yield curves for the four geographical regions from season data beginning in the 1950-1951 season. This method was relatively unsuccessful due to the large fluctuations in population levels during the period considered. In order to overcome the difficulties posed by these population fluctuations, three additional estimation techniques were tried. First, the regression approach was applied to data from only those years judged to have the highest population abundance. In this way it was hoped to construct a data series for which the population fluctuations are held to a minimum. Then the Schaefer method for fisheries out of equilibrium was tried for both the Schaefer and exponential models (see Schaefer 1957). Finally, the generalized production model was fit to the data by the method of Pella and Tomlinson (1969). Essentially, this method finds the catch history, consistent with the model, which minimizes the squared deviations of the expected catch for each season from the observed catches. The method develops a statistic, R^2, which allows a test of the goodness of fit of any expected catch history to the actual catch data. This statistic is analogous to the r^2 of regression analysis in that it indicates the percentage of variation from the mean which can be accounted for by the hypothetical relationship (model) used to generate the expected catches. Thus, the statistic R^2 can be calculated for each of the models specified, and used as a basis for comparing them.

It was felt that the number of pot lifts in a season would be a more realistic measure of effort than pots fished. However, no direct measure of pot lifts has ever been recorded. Examination of the data on pots fished per trip per month obtained from the fisherman questionnaires indicated that the average number of pots per trip was approximately constant throughout the season. Therefore, it was decided that numbers of landings would be approximately proportional to pot lifts. Numbers of landings per season were thus used in place of pots fished per season in the simple Schaefer curve analysis. In each case the regression line had a positive slope, indicating that the response on the part of the fishermen to increased crab abundance was to increase the number of landings. This relationship swamped any tendency for catch per landing to decline as landings increased. Therefore, we have concluded that while landings may be a more reasonable measure of effort than pots fished, the speed with which fishermen can alter the number of pots they fish is slower and as a consequence pots fished works better in the surplus yield analysis.

Therefore, in the following discussion effort is defined as number of pots fished.

The preliminary estimates of MSY and associated effort reported in our previous paper are shown in Table 7. For the State of Oregon the estimate is based on the data series of the Oregon Fish Commission. For Washington and California the estimates are based on data from the U.S. Fishery Statistics. Unlike the other two states, there is a major discrepancy between data on pots fished as reported by the U.S. Fishery Statistics and by the Oregon Fish Commission. Unfortunately, we have not been able to ascertain the cause of the discrepancy, but we believe the Oregon Fish Commission data are more accurate so we used that data series in our analysis. The only substantial improvements over these early attempts were achieved with the peak year analysis and the generalized production model. The results of these methods are summarized in Table 8. None of the attempts produced useful results for central California and only the peak year results were useful for northern California. However, both methods appear to have worked well for Oregon and Washington.

Using the generalized production model, Oregon shows a peak yield somewhere between 25,000 and 32,500 pots. This is consistent with the peak at 30,125 pots indicated by the peak year Schaefer curve, since one must expect higher yields and possibly higher effort levels during years of greater than average abundance. The results for Washington are also consistent in this manner, but the generalized production model did not indicate such a definite peak. In fact, the results indicate a yield curve which is quite flat from about 12,500 to 25,000 pots. Consequently, the most that can be said on the basis of these results is that the MSY for Washington is probably obtained somewhere within that range. The peak year estimate for Washington of 26,375 pots appears to be as reliable as that for Oregon. In northern California there is nothing to compare the 26,384 pot peak year estimate with, since the other methods failed to produce meaningful results. However, the value of r^2 is incredibly high for the peak year fit. All three peak year estimates of the slope of the regression line are significant at the 5% level or better.

LENGTH-FREQUENCY AND MARK-RECAPTURE DATA

Aside from the surplus yield analysis reported above, the only scientific evidence bearing on the question of where the yield curve peaks comes from length-frequency data and mark-recapture data.

Exploitation rates for Dungeness crab have been estimated from mark-recapture data by Cleaver (1949) and Jow (1965). The work by Cleaver, especially, is often cited to justify the assumption that the crab caught in a given year represent nearly all the crab available during that year. In an early draft of the Phase II proposal, for example, Cleaver's work was cited as indicating that 80-90% of the legal-sized crab available during a given year are landed in that year. Effort levels in 1954-1955 were then compared to effort levels in 1971-1972 on the assumption that nearly equal catches in those seasons indicate nearly equal populations of legal crab.

Cleaver tagged and released 3,880 crabs during the winter of 1947 and 4,446 crabs during the winter of 1948. Based on the numbers of these marked crab estimated as having been caught in the commercial fishery in each of the two seasons he estimated the fishing mortality rates for the two seasons at 73.7% and 82.2% respectively. However, his figures indicate a wide variation in tag recovery rate by area, with the highest rates being obtained in areas fished most intensively. When he excludes Grays Harbor and Willapa Bay, the calculated rates become 78.6% and 87.2%. During that one year interval pots fished increased from 15,300 and 22,100. Pots did not again reach the 22,000 level until 1969. It is difficult to conclude, on the basis of these figures, that more effort would not have increased the yield during the seasons covered by Cleaver's study.

A similar study by Jow (1965) on the northern California-southern Oregon crab fishery indicated an exploitation rate of 84% for the 1962-1963 season. In this particular season the catch from northern California was only 900,733 pounds with 12,010 pots. One of Jow's conclusions is that fishing mortality drops in years of greater crab abundance. Presumably, then, greater effort in years of abundance would maintain the fishing mortality and increase the catch.

Another indication of fishing mortality is obtained through observations on the percentage of crab caught in a given year which were legal in the previous year. Such "carryover" crab will generally have molted once since the previous year, in which case they may be identified by their large size. Therefore, given the size distribution of crabs which have molted once since recruitment into the fishery, and given the assumption that carryover crab all molt once after recruitment, the percentage of carryovers in the catch may be estimated using length-frequency data. Such length-frequency data have been gathered in all three states and are sometimes cited as evidence that nearly all the crab are caught every year.

In order to calculate the percentage of available crab caught in a given year (the exploitation rate) from the percentage of carryovers observed in the following year's catch, it is necessary to estimate the population of legal crab in the second year in order to convert the sample ratio to numbers of crab. Then it is necessary to estimate the number of unharvested crabs which die of natural causes before they can be observed in the following year. Finally, it is necessary to divide the catch in the given year by some estimate of population in the same year. This procedure has been followed here, except that the catch in the second year has been used in place of total population in estimating the total number of carryover crabs. The population of legal crabs in the first year was estimated by adding the catch for that year to the carryover estimate and the estimate of natural mortality.

