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Title: PREDICTION OF ABUNDANCE OF HARVESTABLE DUNGENESS CRAB (CANCER MAGISTER)

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A method for predicting the harvest of commercial Dungeness crab (*Cancer magister*) one year in advance of the fishing season is described. The technique is based on the hypothesis that the relative abundance of sub-legal crabs one year is directly proportional to the harvest of legal crabs the following year.

Sampling was conducted out of Newport and Astoria, Oregon from commercial fishing vessels during the 1971-72, 1972-73, and 1973-74 winter seasons. Specimens were captured with modified commercial pots designed to retain sub-legal as well as legal crabs. Over 7,200 adult crabs were captured, of which 18 percent were legal males, 35 percent were sub-legal males, and 47 percent were females.

Analysis of the relationship between the abundance of sub-legal crabs one year and the harvest of legal crabs the following year

resulted in predictions of crab harvest for the 1973-74 and 1974-75 seasons at both ports, and for the entire state. By this method, crab harvest was underestimated at both ports; however, projected total harvest for the state was within 10-20 percent of the actual landings for the two seasons predicted.

Prediction of Abundance of Harvestable Dungeness Crab (*Cancer magister*)

by

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PREDICTION OF ABUNDANCE OF HARVESTABLE DUNGENESS CRAB (CANCER MAGISTER)

INTRODUCTION

The results of research leading to the development of a method for predicting the harvest of Dungeness crab (*Cancer magister*) one year in advance of the commercial fishing season are reported in this thesis. The investigation was conducted to provide a forecast of crab harvest which would benefit both fishermen and processors in the allocation of their resources prior to each fishing season. Conservation agencies also should find the information helpful in formulating short-range management decisions regarding the conservation of Dungeness crabs. Data from crabs collected off Newport and Astoria, Oregon, during the 1971-72, 1972-73, and 1973-74 crab fishing seasons[1] were used to test the hypothesis that the relative abundance of sub-legal crabs one year is in direct proportion to the harvest of legal crabs the following year.

Following the 1948-49 season, when the commercial crab harvest in Oregon was restricted to male crabs greater than 6 1/4-in

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[1] Crab seasons in Oregon usually begin in December of one year and run through the following August or September.

(159 mm) shoulder width (SW),[2] the seasonal harvest has fluctuated on a relatively cyclic basis ranging from 1.4-6.7 million kg and averaging 3.2 million kg (Figure 1). Because the cycles of abundance of Dungeness crabs are wide-spread and occur rather uniformly within their range, concurrent cycles of environmental conditions are possibly responsible for such fluctuations. These large and naturally occurring fluctuations tend to promote economic inefficiency within the industry, as both fishermen and processors must make substantial investments in preparation for the season with scant knowledge of the potential harvest.

In previous attempts to estimate the abundance of Dungeness crabs in advance of the fishing season, both the sex ratio (McMynn 1951) and the amount of breeding activity of sub-legal males (Butler 1960) were suggested (but not used) as useful indices of the exploitation of crab populations.

Attempts to estimate the abundance of incoming year-classes from data collected on trawling cruises were not successful (Pacific Marine Fisheries Commission 1959, 1962). Special preseason trapping cruises to evaluate the abundance of legal crabs off northern California (Pacific Marine Fisheries Commission 1964,

[2] Shoulder width is defined as the straight-line measurement across the carapace immediately in front of the 10th antero-lateral spines, and is a standard measurement because it is not affected by broken and/or eroded spines.

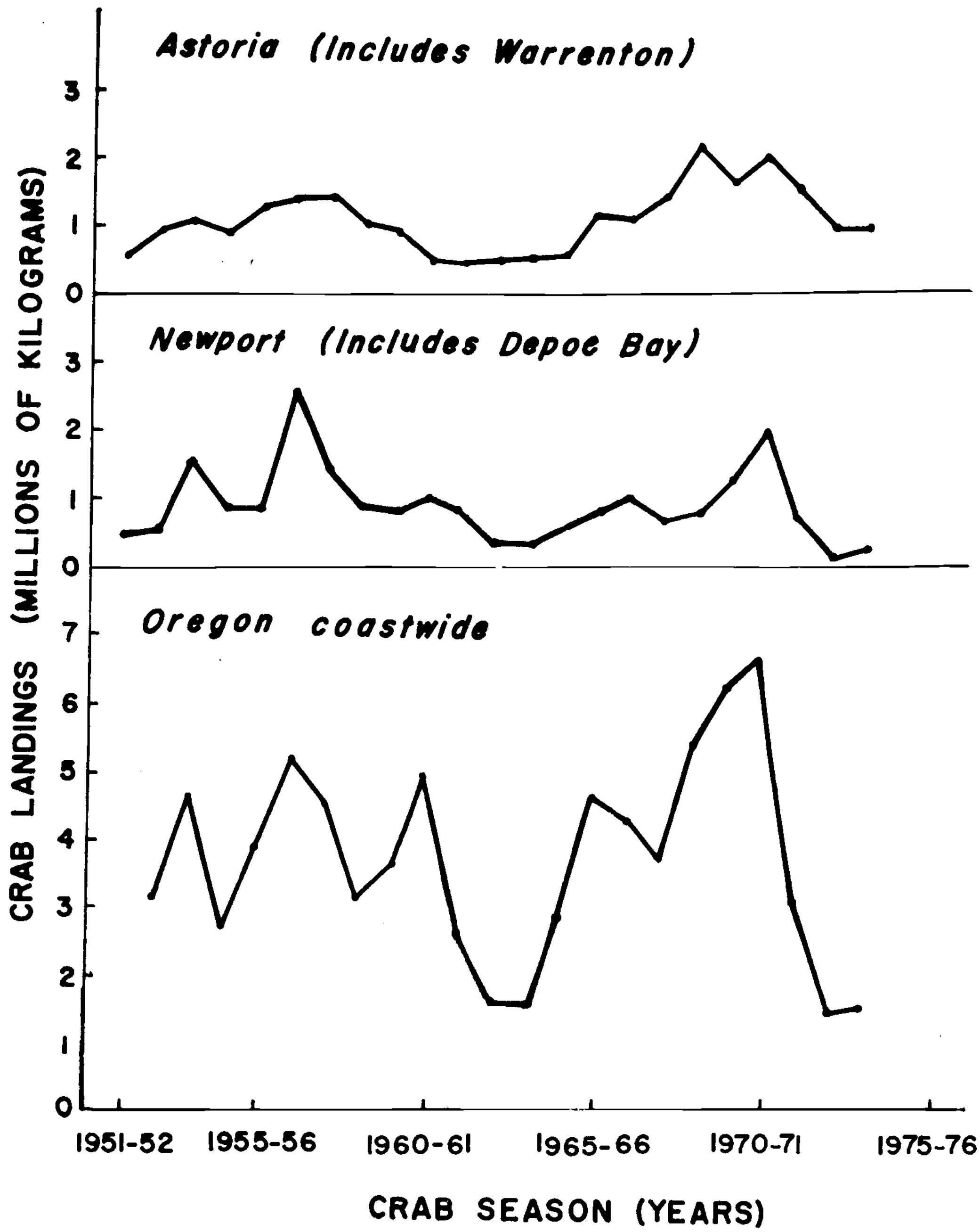


Figure 1. Commercial landings of Dungeness crab at selected Oregon ports and coastwide, 1951-52 to 1973-74 (Pacific Marine Fisheries Commission 1974).

1968) and Oregon (Personal communication, C. Dale Snow, Fish Commission of Oregon, Newport, February, 1974) achieved some success. The utility to fishermen of these forecasts is debatable because of the short time interval between the predictions and the opening of the crab fishing season.

More recently, certain environmental factors were used as indices of crab abundance. Winnor (1966, in Lough 1975) concluded that sea surface temperature during the crab's larval period could be used to predict future landings off central California. His work could not properly be evaluated because the crab population collapsed in that region subsequent to his sampling.

