REPORT

on the

PROPOSAL

FOR EXTENSION OF DUNGENESS CRAB STATE/FEDERAL FISHERIES MANAGEMENT PLAN DEVELOPMENT FOR THE CALIFORNIA, OREGON, AND WASHINGTON DUNGENESS CRAB FISHERY

PART III. Preparation of background information for management planning based on the requirements of P.L. 94-265.

Prepared by: Ad hoc Dungeness Crab Management Review Team
Jack G. Robinson - Biologist, Newport, Oregon
Melvyn W. Odemar - Biologist, Sacramento, California
Jack A. Richards - Economist, Seattle, Washington
Ronald Westley - Biologist, Brinnon, Washington

Submitted April 1977 to the
State/Federal Dungeness Crab Fisheries Management Program

The preparation of this report was supported by NMFS Contract No. 03-5-208-302, June 1, 1976 through December 31, 1976 (as extended). The contract was administered by the Pacific Marine Fisheries Commission

TABLE OF CONTENTS

INTRODUCTION

In 1973 the states of California, Oregon, and Washington, with the National Marine Fisheries Service and the Pacific Marine Fisheries Commission entered into a cooperative State/Federal Dungeness Crab Management Program. The primary objective of the program was to manage the Dungeness crab fisheries on a basis consistent with sound biological principles to enhance the net benefits from the resource and to promote an orderly fishery on a coastwide basis.

The initial program consisted of two phases. Phase I began in June 1973 and concentrated on developing preliminary recommendations for management concerning seasons and certain fishery practices. Phase II began in June 1974 and lasted two years. The objectives of Phase II were to determine if the Dungeness crab fishery was overcapitalized and if so determine the net benefits that would result from selected effort management schemes designed to achieve economic efficiency and predict the probable distribution of benefits resulting from each.

In April 1976, the Dungeness Crab Subcouncil authorized an extension of the program (Contract No. 03-5-208-302) through December 1976. One element of the extension included part III, preparation of background information for management planning in light of P.L. 94-265. To complete this phase, the three state agencies and the National Marine Fisheries Service each appointed a representative to an Ad Hoc Dungeness Crab Management Review Team. The team was directed to "inventory and evaluate the available management information on Dungeness crabs and identify the data needed for the development of a comprehensive management plan based on the requirements of H.R. 200 (Public Law 94-265, the Fishery Conservation and Management Act of 1976)." The available information was to be compiled and steps recommended to obtain additional required data. The team was to complete its task and submit a report by December 31, 1976.

The Ad Hoc Management Review Team was appointed in June 1976. Members were Jack G. Robinson (chairman), Oregon Department of Fish and Wildlife; Melvyn W. Odemar, California Department of Fish and Game; Ronald E. Westley, Washington Department of Fisheries; and Dr. Jack A. Richards, National Marine Fisheries Service. The team first met on August 12, 1976, in Portland, Oregon and decided to list realistic alternative techniques that could be used for management of the crab fishery, and review the types of available data or information needed

for each alternative. The information needed and/or available was evaluated with respect to the requirements of P.L. 94-265. Many of the requirements for management listed in Section 303 of P.L. 94-265 can be found in the Phase I and II completion reports of the Study Team during the period June 1973 - June 30, 1976, and in published and unpublished data/reports on which the Phase I and II reports were based. Section 303 of P.L. 94-265 specifies the contents of a fishery management plan for fisheries falling under the authority of the Management Councils established by the Act. Among these requirements are (1) a complete description of the fishery; (2) an assessment of the fishery's present condition, probable future condition, maximum sustainable yield, and optimum yield, and an assessment and specification of the capacity and desire of the U.S. fishing fleet to harvest the optimum yield and the portion which will not be so harvested and can be made available to foreign fleets; (3) specification of pertinent statistics which must be submitted to the Secretary on fishing effort, gear, species taken, and locations of activity; and (4) necessary management measures governing foreign and domestic fishing consistent with the national standards (Section 301 of the Act) and other applicable law. In addition, Section 303 lists seven discretionary items which Management Councils may include in management plans. The Team decided that Sections 301 and 303 of the Act were pertinent to our charge; since it was decided that we would not draft a management plan, the subsection of Section 303 dealing with management measures (listed as 4 above, but subsection 1 in the Act) was deemed not relevant to our assignment.