We attempted to estimate carryover by examining length-frequency data collected in Oregon between 1947 and 1970 (Table 9). We used growth data presented by Butler (1961) and Poole (1967) to determine the minimal size for considering a crab as being a carryover. Their data indicate that a crab measuring 159 mm (which is the minimum legal size of 6¼ inches) in carapace width would increase in size by approximately 16 to 18 percent (25 to 29 mm) following the next molt. Therefore, we assumed that if each legal-sized carryover crab molted it would be larger than 184 mm. Because of the variability in growth we also made estimates of carryover based on crabs larger than 189 mm. We feel that a crab within this size range or larger would represent a carryover of a crab that would have been legal sized the previous year (season). Those crabs that were between 159 and 184 or 189 mm the previous year and did not molt are not included in the estimate.

Sample sizes were small and in several cases were confined to the first 1 to 3 months of the season. In addition, we were unable to sort out those crabs which may have molted into the larger size group since the season opened. Most of the length-frequency samples were obtained from sampling the commercial landings at dockside, and may not adequately represent the overall legal population because fishing effort may have been concentrated in certain areas rather than being evenly spread over all of the crab grounds. Finally, the use of catch as a substitute for population in the conversion of sample ratios to estimates of carryover crab causes these estimates to be lower than they should be. For these reasons the reliability of our estimates of the yearly exploitation rates may be questionable, but we feel that they tend to be biased upward.

Looking at the estimates given in Table 9 we can see the effect that different natural mortality rates have on the estimates of yearly exploitation rates. If one assumes a natural mortality rate of 0.15 and a demarcation line at 184 mm, then the estimates of exploitation rates range from 68% to 95%. At the other extreme, assuming a mortality rate of 0.45, the exploitation rates range from 58% to 93%. We conclude from this that the exploitation rate varies from year to year and may not be as high as was formerly believed.

Summarizing the implications of the mark-recapture and length-frequency data, neither is reliable enough or complete enough to serve as the sole basis for conclusions concerning the effort level needed for MSY. However, they are consistent with the results of the surplus yield analysis in that all three indicate that not all of the available crab are being taken each season.

COMPARISON WITH CURRENT LEVELS OF EFFORT

Comparisons between the number of pots fished in a particular year and the number necessary for MSY are only meaningful for years when the crab population is equal to the long-run average. Even when an appropriate year is being considered, the results may be distorted by the 1 to 2-year time lag involved in the fishery's adjustment of effort to crab abundance. The existence of this time lag will cause the effort in an average abundance year to be higher if it follows several high years than if it follows several low years. In order to avoid this problem, the average number of pots fished in each area over the last decade (which covers one complete abundance cycle) is compared with the estimated number of pots needed for MSY.

In the State of Washington the average number of pots fished from the 1963-1964 season through the 1972-1973 season was 27,429. This figure is somewhat higher than the upper end of the range for MSY as indicated by the generalized production model and slightly above the 26,375 pots estimated as required to harvest the MSY even in peak years. Therefore, if nothing more than the net monetary returns to the fishery are considered, we must conclude that there have been too many pots used in the fishery. Moreover, inasmuch as the catches in the last two years have been far below the decade average while the pot levels have remained above the average, the excess effort indicated is probably understated.

The situation in Oregon appears to be similar to that in Washington. The average number of pots fished in Oregon over the decade from 1962-1963 to 1971-1972 is 31,762. This is slightly lower than the upper end of the range for MSY and slightly above the required level for peak years. Pot estimates for the last two years are not available for Oregon.

In northern California the average for the decade 1963-1964 to 1972-1973 has been 24,340 pots. This is 2,000 pots less than our estimate for the number required to take the MSY in peak years, but is probably more than would be required in average years.

No estimates were obtained for central California, but the drastic decline in catch, number of pots, and catch per pot over the last two decades indicate that the fishery cannot tolerate nearly as much effort as the areas to the north. The average number of pots in central California from 1963-1964 to 1972-1973 was 12,532.

LITERATURE CITED

Butler, T.H. 1961. Growth and age determination of the Pacific edible crab, *Cancer magister* Dana. J. Fish. Res. Bd. Canada 18:873-891.

Cleaver, F.C. 1949. Preliminary results of the coastal crab (*Cancer magister*) investigation. Wash. State Dept. of Fish., Biol. Rept. 49A:47-82.

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part 1. Fish population analysis. Food and Agriculture Organization of the United Nations.

Jow, T. 1965. California-Oregon cooperative crab tagging study. Pac. Mar. Fish. Comm., 17th Ann. Rept. for the year 1964, pp. 51-52.

Pella, J.T. and P.K. Tomlinson. 1969. A generalized stock production model. Inter-American Tropical Tuna Commission Bulletin, 13(3):420-488.

Poole, R.L. 1967. Preliminary results of the age and growth study of the market crab (*Cancer magister*) in California: The age and growth of *Cancer magister* in Bodega Bay. In Proceedings of the Symposium on Crustacea, Part II. Mar. Biol. Assoc., India., pp. 553-567.

Richards, F.J. 1959. A flexible growth function for empirical use. J. Exp. Bot. 10(29):290-300.

Schaefer, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Inter-American Tropical Tuna Commission Bulletin, 2(6):254-285.

Table 1. Dungeness Crab Landings and Effort for Washington, Oregon, and California (From PMFC Data Series Unless Noted otherwise)

Season	Pounds Landed1/	Number Boats2/	Pounds Per Boat	Number Pots3/	Pounds Per Pot	Number Deliveries	Pounds Per Delivery
1950-51	24,041,597	-	-	46,437	518	-	-
1951-52	21,381,195	625	34,210	49,024	436	-	-
1952-53	19,985,837	558	35,817	47,046	425	24,747	808
1953-54	24,814,931	590	42,059	55,052	451	25,730	964
1954-55	18,067,586	533	33,898	57,839	312	22,203	814
1955-56	30,541,571	559	54,636	-	-	28,450	1,074
1956-57	41,893,441	495	84,633	73,042	574	24,486	1,711
1957-58	38,351,755	541	70,890	68,617	559	25,682	1,493
1958-59	32,596,680	642	50,774	78,339	416	27,883	1,169
1959-60	31,072,285	681	45,627	82,474	377	-	-
1960-61	29,670,452	675	43,956	77,348	384	25,262	1,175
1961-62	14,184,060	-	-	77,694	183	21,109	672
1962-63	10,075,307	548	18,386	70,583	143	17,989	560
1963-64	8,927,065	502	17,783	69,165	129	16,993	525
1964-65	17,464,047	511	34,176	69,411	252	18,062	967
1965-66	31,061,225	474	65,530	72,781	427	-	-
1966-67	28,708,929	434	66,150	79,712	360	21,417	1,340
1967-68	34,163,913	422	80,957	92,142	371	21,230	1,609
1968-69	44,084,119	505	87,295	104,229	423	24,609	1,791
1969-70	47,372,916	611	77,533	106,785	444	28,841	1,643
1970-71	36,052,599	-	-	135,522	266	23,658	1,524
1971-72	18,875,041	673	28,046	137,904	-	20,211	934
1972-73	8,963,216	-	-	-	-	16,169	554
1973-74	7,817,300	-	-	-	-	-	-

1/ Oregon data from OFC.
2/ Washington data from 1950-51 season through the 1966-67 season from U.S. Fishery Statistics.
3/ Oregon data from OFC. California and Washington data from U.S. Fishery Statistics, except for 1971-72 when California's estimate was obtained from CDFG.