Peterson (1973) suggested a relationship between fluctuations in annual upwelling and crab catches one and one-half years later in northern California and Oregon, but he did not attempt a prediction of annual harvest.

Lough (1975) declared that crab landings could be predicted four years in advance using readily obtainable climatological data, primarily precipitation in coastal areas during February. His predictions of harvest, thusfar, have exceeded actual landings by a factor of 2-5 times.

Commercial crab fishermen have long been aware of the general relationship between the number of sub-legal crabs one year and the harvest of legal crabs the following season. They estimate the following year's harvest by observing the number of "measuring" crabs (those just smaller than legal size) that are caught in their pots. This knowledge helps them to determine the intensity of their fishing the following season, and it also plays a role in their price negotiations with crab buyers. Unfortunately, their estimates of abundance are not always accurate and tend to be more towards the average catch than the extremes.

Cleaver (1949) contended there was a possibility of predicting the abundance of crabs during the next season by evaluating the abundance of sub-legal males during the current season. He observed that sub-legal males (13-16 cm SW) entered the pots in varying numbers as did those of commercial size, and speculated that it was possible to establish a ratio between the undersized and legal individuals. Cleaver recognized several difficulties inherent in this approach: the undersized crabs were relatively scarce in the pots during the late winter months and became increasingly abundant as the season proceeded; and the smaller crabs were more agile and could escape more readily from the pots. Based on relatively few samples, Cleaver felt that the data supported his contention.

Certain characteristics of the Dungeness crab population and fishery provide the possibility of forecasting harvest by evaluating the abundance of sub-legal crabs during the current fishing season:

The crabs are non-migratory (Waldon 1958), their growth occurs in fairly constant increments during ecdysis (Poole 1967), and each year's harvest in this region is composed primarily of 4-year-old male crabs, of which very few escape capture (Pacific Marine Fisheries Commission 1964).

Studies of the growth of Dungeness crabs indicate that each year's fishery relies heavily on molting crabs attaining enough size to enter the fishery (Cleaver 1949; Pacific Marine Fisheries Commission 1964), and that crabs 13-16 cm SW comprise the incoming year-class (Poole 1967). Because two-year-old and older male crabs usually molt annually in late summer and fall in this region (Personal communication, C. Dale Snow, Fish Commission of Oregon, Newport, February, 1974), the population size of sub-legal crabs (13-16 cm SW) during the winter fishing season should correspond well with the following year's harvest.

At the start of each fishing season, there is a finite number of crabs eligible for harvest, and fishing continues until most of these crabs are captured. Tagging studies indicate that a minimum of 79-87 percent of the eligible crabs are harvested each season (Cleaver 1949; Jow 1964), although Oregon shellfish biologists believe that 90-95 percent of the available crabs are harvested (Personal communication, C. Dale Snow, Fish Commission of Oregon, Newport, February, 1974). Thus, the total quantity landed in a season gives an excellent indicator of the population size of harvestable Dungeness crabs.

My investigation had the following specific objectives:

1. To develop a relatively simple and inexpensive technique for accurately determining the ratio between the numbers of sub-legal and legal male *C. magister* during the winter fishing season.

2. To develop a method for predicting the harvest of *C. magister* one year in advance of the fishing season by evaluating the relative abundance of the sub-legal male crabs.

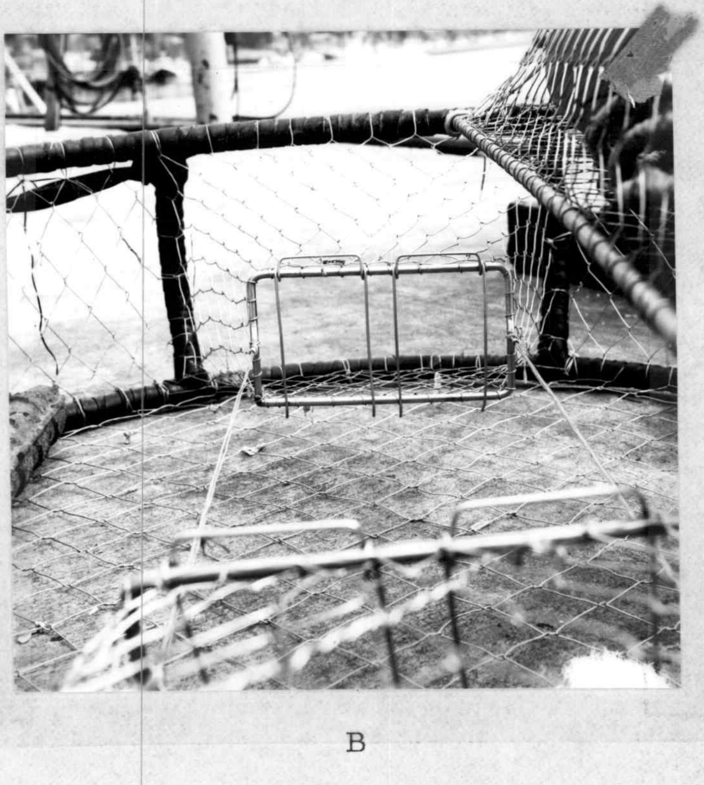
METHODS AND MATERIALS

Samples of Dungeness crabs were captured in modified commercial crab pots set in ocean waters commonly fished by crabbers from Newport and Astoria, Oregon. The experimental pots were transported to sea aboard commercial fishing vessels, set randomly in strings of commercial gear in water 13-18 m deep, and run (taken aboard, emptied, rebaited, and reset) by the crew of the vessel during normal fishing operations. At Newport the author was aboard the vessel to process the crabs from each pot; at Astoria, the crew of the vessel did the processing following my instructions.

Newport-design crab pots, which are heavier (61.2 kg), and shallower (30 cm), but otherwise similar to the 42-inch (97-cm) diameter pot described by Hipkins (1972), were modified to retain sub-legal as well as legal crabs (Figure 2). The entire pot and tunnels were webbed with soft, stainless steel wire hand-woven into about 5-cm mesh. Each tunnel opening (eye) into the pot was equipped with two pairs of stainless steel, spring-wire triggers. There were no escape ports.

The experimental pots were slightly more expensive than normal fishing gear, due mainly to the extra labor involved in hand-knitting the small mesh (which was about one-half the size of normal mesh). In January, 1972, 14 pots (including knitting, buoys, line,

A



B

Figure 2. Experimental crab pots designed to retain sub-legal crabs. Note the small mesh and absence of escape ports (A); and the two pairs of triggers on the tunnel eyes (B).

bait boxes, etc.) were purchased for $53.00 each. In January, 1973, an additional 18 pots cost $62.50 each, and in January, 1975, 10 pots to replace those lost the previous three seasons cost $100.20 each.

By furnishing my own pots, and being aboard the fishing vessel to process the crabs from those pots, I was able to obtain many days of ocean research time through the generosity of vessel owners acknowledged earlier. At Astoria, the crew of the vessel was hired to process and record the crabs captured in the test pots, following specific instructions which I provided.

Because the experimental pots were run along with commercial gear, the length of time between collections ranged from 2-20 days, with from 2-15 pots being sampled each day of fishing. The frequency of collections was dependent upon the availability of crabs, and weather and ocean conditions.

Delays in construction of the experimental pots and inclement weather limited sampling in 1971-72 and 1972-73 to the latter part of the season; in 1973-74, however, the pots were set when the season opened. Sampling continued through March each season, or until the commercial gear was brought back to port.

Preliminary sampling was conducted at Newport with 12 pots in 1971-72, and 30 pots were divided equally between Newport and Astoria during 1972-73 and 1973-74. Those two ports normally account for 50 percent or more of Oregon's total crab harvest.