This report presents the Ad Hoc Team's assessment of available background information for management planning. We considered eight management techniques, most of which are or have been used in one or more of the three states. Combinations of some or all of the eight management techniques form a logical ninth "technique", and are indeed in force now in Oregon, Washington and California. They are:

A. Size limitations
B. Closed seasons.
C. Sex limitations.
D. Crab condition (softshell, hardshell, etc.).
E. Area limitations.
F. Catch limit or quota.
G. Limitations on harvest method or tool.

H. Limited access.
   1. Taxes.
   2. Individual fisherman or boat catch quota.
   3. License limitation.

We then listed the information types needed for each management technique. We felt that each of the eight techniques needed six or more information types. We recognize that we may not have listed some information types under a given Technique that should be; however our best judgment was that the following are the most pertinent:

Technique	Information type
A	1-4, 10, 16, 21, 23
B	3, 5, 6, 10, 11, 13, 16, 18, 21-23
C	1-5, 7, 8, 10, 11, 14-17, 19, 22, 23
D	1, 3, 5, 8, 10, 16, 21, 23
E	3, 5, 6, 10, 19-23
F	1, 6, 9-11, 13-19, 21-23
G	4, 5, 12, 13, 21, 22
H (1)	9-11, 16-23
H (2)	6, 9-11, 16-23
H (3)	1-6, 11, 16-23

The twenty-three types of information about the crab resources and/or fishery are: (1) mortality rates; (2) growth rate; (3) molting, condition and meat yield; (4) size at sexual maturity; (5) handling mortality; (6) vessel mobility; (7) information on harvest of female crabs; (8) population density; (9) assessment of catch per unit of effort data; (10) statistics and historical data; (11) stock assessment; (12) interfishery problems; (13) savings gear; (14) recreational fishing; (15) migration and movement; and eight types of economic or social information, including (16) marketing characteristics; (17) social characteristics; (18) contribution to economic activity; (19) alternative uses for fishing resources; (20) information needed for effort control; (21) enforcement and management costs; (22) costs and earnings; and (23) processing efficiency.

All of these alternatives will need to be considered under P.L. 94-265 when a management plan is drafted. We believe the management team or entity which will develop such a plan can profitably use this report in their deliberations.

We have described briefly what is known about each of the twenty-three information types, including citations of available literature, published and unpublished, and summarized such under each of twenty-three major sections in the Discussion section of this report. The reader will find under each information type discussion, our best assessment of what steps, if any, are necessary to obtain additional required data for a management plan.

DISCUSSION

MORTALITY RATES

Reasonable estimates of mortality rates are needed for population dynamics studies. Precise estimates of fishing mortality rates over an extended period of time are not available. However, fishing mortality on legal-sized male crabs has been relatively high in recent years. Few attempts have been made to estimate natural mortality rates.

Review

Natural Mortality. Little is known about natural mortality of Dungeness crabs. The only published reference dealing with natural mortality is by Jow (1965) who studied a tagged population of legal male crabs (n=901) in the California-Oregon boundary area. Jow estimated a natural mortality rate of 15 percent during the 1962-63 crab season. However, his estimate may be biased because of unreported tag returns.

Gotshall (in press [a]) has estimated mortality rates for legal male crabs from catch-effort data for northern California. Estimates of instantaneous seasonal natural mortality rates for 1967-68, 1969-70, and 1971-72 were 0.54, 0.76 and 1.78, respectively. Expansion of Gotshall's data to an annual basis gives annual natural mortality rates of 58, 71, and 92 percent, respectively.

Fishing Mortality. Several papers have been published that report total recovery from tagging studies but few authors have attempted to relate their data to fishing rates. McMynn (1951) estimated a fishing mortality of about 35 percent for tagged stocks off Graham Island, British Columbia during the 1947 and 1948 seasons. He concluded this rate closely represented the real rate of exploitation. Butler (1951) estimated seasonal exploitation rates based on tag recoveries for three areas in the Graham Island fishery ranging from 9 to 34 and 11 to 34 percent for 1949 and 1950, respectively.