Table 2. Dungeness Crab Landings and Effort for Washington's Coastal Area (From PMFC Data Series Unless Noted Otherwise)

Season	Pounds Landed	Number Boats1/	Pounds Per Boat	Number Pots2/	Pounds Per Pot	Number Deliveries	Pounds Per Delivery
1950-51	3,255,826	69	47,186	10,650	306	3,974	819
1951-52	3,364,112	69	48,755	10,300	327	5,280	637
1952-53	5,295,677	76	69,680	11,675	454	4,750	1,115
1953-54	6,418,057	116	55,328	18,300	351	6,123	1,048
1954-55	5,801,123	88	65,922	15,600	372	5,296	1,095
1955-56	8,547,876	102	83,803	18,225	469	6,444	1,326
1956-57	10,876,236	93	116,949	13,600	800	3,858	2,819
1957-58	10,961,119	93	117,861	14,900	736	4,224	2,595
1958-59	7,685,525	97	79,232	16,800	457	4,636	1,658
1959-60	6,911,299	105	65,822	21,585	320	4,554	1,518
1960-61	5,865,415	93	63,069	18,515	317	3,734	1,571
1961-62	4,384,234	88	49,821	17,550	250	4,083	1,074
1962-63	4,112,664	103	39,929	18,115	227	4,406	933
1963-64	3,342,341	95	35,183	17,965	186	4,396	760
1964-65	6,296,500	90	69,961	17,845	353	4,014	1,568
1965-66	10,165,395	83	122,475	17,275	588	4,250	2,392
1966-67	8,422,551	81	103,982	18,400	458	4,111	2,049
1967-68	10,789,893	70	154,141	19,524	553	4,163	2,592
1968-69	18,433,896	97	190,040	26,300	701	5,474	3,368
1969-70	17,745,643	138	128,592	34,000	522	7,376	2,406
1970-71	12,552,037	-	-	39,752	316	5,721	2,194
1971-72	9,199,701	173 3/	53,177	45,595	202	6,200	1,484
1972-73	4,339,221	147	29,519	37,637	115	5,153	842
1973-74	3,520,300	-	-	-	-	-	-

1/ Number boats from 1950-51 season through the 1966-67 season from U.S. Fishery Statistics.

2/ From U.S. Fishery Statistics.

3/ Includes 21 boats from Oregon and California.

Table 3. Dungeness Crab Landings and Effort for Oregon (From PMFC Data Series Unless Noted Otherwise)

Season	Pounds Landed[1]	Number Boats	Pounds Per Boat	Number Pots[1]	Pounds Per Pot	Number Deliveries	Pounds Per Delivery
1950-51	7,478,400	-	-	13,626	549	-	-
1951-52	5,407,675	83	65,153	15,709	344	-	-
1952-53	6,413,275	71	90,328	13,507	475	5,681	1,129
1953-54	10,131,125	83	122,062	16,177	626	6,282	1,613
1954-55	6,413,100	89	72,057	19,634	327	5,932	1,081
1955-56	8,910,600	92	96,854	18,923	471	7,355	1,212
1956-57	11,737,800	68	172,615	19,206	611	5,269	2,228
1957-58	10,103,000	75	134,707	21,307	474	6,185	1,633
1958-59	7,125,525	105	67,862	21,824	326	7,181	992
1959-60	8,296,125	103	80,545	20,623	402	-	-
1960-61	11,359,000	110	103,264	24,443	465	7,987	1,422
1961-62	5,813,125	--	-	28,399	205	9,171	634
1962-63	3,620,975	121	29,925	24,618	147	6,496	557
1963-64	3,586,335	95	37,751	23,000	156	7,384	486
1964-65	6,418,411	100	64,184	22,085	291	7,362	872
1965-66	10,476,476	81	129,339	25,016	419	6,287[2]	-
1966-67	9,580,986	87	110,126	27,116	353	8,220	1,166
1967-68	10,214,695	90	113,497	28,550	358	7,680	1,330
1968-69	11,965,246	105	113,955	29,221	409	9,558	1,252
1969-70	14,062,793	143	98,341	33,491	420	10,427	1,349
1970-71	15,000,000	193	77,720	49,580	303	10,725	1,399
1971-72	6,800,000	205	33,171	54,939	124	8,767	776
1972-73	3,124,320	-	-	-	-	6,221	502
1973-74	3,417,385	-	-	-	-	5,293	646

1/ From OFC.
2/ For January through August only.

Table 4. Dungess Crab Landings and Effort for California. (From PMFC Data Series Unless Noted Otherwise)

Season	Pounds Landed	Number Boats	Pounds Per Boat	Number Pots1/	Pounds Per Pot	Number Deliveries	Pounds Per Delivery
1950-51	13,307,371	450	29,572	22,161	600	18,030	738
1951-52	12,609,408	473	26,658	23,015	548	16,858	748
1952-53	8,276,885	411	20,138	21,864	379	14,316	578
1953-54	8,265,749	391	21,140	20,575	402	13,325	620
1954-55	5,853,363	356	16,442	22,605	259	10,975	533
1955-56	13,083,095	365	35,844	51,383 2/	---	14,651	893
1956-57	19,279,405	334	57,723	40,236	479	15,359	1,255
1957-58	17,287,636	373	46,348	32,410	533	15,273	1,132
1958-59	17,785,630	440	40,422	39,715	448	16,066	1,107
1959-60	15,864,861	473	33,541	40,266	394	15,292	1,037
1960-61	12,446,037	472	26,369	34,390	362	13,541	919
1961-62	3,986,701	408	9,771	31,745	126	7,855	508
1962-63	2,341,668	324	7,227	27,850	84	7,087	330
1963-64	1,998,389	312	6,405	28,200	71	5,213	383
1964-65	4,749,136	321	14,795	29,481	161	6,686	710
1965-66	10,419,354	310	33,611	30,490	342	8,607	1,211
1966-67	10,705,410	266	40,246	34,196	313	9,086	1,178
1967-68	13,159,325	262	50,226	44,068	299	9,387	1,402
1968-69	13,684,977	303	45,165	48,708	281	9,577	1,429
1069-70	15,564,480	330	47,165	39,294	396	11,038	1,410
1970-71	8,500,562	357	23,811	46,190	184	7,212	1,179
1971-72	2,875,340	295	9,747	37,370 3/	-	5,244	548
1972-73	1,499,675	243	6,172	30,720 3/	-	4,795	313
1973-74	880,000	-	-	-	-	-	-

1/ From U.S. Fishery Statistics
2/ Estimate appears high.
3/ From CDFG.