Each sample (N) consisted of the catch from a single pot, and all crabs taken in a sample were measured for SW to the nearest millimeter and recorded by sex in 5-mm groups. Data from all samples taken each month were pooled by port, and the sample ratio ($\hat{R}$) of number of sub-legal to legal male crabs was calculated. Statistical tests on $\hat{R}$ were performed by the methods described in Cochran (1963).

Records of the quantity of crabs landed by port and month were furnished by C. Dale Snow, Fish Commission of Oregon, Newport (Appendix 1).

My hypothesis, that the equivalency

$$\frac{\text{Total number of sub-legal males}}{\text{Total number of legal males}} = \frac{\text{harvest of following season}}{\text{harvest of current season}}$$

could be solved for the harvest of the following season, was developed in the following manner:

1. Assuming that the total population of legal crabs available to a port (TPL_p) is equal to the total harvest at that port (TH_p) divided by 0.84 fishing mortality (Jow 1964; Cleaver 1949), then

$$TPL_p = TH_p/0.84$$

and, as the season progresses, the population is reduced by the sum of the monthly harvests at that port (MH_p), then

$$TPL_p = (TH_p/0.84) - \Sigma MH_p$$

2. Assuming that the total population of sub-legal crabs at a port (TPS_p) minus natural mortality during ecdysis (a)[3] equals the future total harvest at that port (FTH_p) divided by 0.84 fishing mortality, then

$$TPS_p - (a)TPS_p = FTH_p/0.84$$

and factoring

$$TPS_p = FTH_p/0.84\ (1 - a)$$

3. By definition, $\hat{R}$ = sample number of sub-legal crabs divided by the sample number of legal crabs, and $\hat{R}$ is an unbiased estimate of the population R, then

$$\hat{R} = TPS_p/TPL_p = \frac{\dfrac{FTH_p}{0.84\ (1 - a)}}{\dfrac{TH_p}{0.84} - \Sigma MH_p}$$

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[3]For my calculations, I estimated natural mortality to be 0.10.

4. Solving for the unknown quantity (FTH_p) gives

$$FTH_p = [\hat{R}(TH_p/0.84) - \Sigma MH_p][0.84(1 - a)]$$

This equation was used to determine the following season's total harvest at a port for each month of sampling, and these estimates were averaged to give a total prediction of abundance of harvestable Dungeness crabs at that port for the following season.

Linear regression techniques were used to correlate seasonal landings at Newport and Astoria with total Oregon landings over the past ten seasons (1963-64 to 1972-73). The correlation was expressed by:

$$Y = 204,612 + 1.802\ (X)$$

where Y is the total Oregon harvest in kilograms, 204,612 is the intercept, 1.802 is the slope of the regression line, and (X) is the sum of the seasonal harvests of Newport and Astoria, with 88 percent of the variation in Oregon harvests being explained by the variation in harvests from the two ports (r = .94).

RESULTS

During the three fishing seasons, 7, 227 crabs were captured: 1, 283 legal males, 2, 516 sub-legal males, and 3, 428 females. Except for the 1972-73 season at Astoria, the average catch per pot was 21-24 crabs (Table 1), even though the size and sex composition of the catch was quite variable. Evidently the size of the pot or some other factor limited the total number of crabs which would enter the pot, regardless of sex or size.

Unexpectedly, the experimental pots were as successful in capturing legal size males as the normal commercial fishing gear. I had anticipated that because the experimental pots retained all crabs that entered, there would be a tendency for any late arriving large males to be disinclined to enter the pots and thus lower the average legal catch. Either large males entered the pots first, or they weren't discouraged by the crowded conditions inside the pots when they arrived.

I believe that the above observations indicate that there is a great deal of traffic of sub-legal males and females through normal commercial fishing gear, and the belief that large male crabs will prevent smaller crabs from entering the pots (Cleaver 1949) cannot be supported.

The size of crabs captured ranged from 75-209 mm SW.

Table 1. Data showing location and period of capture, number of pots sampled (N), and average composition of catch of Dungeness crabs per experimental pot.

Port of landing	Period of capture	N	Average number of crabs per pot: Males $\geq$159 mm SW[1]	Males < 159 mm SW	Females	Total
Newport	2-26 to 3-20-72	28	2.46	9.32	12.07	23.86
	2-8 to 3-26-73	64	2.34	11.88	6.59	20.81
	1-1 to 3-3-74	63	5.02	9.11	9.25	23.38
Astoria	1-5 to 3-21-73	56	3.04	4.30	5.50	12.84
	12-11 to 4-15-74	135	4.28	5.04	13.16	22.48

[1] Shoulder width of carapace.

Although small individuals could possibly pass freely between the tunnel eye triggers, it is my opinion that very few crabs larger than 120 mm SW escaped.

During the 1971-72, and 1972-73 seasons, few crabs of less than 120 mm SW were captured (Figures 3-5), and I initially thought this was due to the design of the fishing gear. But in the 1973-74 season (Figures 6-7), many crabs 75-120 mm SW were taken. Crabs in this size range are two years away from harvest (Poole 1967). I feel that the scarcity of small crabs was not due to the design of the pots, but rather that the number of two-year-old crabs during the first two seasons of sampling was extremely low.

Carapace width-frequency plots (Figures 3-7) of male crabs collected supported other reports (Poole 1967) that crabs 135-158 mm SW represent the incoming year-class. Ratios ($\hat{R}$) calculated for the numbers of male crabs 135-158 mm SW versus the number of crabs $\geq$159 mm SW collected during each month of fishing are shown in Table 2. The continuing harvest of legal crabs over the season was reflected in the generally increased $\hat{R}$ values calculated for each successive month of fishing. In all cases, the exceptions to this general pattern occurred between the February and March data.

Predictions of crab harvest for the ports of Newport and Astoria are given in Table 3. Compared with actual harvest figures,

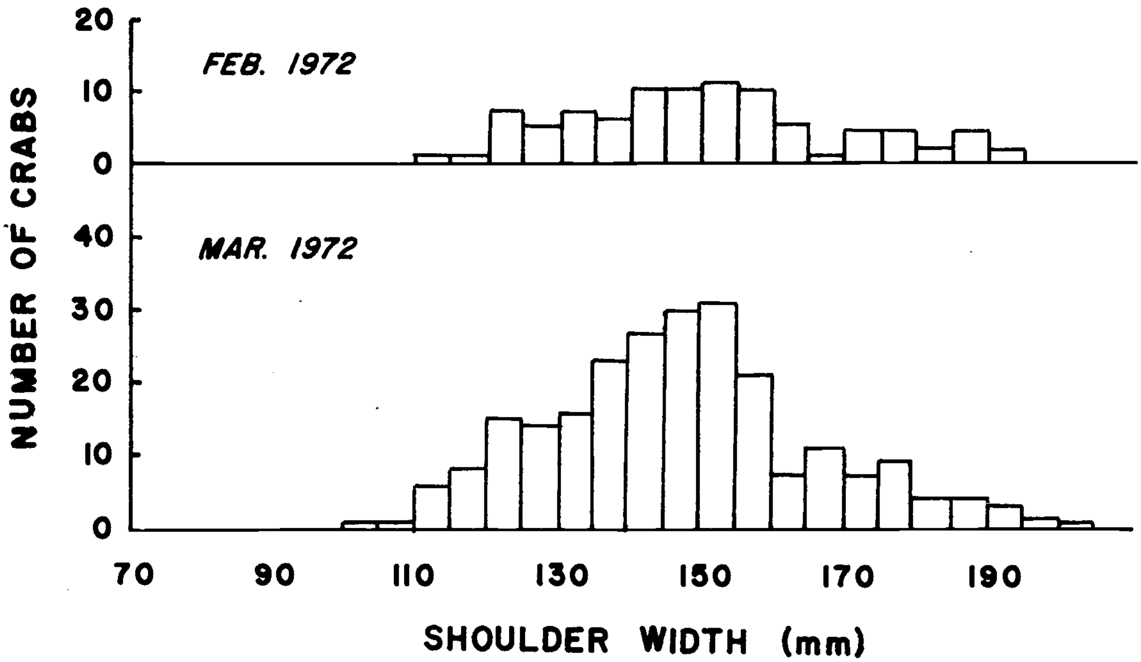

Figure 3. Carapace width-frequency histograms of male C. magister caught off Newport, Oregon, during the 1971-72 season. Data pooled for all sampling stations by month of capture.