Cleaver (1949) estimated fishing mortality rates for the 1947 and 1948 seasons in Washington at 74 and 82 percent, respectively. Jow (1965) reported an exploitation rate of 84 percent for the 1962-63 season in the northern California-Oregon border area. Gotshall (in press [a]) calculated seasonal instantaneous fishing mortality rates for crabs in northern California ranging from 0.68 to 4.99 for the 1966-67 season through the 1971-72 season. These instantaneous rates correspond to annual fishing mortality rates of 0.69 and 0.999, respectively.

Collinsworth et. al. (1976) estimated the percentage of available crab caught in a given year by examining length-frequency data collected in Oregon between 1947 and 1970. At assumed natural mortality rates of 0.15, 0.30, and 0.45 they estimated exploitation rates ranging from 68 to 95, 64 to 94, and 58 to 93 percent, respectively.

Total Mortality. The only available estimates of total mortality are those by Jow (1965) who estimated a total mortality of 99.4 percent of tagged legal males during the 1962-63 crab season and Gotshall (in press [a]) who calculated seasonal total mortality rates ranging from 14 percent during the 1966-67 season to over 99.9 percent in the 1971-72 season.

Recommendations

It is recommended that studies be initiated to improve estimates of mortality rates of Dungeness crabs. Reliable estimates of fishing and total mortality rates are needed to help obtain more reliable estimates of natural mortality. There is also a need for better estimates of mortality caused by certain fishery practices which are discussed under the section on interfishery problems in this report. This type of information is needed to better consider management techniques such as size limitations, sex limitations, and some types of catch limits on quotas as well as to determine MSY and OY.

Reliable estimates of mortality rates will be difficult and probably expensive. Methods would be either by mark-recovery techniques or analysis of catch per effort data. The latter method requires reliable measures of effort which are presently imprecise. A useable unit of effort needs to be defined before adequate mortality estimates can be calculated in the future (see section on Assessment of Catch Per Unit of Effort).

GROWTH RATE

Several papers have been published that deal with growth of Dungeness crabs. Growth data has been collected from: (1) laboratory reared larvae; (2) post-larval crabs collected from the field and held in the laboratory; (3) juvenile and adult crabs that molted in captivity, crab pots, and trawl nets that could be matched with the shed carapaces; (4) field observations of crabs that molted soon after being caught; (5) return of tagged or marked individuals that had molted prior to recapture; and (6) length-frequency measurements from field samples.

Reports by Lehman and Osborn (unpublished manuscripts), Butler (1961); Cleaver (1949), Poole (1967), and Orcutt et. al. (1975) contain good general discussions on growth of crabs. Orcutt et. al. (1975) give a comparison of shell widths of male Dungeness crab post-larval instars from central California, Washington and British Columbia. Osborn (unpublished manuscript) presents comparative growth curves for California, British Columbia, and southeast Alaska.

Review

In general, the results of the various growth studies show the following:

1. Crab larvae are free swimming for 3-5 months and pass through 5 zoeal and 1 megalops stage before leaving the water column.

2. Post-larval crabs pass through 11-12 instars before reaching sexual maturity and 13-14 before reaching the legal minimum size of 159 mm (6¼ inches).

3. Most crabs are approximately 4 years old when first harvested.

4. After attaining a carapace width of about 102 mm (4 inches) a crab will grow from about 25 to 30 mm at each molt.

5. Growth rates of males and females are comparable until a carapace width of about 93-108 mm (3.7-4.2 inches) is attained; after which growth of females is slower than males and the males attain a larger maximum size. This change in growth rate corresponds with the onset of sexual maturity.

Recommendations

Much data have been collected on growth of Dungeness crabs. If the present policy of not harvesting male crabs less than 159 mm (6.25 inches) in carapace width and complete protection of female crabs is continued there is not an immediate need for additional growth studies. However, if consideration is given to changing the minimum size of male crabs or to harvesting large female crabs, then additional data on molting frequency and natural mortality rates for crabs would be needed.