Table 5. Dungeness Crab Landings and Effort for Northern California1/
(From PMFC Data Series Unless Noted Otherwise)

Season	Pounds Landed	Number Boats	Pounds Per Boat	Number Pots2/	Pounds Per Pot	Number Deliveries	Pounds Per Delivery
1950-51	9,066,302	176	51,513	10,126	895	8,441	1,074
1951-52	9,292,763	196	47,412	10,980	846	8,819	1,054
1952-53	4,118,754	175	23,536	8,980	459	5,984	688
1953-54	4,309,220	143	30,134	8,710	495	4,988	864
1954-55	1,524,511	95	16,047	6,305	242	3,308	461
1955-56	8,063,243	121	66,638	25,5033/	-	7,093	1,137
1956-57	9,980,254	112	89,109	20,925	477	5,906	1,690
1957-58	9,610,277	148	64,934	12,080	796	6,254	1,537
1958-59	12,377,526	184	67,269	16,820	736	7,960	1,555
1959-60	10,728,054	208	51,577	18,911	567	7,624	1,407
1960-61	10,042,841	213	47,149	18,110	555	7,487	1,341
1961-62	3,251,318	190	17,112	15,560	209	4,787	679
1962-63	900,733	124	7,264	12,010	75	2,537	355
1963-64	814,997	117	6,966	14,105	58	1,949	418
1964-65	3,978,997	164	24,262	15,256	261	4,170	954
1965-66	9,963,195	169	58,954	20,280	491	6,995	1,424
1966-67	10,299,159	168	61,305	24,626	418	7,732	1,332
1967-68	12,142,853	173	70,190	30,904	393	7,648	1,588
1968-69	12,848,716	194	66,230	31,316	410	7,850	1,637
1969-70	14,103,769	237	59,510	26,390	534	8,916	1,582
1970-71	7,838,049	250	31,352	32,020	245	5,838	1,343
1971-72	2,541,779	190	13,378	27,5004/	-	4,049	628
1972-73	1,154,002	153	7,542	21,0004/	-	3,495	330

1/ North of Point Arena.
2/ From U.S. Fishery Statistics.
3/ Estimate appears high.
4/ From CDFG.

Table 6. Dungeness Crab Landings and Effort for Central California[1/]
(From PMFC Data Series Unless Noted Otherwise.)

Season	Pounds Landed	Number Boats	Pounds Per Boat	Number Pots[2/]	Pounds Per Pot	Number Deliveries	Pounds Per Delivery
1950-51	4,241,069	274	15,478	12,035	352	9,589	442
1951-52	3,316,645	277	11,973	12,035	276	8,039	413
1952-53	4,158,131	236	17,619	12,884	323	8,332	499
1953-54	3,956,529	248	15,954	11,865	333	8,337	475
1954-55	4,328,852	261	16,586	16,300	266	7,667	565
1955-56	5,019,852	244	20,573	25,880[3/]	-	7,558	664
1956-57	9,299,151	222	41,888	19,311	482	9,453	984
1957-58	7,677,359	225	34,122	20,330	378	9,019	851
1958-59	5,408,104	256	21,125	22,895	236	8,106	667
1959-60	5,136,807	265	19,384	21,355	241	7,668	670
1960-61	2,403,196	259	9,279	16,280	148	6,054	397
1961-62	735,383	218	3,373	16,185	45	3,068	240
1962-63	1,440,935	200	7,205	15,840	91	4,550	317
1963-64	1,183,392	195	6,069	14,095	84	3,264	363
1964-65	770,139	157	4,905	14,225	54	2,516	306
1965-66	456,159	141	3,235	10,210	45	1,612	283
1966-67	406,251	98	4,145	9,570	42	1,354	300
1967-68	1,016,472	89	11,421	13,164	77	1,739	585
1968-69	836,261	109	7,672	17,392	48	1,727	484
1969-70	1,460,711	93	15,707	12,904	113	2,122	688
1970-71	662,513	107	6,192	14,170	47	1,374	482
1971-72	333,561	105	3,177	9,870[4/]	-	1,195	279
1972-73	345,673	90	3,841	9,720[4/]	-	1,300	266

1/ South of Point Arena.
2/ From U.S. Fishery Statistics.
3/ Estimate appears high.
4/ From CDFG.

Table 7. Preliminary Estimates of Effort-Yield.

	MSY (lbs)	Number of Pots at MSY
Washington	9,618,627	25,098
Oregon	11,042,319	39,718
California	11,620,000	39,462

Table 8. Estimates of MSY and Effort Based on the Peak Year Analysis and the Generalized Production Model.

	MSY (lbs)	Number of Pots at MSY	r^2	R^2
Washington				
Schaefer Peak Years	15,882,362	26,375	0.8501	N/A
Generalized Production Model	8,442,000 to 11,500,000	12,500 to 25,000	N/A	0.487
Oregon				
Schaefer Peak Years	12,836,355	30,125	0.8171	N/A
Generalized Production Model	8,600,000 to 10,360,000	25,000 to 32,500	N/A	0.272
Northern California				
Schaefer Peak Years	14,153,795	26,384	0.9992	N/A

Table 9. Estimates of Legal Crab Abundance and Harvest R[illegible]s for Oregon's Commercial Fishery from 1946 through 1969.