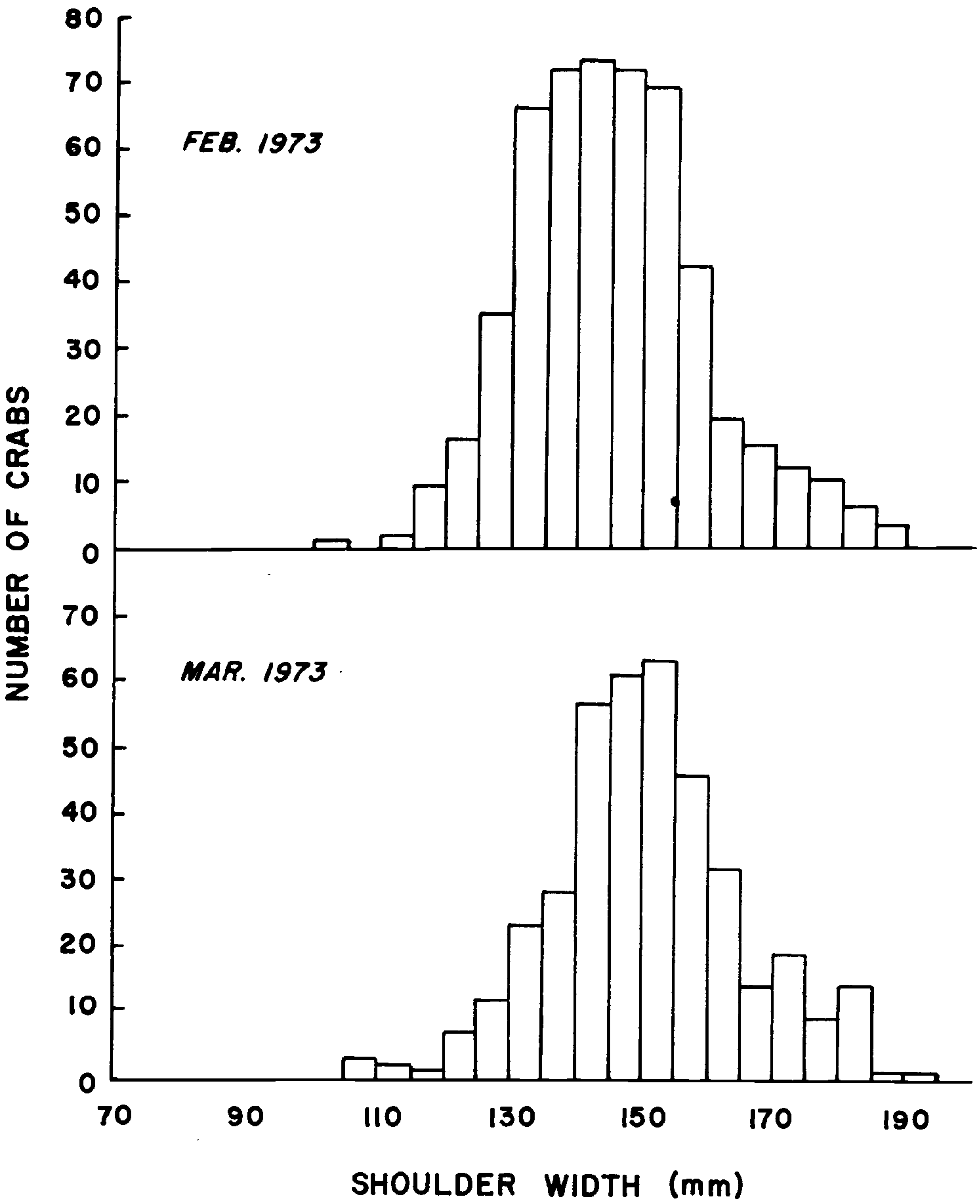

Figure 4. Carapace width-frequency histograms of male C. magister caught off Newport, Oregon, during the 1972-73 season. Data pooled for all sampling stations by month of capture.

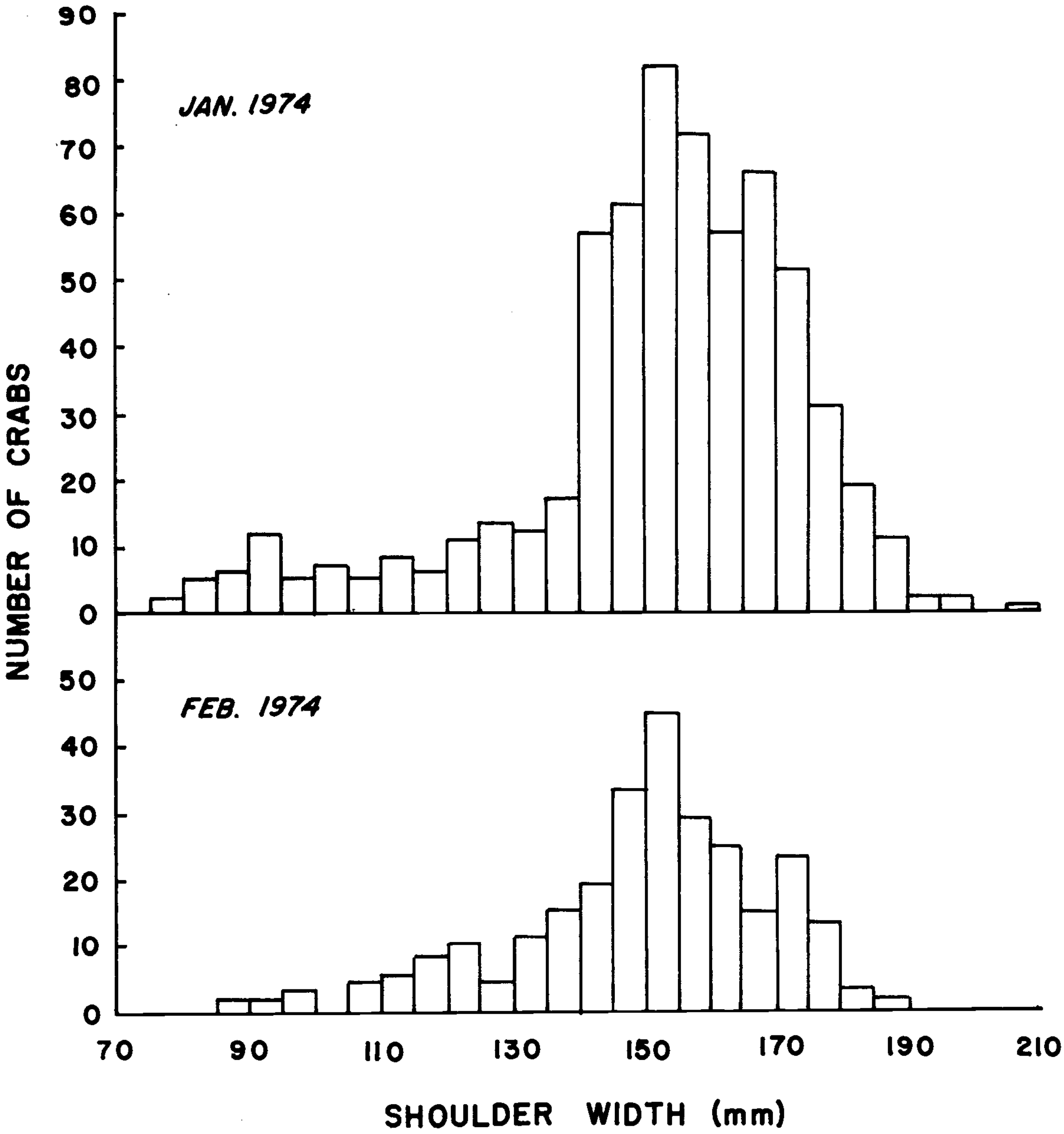

Figure 5. Carapace width-frequency histograms of male C. magister caught off Newport, Oregon, during the 1973-74 season. Data pooled for all sampling stations by month of capture.