MOLTING, CONDITION, AND MEAT YIELD

Growth in the Dungeness crab occurs by molting and crabs have poor meat yield for up to 60 days afterward. During this period, meat yield is low (13-14 percent of live weight). Meats tend to be watery and the softshell crabs are subject to increased handling mortality (Tegelberg 1972). Because prime hardshell crabs have a potential meat yield of 25-30 percent and are resistant to handling mortality, the crab molting cycle has received major consideration and review over the past 20 years in efforts to develop management practices that make overall best use of the crab resource (Collinsworth et. al. 1974). A general management objective has been to open the season when the crab are in good condition.

Review

Data collected over the past 20 years show that crabs do not always molt at exactly the same time each year, and that molting occurs later off the coast of northern Oregon and Washington than in the southern portion of the coastal fishing area. Thus crabs may not be in optimum condition at the same time each year or at the same time throughout their range.

In earlier years this created some management problems which have been magnified in recent years by the trend to harvesting an increasingly larger portion of the catch during the first two or three months of the season. As a result, several efforts have been made to seek approaches to crab management that would delay harvest until crab are in optimum condition throughout most of their range.

Setting an optimum season with respect to crab condition that is satisfactory to all three states has proved difficult because the problems of market demand, economics, and vessel mobility all must be considered. It is possible to adjust crab seasons each year based on acceptable crab condition and during the State/ Federal Dungeness Crab Study a recommended procedure was provided for evaluating crab condition with recommended criteria for a delay in the season opening date, if needed (Anon. 1975). This, however, has the disadvantage to fishermen and processors of creating uncertainties about when the season will start.

Several years of condition data exist for all three states. However, condition data is lacking, particularly in California and Oregon for the late months of the open season. Also there is a gap in condition data in California and Oregon for the 1969-70 period when poor condition early in the season was a major problem. Only Washington has collected significant amounts of pick-out and meat yield data throughout the season.

Recommendations

While more data would be desirable, that now available is probably adequate for present management practices. However, if we embark on setting seasons each year based on crab condition, an extensive and costly ocean sampling effort would be needed prior to each season.

SIZE AT SEXUAL MATURITY

Determination of crab size at sexual maturity is an important consideration in crab management because it is imperative that an adequate breeding population is maintained to ensure successful reproduction of the crab populations.

Review

Efforts to determine minimum size (carapace width) of both male and female crab at sexual maturity have been made by several workers. Cleaver (1949) reported the smallest male crab found mating was 106 mm (4.2 inches). Butler (1960) observed mature males at 110 mm (4.33 inches) (including the tenth antero-lateral spines) mating, but reported that significant breeding does not occur until about 140 mm (5.5 inches) or three years of age. MacKay (1942) reported observing sexually mature male crab at 5.4 inches (137 mm) and the smallest male found in the mating embrace at 6 inches (152 mm). Method of measurement was not specified, but

probably included the tenth antero-lateral spines. Cleaver (1949) reported finding a female crab of 72 mm (2.8 inches) mating. Butler (1960) reported that sexual maturity of females in The Queen Charlotte Islands is likely attained at 100 mm (3.9 inches) (including tenth antero-lateral spine) and at an estimated age of two years. MacKay (1942) reported that female crabs probably reach sexual maturity at about 4 inches (102 mm).

Recommendations

The published information on this topic is not extensive. However, when combined with the unpublished observations of the state management agencies, it appears the information is adequate to substantiate current crab management practices of not harvesting male crabs at less than 159 mm (6.25 inches). If smaller size limits or harvest of female crabs are to be considered in the future, more information would be needed.

HANDLING MORTALITY

During past crab tagging studies it was noted that recoveries of crab tagged while in the softshell condition were significantly lower than for hardshell crabs (Cleaver 1949). This, plus routine observations of commercial fishing operations, indicates that at certain times handling mortality of softshell crab could be quite high. Because substantial fishing effort has occurred off the Washington Coast while the crabs were in softshelled condition, limited studies have been undertaken there to better assess the significance of this problem.