Season or Year	Pounds of Crab Harvested	Estimate of Legal Crab Carry-Over to Following Season: Pounds of Crab Harvested The Following Season	No. Crabs Sampled	Months Sampled	Percentage of Crabs Over: 184mm	189mm	Pounds of Crab Over: 184mm	189mm	Natural Mortality Rate	Pounds of Crab Lost to Natural Mortality with Carry-Over Above: 184mm	189mm	Estimate of Crab Abundance in Pounds With Carry-Over Above: 184mm	189mm	Percentage of Available Crabs Harvested with Carry-Over Above: 184mm	189mm
1946	7,028,600	7,843,775	1,687	Aug.-Dec.	17.1	7.4	1,341,285	580,439	0.15	236,697	102,430	8,606,582	7,711,469	82	91
									0.30	574,836	248,759	8,944,721	7,857,798	79	89
									0.45	1,097,415	474,904	9,467,300	8,083,943	74	87
1947	7,843,775	10,056,475	14,549	Jan.-Aug.	30.7	17.3	3,087,338	1,739,770	0.15	544,824	307,018	11,475,937	9,890,563	68	79
									0.30	1,323,144	745,616	12,254,257	10,329,161	64	76
									0.45	2,526,004	1,423,448	13,457,117	11,006,993	58	71
1948	10,056,475	9,326,250	4,033	Jan.-July	35.8	23.5	3,338,797	2,191,668	0.15	589,199	386,765	13,984,471	12,634,908	72	80
									0.30	1,430,913	939,286	14,826,185	13,187,429	68	76
									0.45	2,731,743	1,793,183	16,127,015	14,041,326	62	72
1950-51	7,478,400	5,407,675	378	Jan.	6.1 1/	2.6 1/	329,868	140,600	0.15	58,212	24,812	7,866,480	7,643,812	95	98
									0.30	141,372	60,257	7,949,640	7,679,257	94	97
									0.45	269,892	115,036	8,078,160	7,734,036	93	97
1959-60	8,296,125	11,359,000	5,293	Jan.-Dec.	21.0	8.9	2,385,390	1,010,951	0.15	420,951	178,403	11,102,466	9,485,479	75	87
									0.30	1,022,310	433,264	11,703,825	9,740,340	71	85
									0.45	1,951,683	827,142	12,633,198	10,134,218	66	82
1960-61	11,359,000	5,813,125	3,752	Jan.-Apr.	11.8	4.5	685,949	261,591	0.15	121,050	46,163	12,165,999	11,666,714	93	97
									0.30	293,978	112,110	12,338,927	11,732,701	92	97
									0.45	561,231	214,029	12,606,180	11,834,620	90	96
1963-64	3,586,335	6,418,411	3,918	Dec.-Mar.	8.8	3.1	564,420	198,971	0.15	99,604	35,113	4,250,359	3,820,419	84	94
									0.30	241,894	85,273	4,392,649	3,870,579	82	93
									0.45	462,616	162,794	4,613,371	3,948,100	78	91
1964-65	6,418,411	10,476,476	3,771	Dec.-May	13.6	7.0	1,424,801	733,353	0.15	251,435	129,415	8,094,647	7,281,179	79	88
									0.30	610,629	314,294	8,453,841	7,466,058	76	86
									0.45	1,165,746	600,016	9,008,958	7,751,780	71	83
1965-66	10,476,476	9,580,968	2,547	Dec.-Apr.	27.2	14.5	2,606,023	1,389,240	0.15	459,886	245,160	13,542,385	12,110,876	77	87
									0.30	1,116,867	595,389	14,199,366	12,461,105	74	84
									0.45	2,132,201	1,136,651	15,214,700	13,002,367	69	81
1966-67	9,580,968	10,214,695	4,387	Dec.-Apr.	21.7	12.8	2,216,589	1,307,481	0.15	391,163	230,732	12,188,720	11,119,181	79	86
									0.30	949,967	560,349	12,747,524	11,448,798	75	84
									0.45	1,813,573	1,069,757	13,611,130	11,958,206	70	80
1967-68	10,214,695	11,965,246	1,447	Dec.-Feb.	20.0	9.4	2,393,049	1,124,733	0.15	422,303	198,482	13,030,047	11,537,910	78	89
									0.30	1,025,592	482,028	13,633,336	11,821,456	75	86
									0.45	1,957,949	920,236	14,565,693	12,259,664	70	83
1968-69	11,965,246	14,062,793	1,657	Jan.-May	8.9	2.4	1,251,589	337,507	0.15	220,868	59,560	13,437,703	12,362,313	89	97
									0.30	536,395	144,646	13,753,230	12,447,399	87	96
									0.45	1,024,027	276,142	14,240,862	12,578,895	84	95

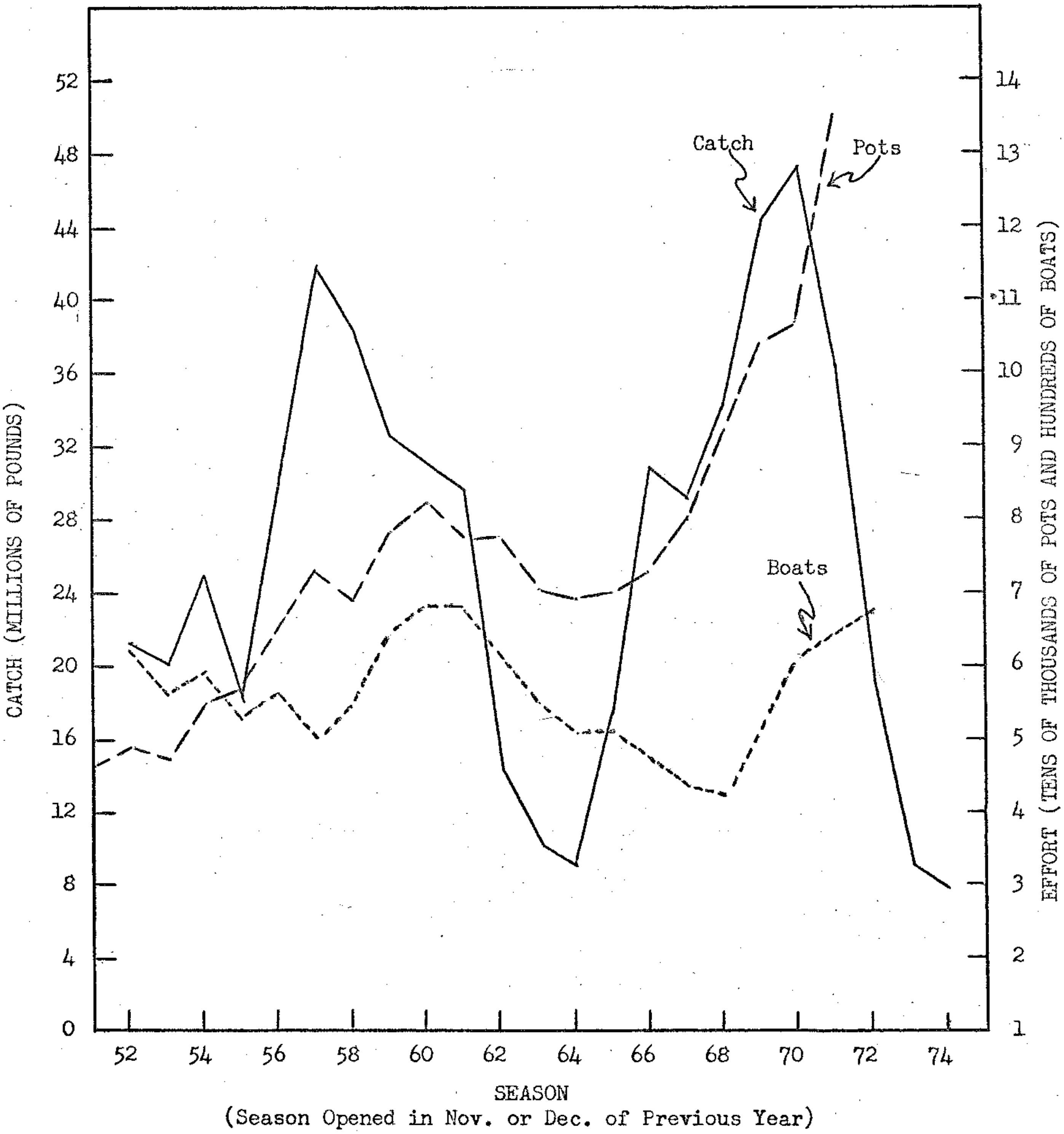


Figure 1. Relationship Between Catch and Effort for the Coastal Fishery, 1951-52 through 1973-74 Seasons.