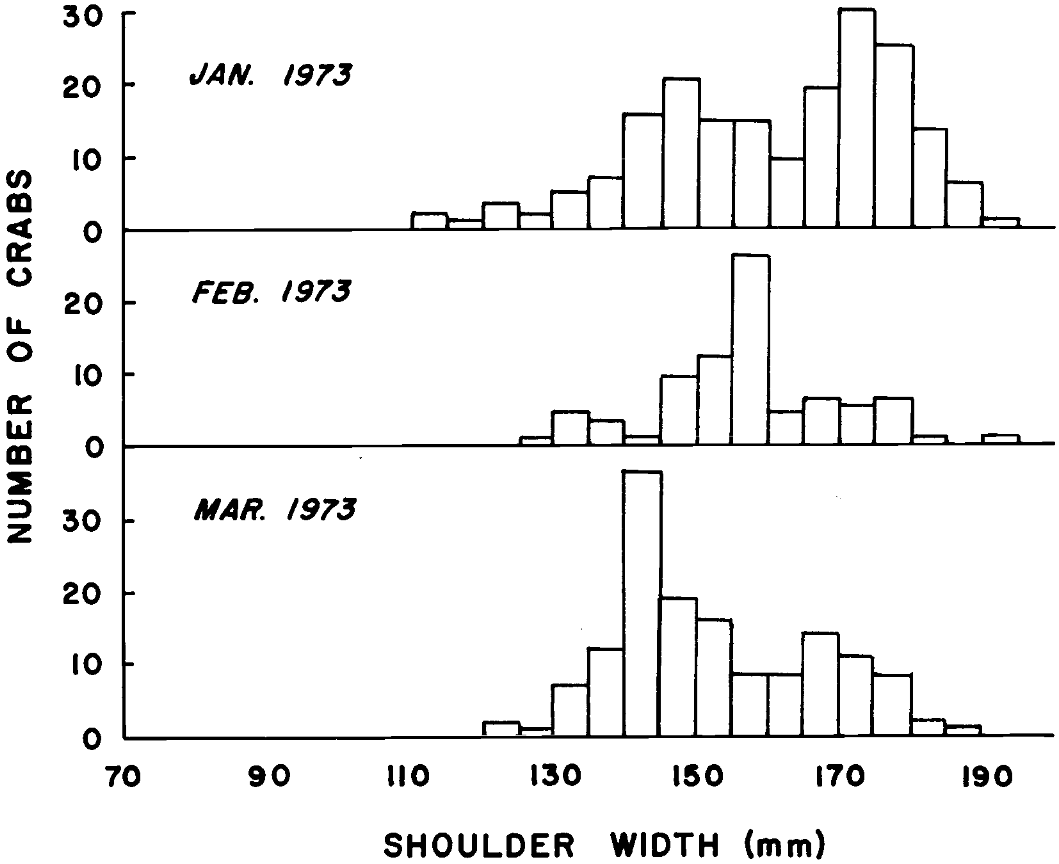

Figure 6. Carapace width-frequency histograms of male _C. magister_ caught off Astoria, Oregon, during the 1972-73 season. Data pooled for all sampling stations by month of capture.

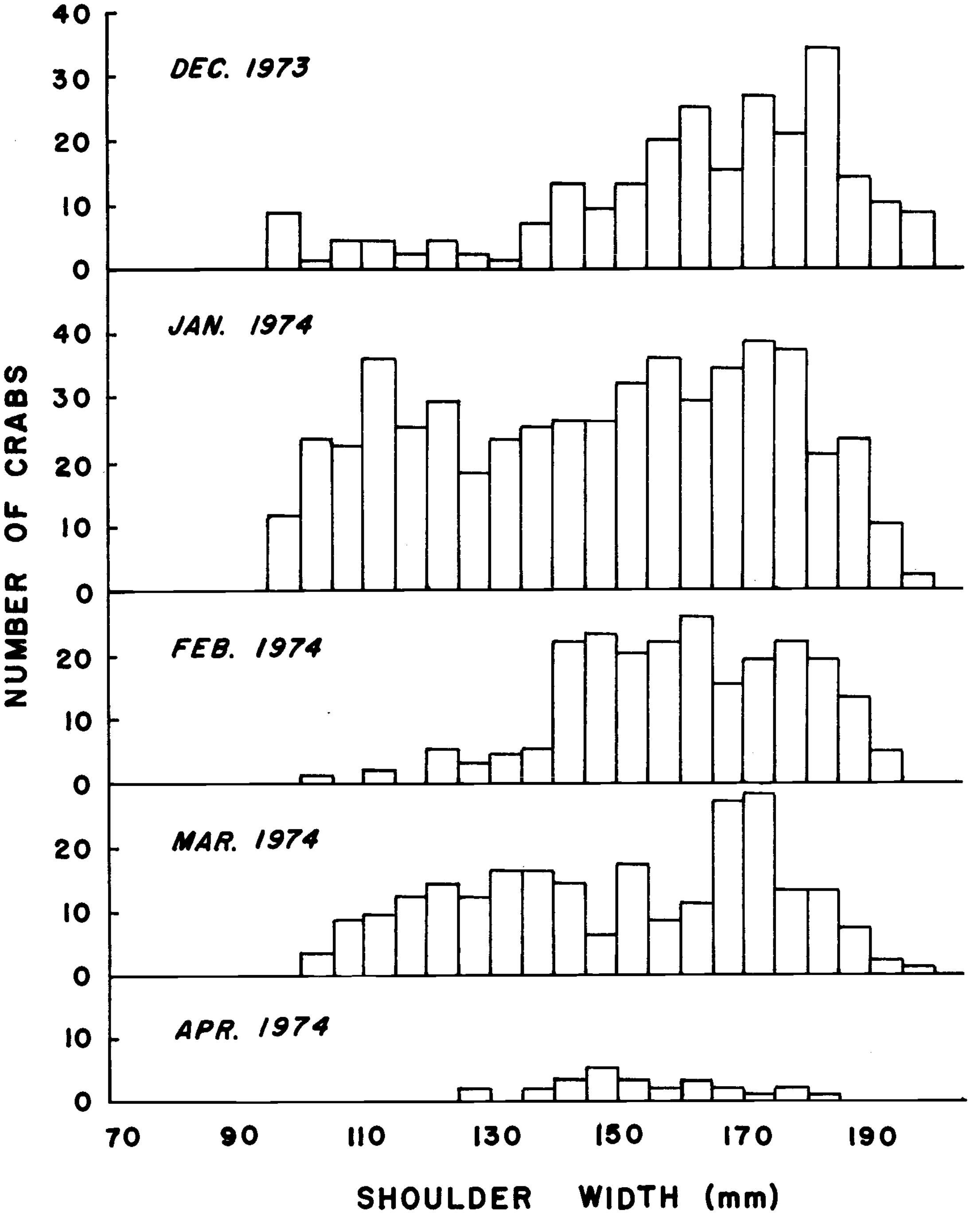

Figure 7. Carapace width-frequency histograms of male C. magister caught off Astoria, Oregon, during the 1973-74 season. Data pooled for all sampling stations by month of capture.

Table 2. Data showing location, number of pots sampled (N), month of sampling, ratio ($\hat{R}$) of male crabs 135-158 mm SW[1] to male crabs $\geq$159 mm SW, standard error of $\hat{R}$ [$s(\hat{R})$], and coefficient of variation [$s(\hat{R})/\hat{R}$] for Dungeness crabs captured off Newport and Astoria, Oregon, 1972-74.