Review

The Washington Department of Fisheries conducted a series of experiments in 1969 and 1970 to determine mortality of softshell crab during simulated discard handling practices. They found that softshell crab (predominantly grade III[1/]) handled under conditions similar to those found in the commercial fishery and then held in commercial pots for varying lengths of time suffered mortalities of 15-20 percent, depending on the length of holding time after treatment. Injury by dropping softshell crabs on a deck resulted in 57 percent mortality (Tegelberg 1970).

---

[1]Grade III crab are ones that recently molted and the carapace and legs are still flexible and easily broken.

During later experiments conducted in 1971 and 1972 mortality rates of about 8 percent were observed (Tegelberg 1972). However, these experiments were hampered by difficulty in obtaining adequate numbers of newly molted crabs to test. Additional studies on handling mortality of 2-4 inch (50 to 100 mm) crabs done in 1975-76 showed about 1 percent mortality. This relatively low value was at least partly due to the more frequent and irregular molting of smaller crabs making it impossible to obtain sufficient numbers of newly molted crabs for the experiment (Northup 1976).

Handling of softshelled crabs can apparently cause significant mortality. The extent of the mortality can be greatly influenced by the length of time between the occurrence of molting and the initiation of commercial fishing. Very careless handling of newly molted crabs can apparently result in up to 57 percent mortality. Based on the limited data available, a 15 percent discard handling mortality value seems to be representative when fishing occurs on grade III softshell crabs. Therefore, the extent of the handling mortality problem in any given season will depend upon the relative abundance of softshell crab, the size of the escape rings in use, and the care taken in sorting during fishing.

Recommendations

The available data indicate that mortality due to discard handling can at times be substantial. Therefore, if fishing seasons are considered that allow fishing on softshell crabs then there is a need to further evaluate the problem. However, experiments that will adequately simulate actual fishing operations will be difficult to attain.

VESSEL MOBILITY

Vessel mobility in the Dungeness crab fishery has received considerable attention in recent years as new and larger boats have entered the fishery and as trends of crab abundance have at times made fishing successful in only some portions of the Pacific Coast. During certain years crab fishermen from one state or area have moved to another state or area and fished either before the legal opening date in the host state or have taken advantage of multiple season opening dates when a staggered season opening exists. The problem is that the fishermen from the host state or area often resent the influx of fishermen from outside areas.

Review

Fishing by Citizens from a State with an Open Crab Season Beyond Three Miles of a Second State with a Closed Crab Season. Prior to passage of P.L. 94-265, the individual states sought to control this problem by passage of complementary regulations making it illegal for their citizens to fish off another state during that state's closed season. Initially this procedure controlled the problem; however, in an incident in 1971 it was found that enforcement of this regulation was difficult and henceforth this procedure was of limited value (Tollefson 1972). Passage of P.L. 94-265 appears to solve this problem and provides the legal mechanism for effective control.

Movement of Vessels from Area to Area Under Lawful Open Seasons. This involves movement of vessels either inter- or intra-state. This situation does not occur every year, but when it has it has usually been during the first month after the season opening. The conditions, singly or in combination, that have led to the problem are as follows:

1. Substantial differences in relative abundance of crab between states or major fishing areas.

2. High demand and price for crab.

3. The existence of a staggered crab season opening between states or major fishing areas.

The most recent instances of a significant movement of vessels was during the 1971-72 and 1972-73 seasons. In 1971-72, a staggered season was in effect and the Washington season opened one month later than Oregon and California. Crab abundance was high off Washington and about 54 out-of-state vessels fished off Washington early in its season. Of these, 11 were identified as Astoria-Warrenton vessels. In 1972-73, a uniform season existed among the three states, but crab abundance was still much greater off the northern area. In this case 36 out-of-state vessels fished early in the season off Washington; of these, 13 were identified as Astoria-Warrenton vessels (Anonymous 1972; Tegelberg 1975; and Stewart 1976). While determination of exact numbers is difficult, it is obvious that a significant increase in the number of out-of-state boats occurred off Washington in those two years.

In years without a staggered season or with relatively uniform crab abundance along the coast this has not been a major problem.

In 1977, helicopters came into use in Oregon. Limited observations of this operation indicate they are highly mobile and profitable at least in years of high crab abundance. Their use may intensify problems.