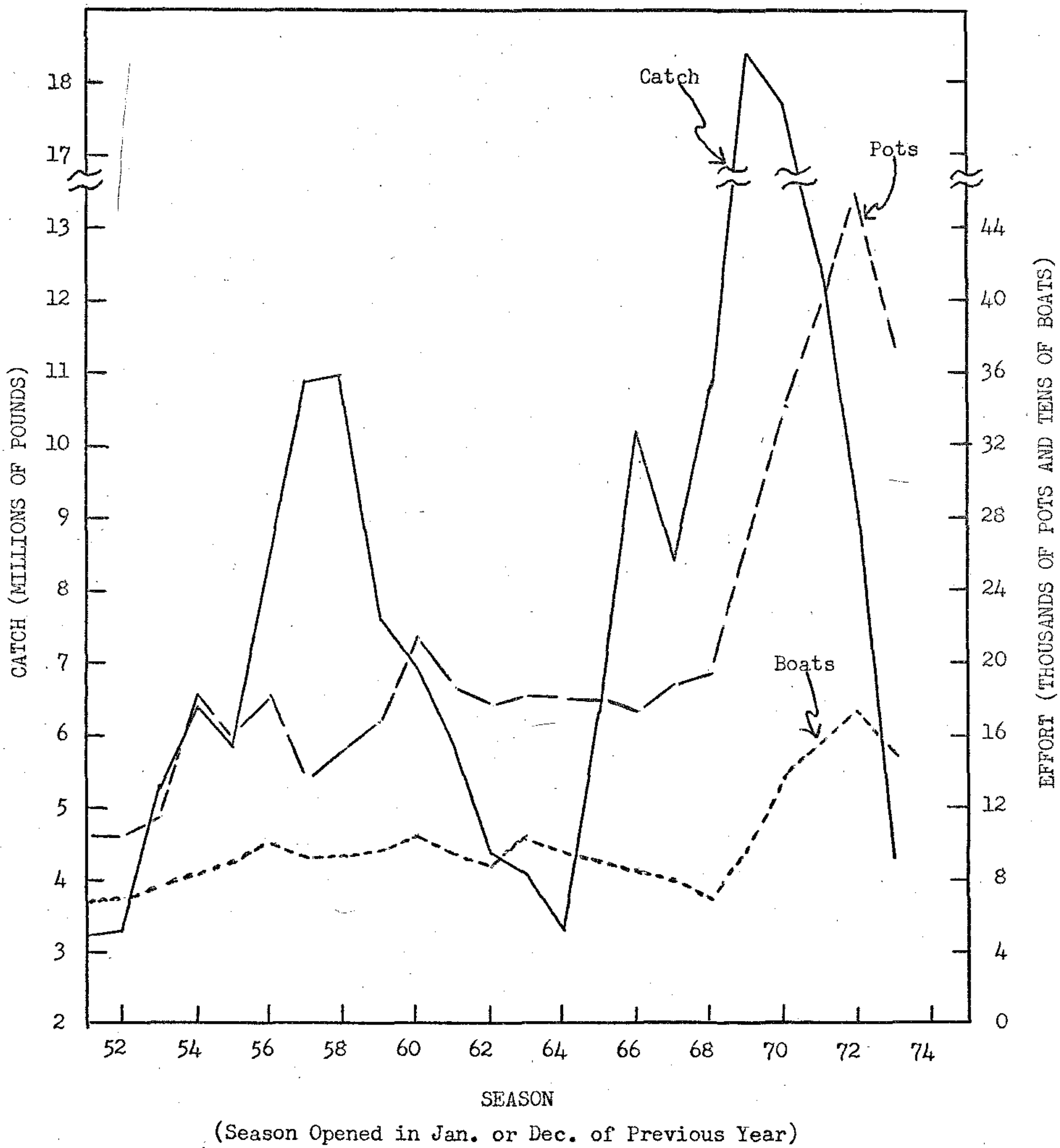
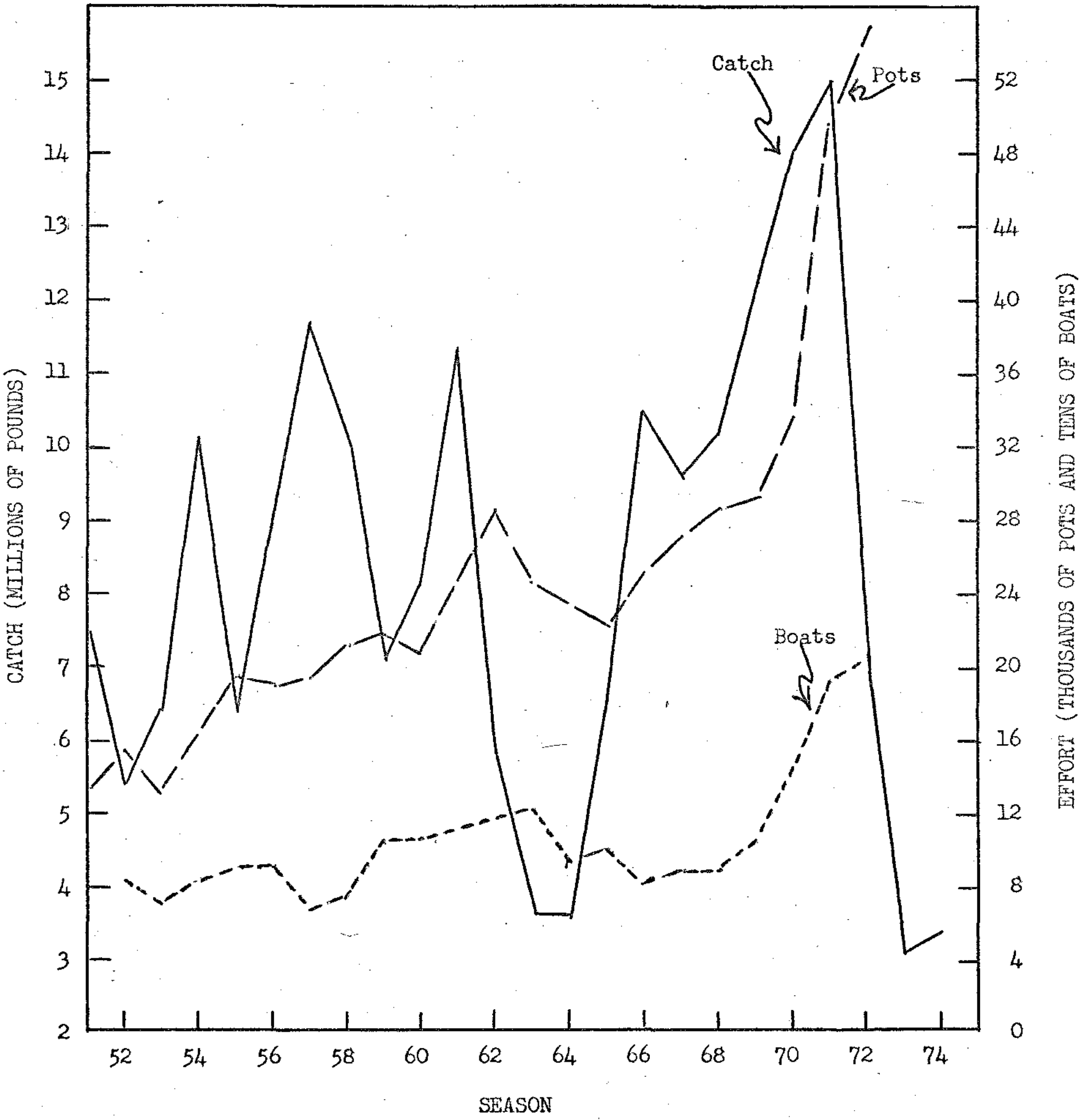