Ports of landing	Months of collection	$\hat{R}$	$s(\hat{R})$	Coefficient of variation (%)	N
Newport	February 1972	2.1364	1.1213	52	6
	March 1972	2.8085	0.5880	21	22
	February 1973	5.0462	0.8926	18	36
	March 1973	3.0000	0.3945	13	28
	January 1974	1.2321	0.1402	11	44
	February 1974	1.7407	0.3022	17	19
Astoria	January 1973	0.6796	0.1398	21	24
	February 1973	2.3636	0.5850	25	12
	March 1973	2.0909	0.7280	35	20
	December 1973	0.4052	0.0645	16	19
	January 1974	0.7526	0.1082	14	44
	February 1974	0.7731	0.1310	17	34
	March 1974	0.5980	0.1544	26	26
	April 1974	1.6667	0.8003	48	12

[1] Shoulder width of carapace.

Table 3. Predicted landings compared with actual harvest of Dungeness crabs at Newport and Astoria, Oregon, for the 1972-73, 1973-74 and 1974-75 seasons, based on relative abundance of sub-legal size crabs to legal size crabs sampled during the previous fishing season.

Parts of landing	Season	Actual landings (kg)	Predicted landings	95 percent limits	
				Lower	Upper
Newport	1972-73	161, 899	682, 914	0	1, 915, 662
	1973-74	342, 556	310, 271	53, 422	763, 573
	1974-75		352, 941	44, 241	665, 208
Astoria	1973-74	666, 646	355, 922	0	1, 037, 152
	1974-75		258, 762	0	778, 400

this method of prediction fairly accurately estimates the harvest at Newport, but vastly underestimates landings at Astoria.

Several factors affecting the variable $\hat{R}$ are at least partially responsible for these differences, and the method used to harvest crabs further explains some of the discrepancy between the prediction and reality.

Dungeness crabs have a tendency to aggregate by sex and size during most of the year (Cleaver 1949; McMynn 1951), and crab fishermen try to avoid setting their pots in areas where females and sub-legal males are abundant. This lack of uniform distribution increases the difficulty of interpreting some data collected during this study. In areas where the preferred habitat of crabs is comparatively wide, as at Astoria, it may be that the male crabs are able to effect an almost complete segregation between legal and sub-legal sizes. Whereas, at Newport, the optimum living area is much narrower, and the crabs may not be able to separate as completely, or the pockets of segregation may be much smaller. Whatever the case, data from Astoria showed a much lower catch of sub-legal males than did data collected at Newport.

Commercial harvest of crabs does not occur uniformly within the waters fished out of each port. Fishermen generally set their pots in waters 13 m or deeper until calmer weather arrives in the spring, at which time the pots are transferred to shallower areas.

In addition, the fishermen usually don't move their pots until the supply of legal crabs in an area is almost completely harvested. So the supply of legal crabs within an area is diminished at a much faster rate than would be expected if harvest occurred uniformly over the entire region. For instance, at end of February, the sample pots may be fishing in an area where few of the available crabs are left, whereas harvest figures for the port would indicate that a substantial amount of crabs remained to be harvested. Then, when the experimental pots are moved, they will be sampling in an area where virtually all of the available crabs remain unharvested. Data from the last two seasons at both ports demonstrate this: in February the experimental pots were in areas that had been heavily fished and the data indicated a comparatively large proportion of sub-legal crabs; whereas in March they were moved to areas that had had a very light harvest, resulting in the ratio between sub-legals and legals being lowered from that in the previous months of sampling. The only data set which does not show this is the 1971-72 season, when the experimental pots were not set until late in February and were placed in areas that had been unfished previously.

Using only 30 pots to sample a resource as vast as the Dungeness crab population raises the possibility that an individual aberrant catch could significantly affect the average. In spite of this, the $\hat{R}$ values were quite consistent, with the coefficient of variation (standard error of $\hat{R}$ expressed as a percentage of $\hat{R}$) usually being low (Table 2).

The sum of the Astoria and Newport landings showed a high correlation with total Oregon landings during the seasons 1963-64 to 1972-73. Data for previous seasons was not used as I suspect that fishing pressure was not uniform over the coast, that crabs are harvested more intensively now, and that new fishing areas on the southern Oregon coast had not been exploited previous to the 1960's (Pacific Marine Fisheries Commission 1960, 1961).

The Newport and Astoria predictions were used to project total Oregon landings. Predicted crab landings for the 1973-74 and 1974-75 seasons in Oregon are given in Table 4. Actual harvest in 1973-74 was 1, 550, 126 kg, or 10. 3 percent greater than the predicted harvest, and landings for 1974-75 (projected from December, 1974 through March, 1975 landings) are expected to total about 1, 600, 000 kg, which is 22 percent more than my prediction.

Carapace-width measurements of all female crabs captured were plotted (Figures 8-9) and show that of the 3, 428 females taken, only 3 percent (116) were larger than 159 mm SW, or commercial legal size for males.

As was noticed in the case of male crabs, very few small (< 120 mm SW) female crabs were seen in the 1971-72 and 1972-73 catches, while in 1973-74 large numbers of smaller crabs were trapped.

Table 4. Projected landings of Dungeness crabs for Oregon (1973-74 and 1974-75 seasons) based on prediction of abundance of crabs at Newport and Astoria, Oregon.

Season	Predicted landings (kg)	Actual harvest
1973-74	1, 405, 092	1, 550, 126
1974-75	1, 306, 901	1, 600, 000[1]

[1] Estimated from December, 1974 through March, 1975 landings.