Many points of view exist relative to this subject and about possible solutions. Vessel mobility is a factor that should be considered in any coastwide management plan. It interrelates with crab condition as one of the major factors to consider in setting seasons (Collinsworth et. al. 1974). During some years this problem has caused Washington to open the season before the crab were in good condition and therefore resulted in somewhat wasteful use of the resource. The data developed by the State/Federal Study Team indicate that a uniform delayed opening of the crab season would result in a significant increase in pot losses for the California fishery (Collinsworth et. al. 1974). The validity of the pot loss data analysis was questioned by the Scientific Committee; however the three state agencies did agree on a compromise uniform season opening of December 15. This opening date was not implemented because fishermen in the southern areas opposed the later opening date because they believed it would be to their economic disadvantage.

Recommendations

More information is needed on relative economic efficiency of helicopters and large mobile vessels versus small vessels of limited mobility within the crab fishery. Economic data is also needed to evaluate the results of early entry into the crab market. Resolving the economic aspects of the lost pot issue would be helpful.

In part, solution of these problems lies in developing acceptable trade-offs between the three states involving biological, economic, and social issues.

INFORMATION ON HARVEST OF FEMALE CRABS

Under existing regulations female Dungeness crabs may not be taken for commercial purposes. The question of harvesting female crabs is largely based on the premise that female crabs may be a latent resource, or that the selective harvest of males only may be creating a sex ratio imbalance that is deleterious to the crab population.

Review

A thorough discussion on the advisability of harvesting female crabs is contained in the Phase I Completion Report of the State/Federal Dungeness Crab Fisheries Management Program (Collinsworth et. al. 1974). Based on sex ratio, size frequency, and fertility data as well as discussions with fishermen and processors, the findings were as follows:

1. Meat yield for female crabs averaged 15.9 percent and ranged from 12 to 17 percent. Yield was 49 percent less than for males.

2. Processor production rates are substantially lower for female crabs. Processors claim their pickers cannot "shake" crabs fast enough to make wages.

3. Processors, their employees, and fishermen are almost unanimously opposed to harvest of female crabs.

4. Most, if not nearly all, female crabs 159 mm (6¼ inches) and larger are not barren and, therefore, are not a 'latent' resource of no reproductive value.

Recommendations

The desirability of harvesting female crabs is highly questionable at this time. However, if the matter is to be pursued further, the following factors should be investigated.

Sex Ratio of Adult Crabs. Sex ratios derived from crab catches reflect sex ratios of crab susceptible to the gear and not necessarily of the population. Sex ratios of juvenile crab indicate a 1:1 ratio; however, trap and trawl catches contain a much higher proportion of adult males. Since only males are landed in the commercial fishery, a high proportion of female crabs in the population would normally be expected. The question then is, where are the females and why aren't they caught? If there is a significant population of adult female crabs on the fishing grounds, these crabs may be competing with and/or preying on juvenile crabs, thus significantly lowering the survival rate of juvenile crabs.

Growth Rates and Sexual Maturity of Female Crabs. Age and size of maturity and growth rate data are inadequate to evaluate possible regulations for harvesting female crabs. A summary of data on the size of female crabs at sexual maturity given in the Size at Sexual Maturity subsection of this report's Discussion section indicates that females mature at a smaller size than do males. Since females do not attain the size of males and size at maturity is smaller than for males, the biological reasoning for setting a 6¼-inch size limit for males would not apply to female crabs.

Female Crab Handling and Holding Mortality. An evaluation of the mortality due to handling and holding prior to processing should be conducted in order to determine whether or not this would create a significant wastage of the resource. Observations indicate that female crabs suffer a higher handling and holding mortality than do males (Collinsworth et. al. 1974).

POPULATION DENSITY

Population density factors and how they may affect crab condition, distribution, mortality and abundance are not well understood. Density dependent factors may play an important role in the large periodic fluctuations in abundance of crab.