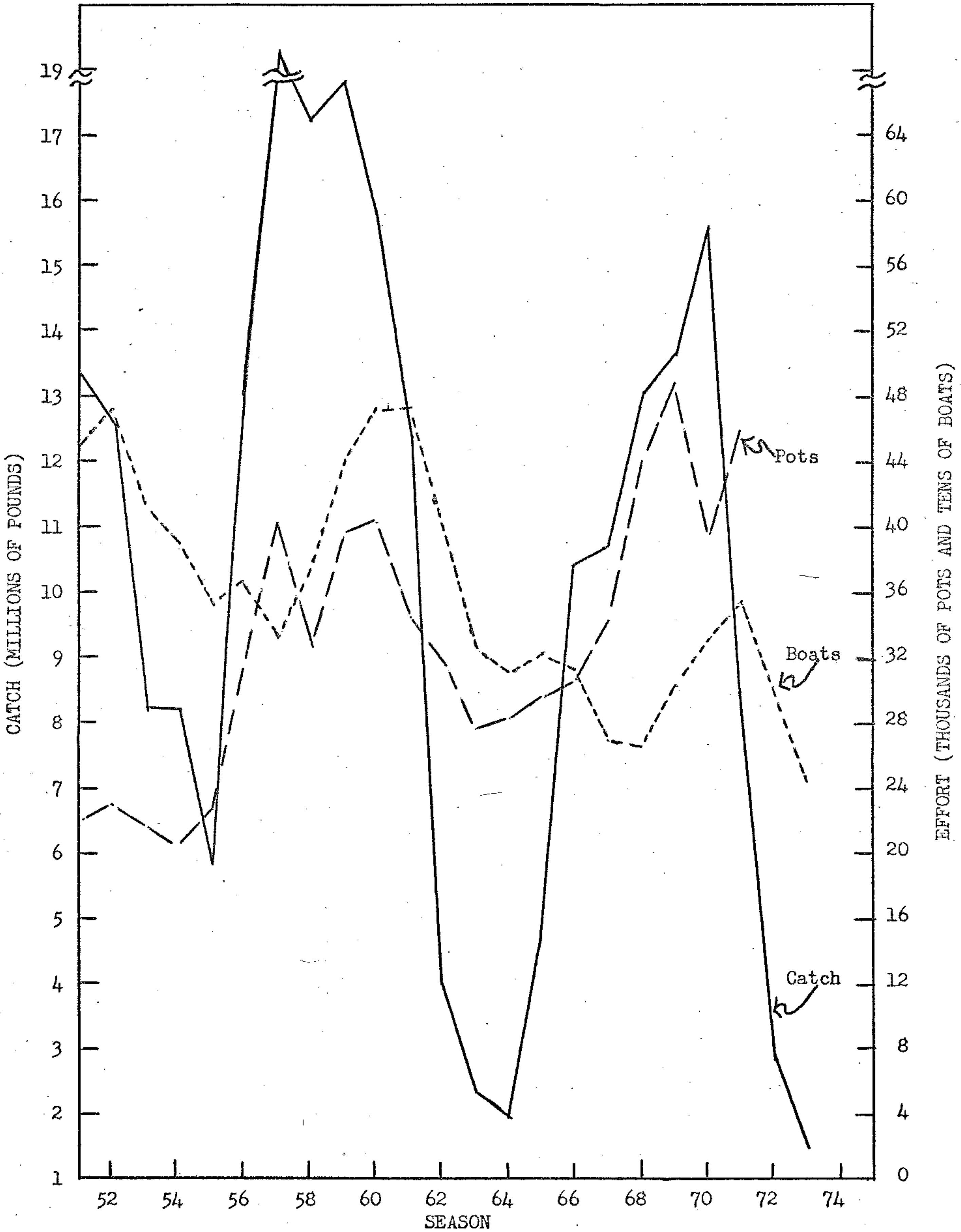