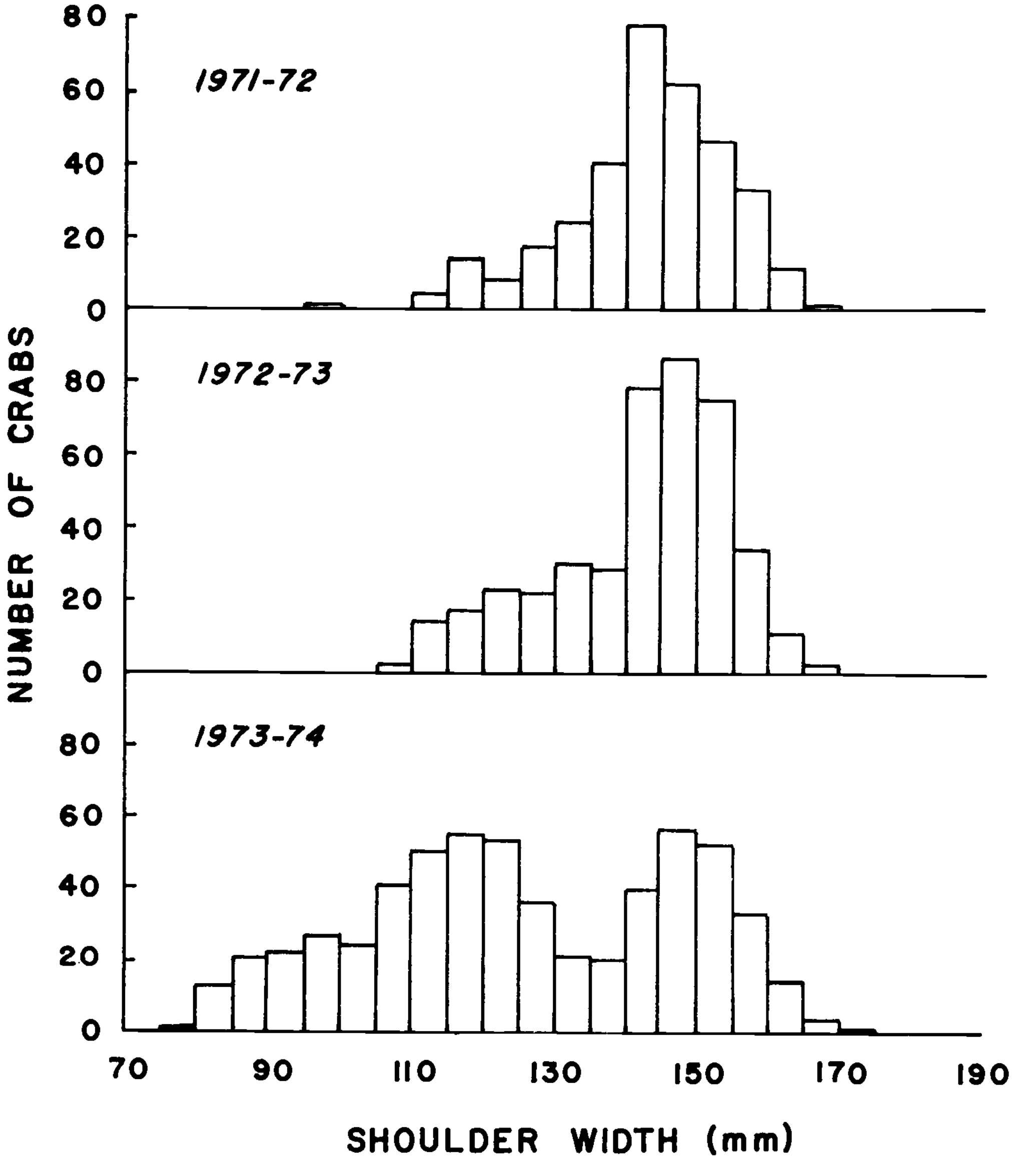

Figure 8. Carapace width-frequency histograms of female C. magister captured off Newport, Oregon.

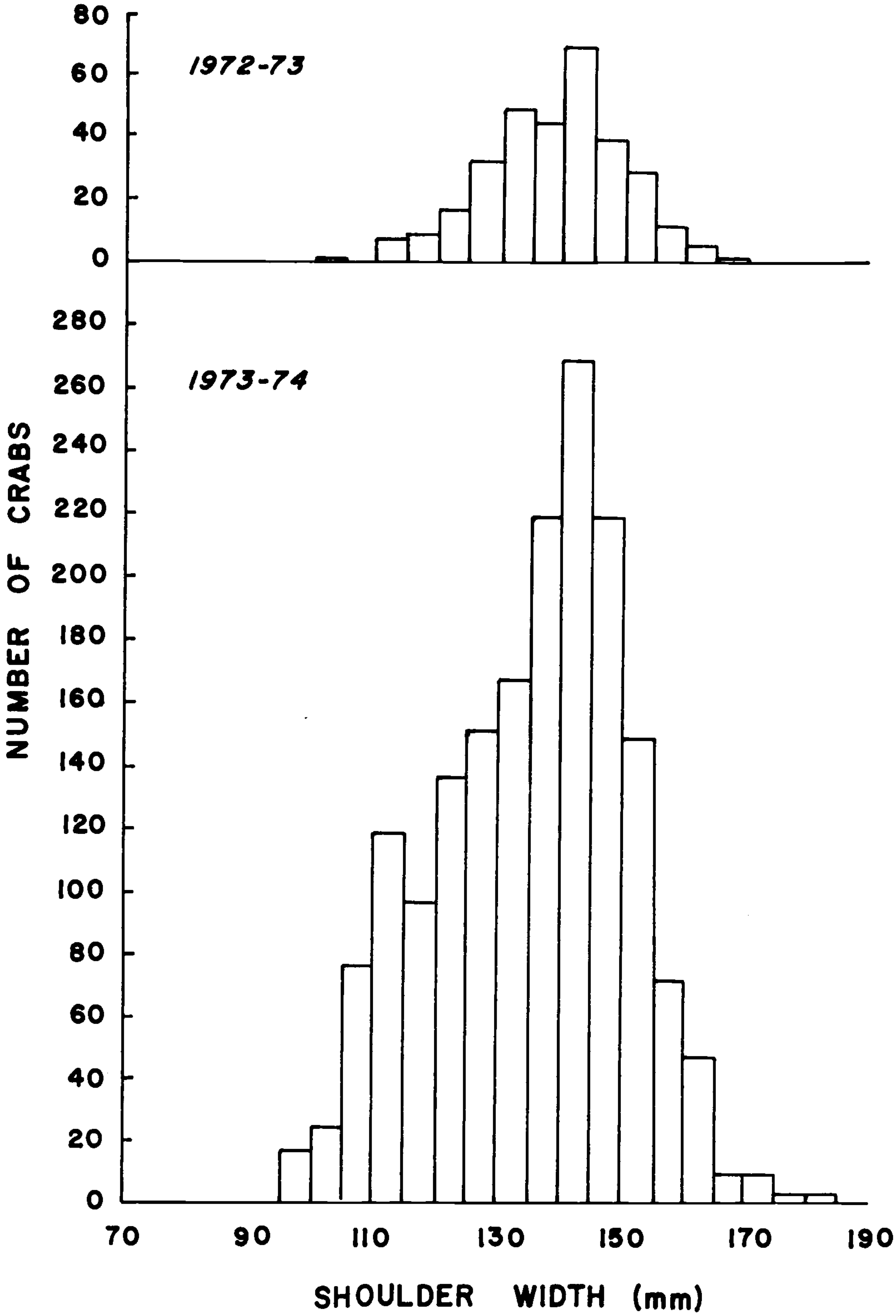

Figure 9. Carapace width-frequency histograms of female C. magister captured off Astoria, Oregon.

DISCUSSION

The trapping of over 7,000 crabs, with 35 percent of them sub-legal males, shows that it is possible to sample the sub-legal male Dungeness crab population during the winter fishing season with a minimum of expense. As noted earlier, the experimental pots retained the 3- and 4-year-old crabs, plus a good proportion of the 2-year-old crabs that entered.

Cleaver's (1949) observation that sub-legal males entered the pots in varying numbers as did those of legal size was confirmed in this study. As he noted, it was possible to establish a ratio between the undersized and legal-sized individuals; however, unlike his study, my research did not find that there was a change in the availability of undersized crabs as the season progressed. Any change in the ratio between undersized and legal-sized crabs was due to the decreasing numbers of legal crabs available rather than a change in behavior of sub-legal crabs. Neither did I notice that the sub-legal crabs escaped more readily from the pots, probably because my pots were designed to retain the smaller crabs, whereas I assume Cleaver was using commercial gear designed to retain only legal-sized individuals.

The length of time a trap was set between lifts did not seem to have any appreciable effect on the number or size of crabs retained. Crab fishermen believe the optimum time between lifts is 3-7 days, depending on the availability of crabs and weather and ocean conditions.

I feel that the experimental ratios between the sub-legal and legal crabs accurately reflected the actual ratio between those segments of the population in the areas sampled. However, because of the factors mentioned earlier (segregation of crabs, uneven harvest), the experimental ratios were not entirely reflective of the total population. Improved sampling techniques could eliminate some of these problems. Others could be solved through more sophisticated data analysis, and some may be impossible to solve.

By setting the pots at the start of the season, as was done in 1973-74, and sampling until the end of February, some of the problems caused by the uneven harvest could be overcome. If it could be assumed that the sub-legal and legal crabs are evenly distributed at the start of the fishing season, then the first month's sampling should indicate the actual ratio of those two populations, and subsequent sampling would reflect the decreasing numbers of legal individuals. It may only be necessary to set the experimental pots during the first month of fishing in order to gain a meaningful ratio. At any rate, continuing sampling beyond the end of February when fishermen begin moving their gear to unfished areas will only serve to confuse the issue since it is not possible to know how much the removal of crabs in other areas has affected the stock in the unfished areas.