Figure 2. Relationship Between Catch and Effort for Washington's Coastal Area, 1950-51 through 1972-73 Seasons.



(Season Opened in Nov. or Dec. of Previous Year)

Figure 3. Relationship Between Catch and Effort for Oregon, 1951-52 through 1973-74 Seasons.



(Season Opened in Nov. or Dec. of Previous Year)

Figure 4. Relationship Between Catch and Effort for California, 1950-51 through 1972-73 Seasons.

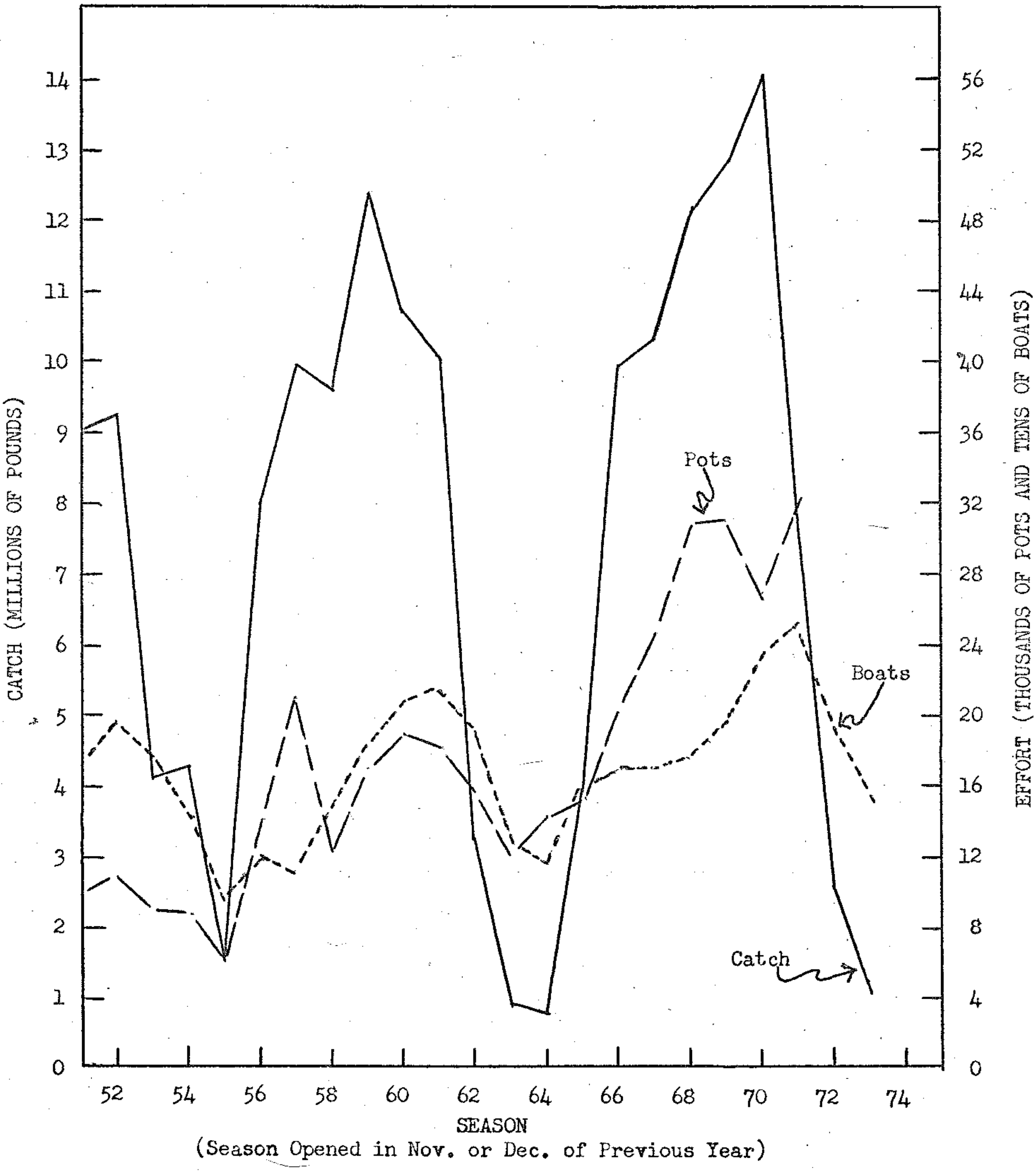
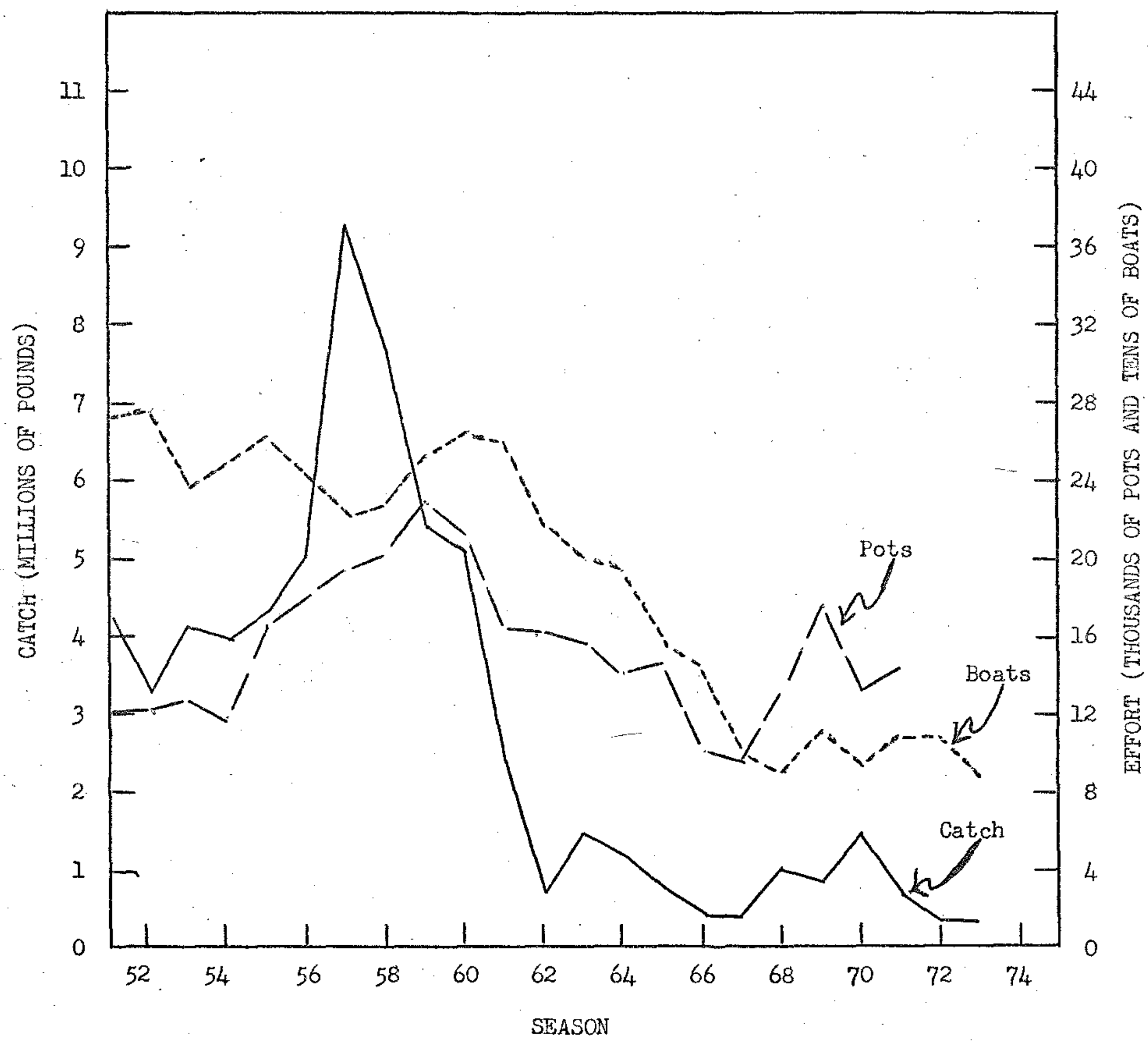


Figure 5. Relationship Between Catch and Effort for Northern California, 1950-51 through 1972-73 Seasons.



(Season Opened in Nov. of Previous Year)

Figure 6. Relationship Between Catch and Effort for Central California, 1950-51 through 1972-73 Seasons.