Further sampling is needed to see how much segregation of the sub-legal and legal populations occurs. The low standard errors, when compared with $\hat{R}$, indicate that my sampling and the population sampled, was consistent within the areas fished at each port. The difference in average ratios between the Newport and Astoria catches, however, indicates that the crab population at Newport exhibits much different behavior than that at Astoria.

More extensive sampling with more pots would help to eliminate the problems caused by the segregation of crabs. But, too many pots cannot be used as this may tend to interfere too much with the operation of the fishing vessel and cause reluctance on the part of the vessel's skipper to volunteer his time and equipment for sampling. Because one of the objectives of this project was to develop an inexpensive technique for sampling, this precludes chartering a vessel specifically to run sampling gear.

Prediction of harvest at Astoria has not proven to be highly reliable at this time. It may be that the differences in the behavior of crabs at that port will necessitate a different analytical technique. Because the combined predicted harvests used to forecast coast-wide landings were extremely accurate, I believe that this procedure will prove to be a valid method for predicting crab harvest for the State.

Continued sampling is needed to determine if this method will work during times of high crab numbers, or when the crab population is increasing or decreasing. My work occurred during the nadir of the crab cycle, and the abundance of legal crabs during the two seasons for which predictions were made for the State was about equal.

The formula derived to predict crab harvest may have to be modified somewhat as more seasons of data are collected. Presently, this formula lacks sophistication, as is to be expected with so little data. The formula does not take into account the harvest of legal crabs which occurs during the month, but only the numbers present at the start of the month. Neither does it account for the uneven harvest which occurs at each port, but rather assumes that the harvest is even over all the areas fished out of that port. Another problem that may arise is that occasionally boat owners will travel long distances to off-load at a specific port; for instance, an owner may set gear in waters south of Newport, but, may sell the catch in Astoria. This usually occurs only during seasons of high crab abundance and may never account for a significant part of any one port's harvest.

Presently, only male crabs greater than 159 mm SW are harvested commercially. As my research has shown, only a very few females ever reach that size. Thus, it is my belief that those few large females could be harvested and, particularly during years of low crab abundance, add a small amount to the crab harvest. Currently, processors maintain that there is no market for female crabs due to a lack of quality and quantity of their meat, but it is possible that a market could be found if the female crabs were available for harvest. Further testing would have to be done to determine if the meat from the females was of equal quality as males, and whether the recovery of meat from the females was equivalent to that of the males. Removal of large females from the breeding stock should not affect reproduction because of the small numbers involved, and could increase production because their harvest may reduce intraspecific competition for food and space required by growing 2- and 3-year-old males, and smaller egg-bearing females.

Even though my research has demonstrated many drawbacks to the problem of crab harvest prediction, I think that this method does warrant further inspection. It has shown that it is possible, with a minimum of expense, to sample the sub-legal portion of the crab population during the winter fishing months. It has also shown, that a sample ratio of sub-legal to legal male crabs can be established which is fairly indicative of the actual ratio between the between the two groups. And, most importantly, it has shown that this ratio can be used to determine the future commercial crab harvest. Now, further sampling is necessary to refine the technique for crab prediction described in this report.

While an accurate prediction of the amount of crabs available for harvest at each port would be valuable to both fishermen and processors in the allocation of their resources, perhaps most importantly, it would give both fishermen and buyers a figure on which to base their price negotiations before the start of the season.

BIBLIOGRAPHY

Butler, T. H. 1960. Maturity and breeding of the Pacific edible crab, Cancer magister Dana. J. Fish. Res. Board. Can. 17:641-646.

Cleaver, F. C. 1949. Preliminary results of the coastal crab (Cancer magister) investigation. Wash. State Dept. Fish., Biol. Rept. No. 49A:47-82.

Cochran, W. G. 1963. Sampling techniques, 2nd ed. John Wiley and Sons, Inc., New York. 413 pp.

Hipkins, F. W. 1972. Dungeness crab pots. Fishery Facts-3. Natl. Mar. Fish. Ser., Extension Pub. 13 pp.

Jow, T. 1964. California-Oregon cooperative crab tagging study. Pac. Mar. Fish. Comm., 17th Ann. Rep., Append. 2, pp. 51-52.

Lough, R. G. 1975. Dynamics of crab larvae (Anomura, Brachyura) off the central Oregon coast, 1969-1971. Ph.D. Thesis. Oregon State University, Corvallis. 299 pp.

McMynn, R. G. 1951. The crab fishery off Graham Island, British Columbia, to 1948. Bull. Fish. Res. Board Can., No. 91, 21 pp.

Pacific Marine Fisheries Commission. 1959-1970. Status of the Pacific coast Dungeness crab fishery. 12th-23rd Ann. Rep., Pac. Mar. Fish. Comm., Portland, Oregon. (Pages variable).

Pacific Marine Fisheries Commission. 1974. Data Series: Crab and shrimp section. Pac. Mar. Fish. Comm., Portland, Oregon. 140 pp.

Peterson, W. T. 1973. Upwelling indices and annual catches of Dungeness crab, Cancer magister, along the west coast of the United States. Fish. Bull. (U.S.) 71:902-910.

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. Proc. Symp. Crustacea, Part II. Symp. Series 2. Mar. Biol. Ass. India: 553-567.

Waldron, K. D. 1958. The fishery and biology of the Dungeness crab (Cancer magister Dana) in Oregon waters. Fish. Comm. Oregon, Contr. No. 24: 1-43.

Winnor, R. A. 1966. Population fluctuations of market crab (Cancer magister Dana) in the San Francisco area. State of Calif. -Resources Agency, Dept. Fish and Game, Marine Resources Region, Sacramento. Marine Resources Office Reference No. 66-29. 14 pp.

APPENDIX

Appendix Table 1. Monthly commercial landings of Dungeness crab at Newport and Astoria Oregon.[1]

Season	Port of landing	Landings by Month (kg) Dec.	Jan.	Feb.	Mar.	Apr.	May-Sept.	Total seasonal landings
1971-72	Newport	193,378	234,235	86,259	115,207	42,847	35,321	707,247
1972-73	Newport	44,570	40,220	15,913	15,389	9,133	36,674	161,899
1973-74	Newport	30,813	107,438	63,808	55,956	31,965	52,376	342,556
1972-73	Astoria	401,604	114,515	42,051	14,044	20,349	73,713	666,276
1973-74	Astoria	184,323	174,505	121,549	68,600	51,246	66,423	666,646

[1] Data from C. Dale Snow, Fish Commission of Oregon, Newport, January 1975.

Appendix Table 2. Predicted landings of Dungeness crabs at Newport and Astoria, Oregon, for the 1972-73, 1973-74 and 1974-75 seasons, based on monthly relative abundance of sub-legal size crabs to legal size crabs sampled during the previous fishing season.

Ports of landing	Months of collection	Predicted season	Predicted landings (kg)	95% limit Lower	95% limit Upper
Newport	February 1972		669, 221	0	1, 915, 662
	March 1972		696, 606	33, 658	1, 359, 554
		1972-73	682, 914	0	1, 915, 662
	February 1973		411, 810	60, 047	763, 573
	March 1973		208, 733	53, 422	364, 044
		1973-74	310, 271	53, 422	763, 573
	January 1974		351, 156	90, 489	611, 822
	February 1974		354, 725	44, 241	665, 208
		1974-75	352, 941	44, 241	665, 208
Astoria	January 1973		201, 186	12, 404	389, 968
	February 1973		495, 085	0	1, 037, 152
	March 1973		371, 494	0	830, 261
		1973-74	355, 922	0	1, 037, 152
	December 1973		243, 112	39, 539	446, 685
	January 1974		346, 696	81, 509	611, 883
	February 1974		254, 123	41, 153	467, 093
	March 1974		141, 616	0	289, 815
	April 1974		308, 264	0	778, 400
		1974-75	258, 762	0	778, 400