Review

Crab Condition and Abundance Levels. The condition data compiled by Stewart (1973) indicate there may be a relationship between the condition of crabs at the beginning of the season and the population level as measured by total crab landings. It appears in some areas that the abundance level of legal sized male crabs is correlated with poor condition of crabs at the opening of the crab season (December 1). This relationship appears to be most prominent in the Washington coastal fishery and to exist in some years in the Oregon coastal fishery. The condition data for California is sketchy, but it appears that the condition of crabs in California waters fluctuates less than in Washington and Oregon.

Inshore-Offshore Distribution. Inshore-offshore distribution of crab stocks may also be affected by density levels. Data bearing on this subject are lacking, but discussions with commercial fishermen on where they find crab indicate that during periods of high abundance levels there appear to be greater numbers of crab found in deeper waters. This subject is also touched on in the migration and movement discussion of this report.

Effect of Crab Abundance on Survival. Intraspecific competition within crab populations may play an important role on mortality of juvenile and adult crabs. Winnor (1966) in discussing population fluctuations of crabs in the San Francisco area has suggested that during years of high abundance the presence of large numbers of adult female crabs may affect the survival of juveniles. Winnor's reasoning is as follows:

> *Basic in any stock-recruitment relationship (i.e., the comparison of spawning year class with their offspring year class) is the fact that even an unfished population is limited in size by the natural controls of the environment. The immediate mechanism of these natural controls commonly involves competition; competition includes any mortality-causing factor of the physical or biological environment whose effectiveness increases with stock density. It can be taken as a general rule that competition favors the larger adult members of a population over the smaller and more vulnerable juveniles.*
>
> *The crabs inhabit the limited areas of sandy bottom and competition is keen at all stages of development. They are voracious feeders and will eat most anything including each other. This cannibalism like any other form of competition, favors the larger adults over the smaller juveniles. Fortunately, the fishermen remove a large portion of the adult males each year before the first post-larval instar settle to the bottom. The females being protected by the present regulations, are not removed and the juveniles must compete with these adult females. In the years of good crab catch there are more females (the sex ratio is approximately 1:1 for all instars, R. L. Poole, personal conversation) that the juveniles must compete with, and their survival is lowered.*

Lough (1975) stated that it seems unlikely the adults could catch the small recruits as Winnor presumes or that the new recruits and the adult spawning year class are in direct competition for food. However, he feels there may be direct competition among older year classes if food is limiting.

The effects of adult density on juvenile survival have not been documented. However, if large numbers of adult females significantly affect juvenile survival as Winnor suggests then consideration should be given to harvesting a portion of the female population.

Survival of incoming year classes may also be affected adversely by high abundance of adult crabs either by predation or by competition for food.

Recommendations

Efforts should be continued and improved to evaluate relationships between adult crab abundance and crab condition, mortality, and distribution. This type of information could lead to better utilization of the resource and to the possibility of dampening the abundance cycle of crab production.

ASSESSMENT OF CATCH PER UNIT OF EFFORT DATA

The lack of a good measure of effort is a major obstacle in the development of fishery based population dynamics information. This lack of data seriously hindered the efforts of the State/Federal Dungeness Crab Study Team to evaluate the relationship between effort and yield in the development of an effort management program. At present the only effort data available for the entire coast are the number of boats, number of pots, and number of deliveries. Catch-per-unit-of-effort data (CPUE) based on fishermen interviews exist for a 12-year period in California and for a shorter period in Washington.

Review

Number of Boats. The number of boats are available from landing records and boat registrations and should be an accurate accounting. However, the CPUE data based on number of boats are of very limited use in the development of population dynamics information.

Number of Pots. The numbers of pots are estimated by the states based on fishermen interviews. There is no uniform routine for collecting this information; however, agency biologists feel that the estimates are reasonably accurate. These estimates are the number of pots the fishermen expect to fish that season and are not necessarily the number of pots that actually were fished. The major weaknesses in the data are: (1) there is no indication of the distribution of effort throughout the season, (2) the number of pot lifts is not known, and (3) effort per unit of time is not known.

Number of Deliveries. The number of deliveries made by each boat can be derived from landing receipts. A delivery usually represents one fishing trip, and as such is a rough unit of effort except in cases where the catch is accumulated in live boxes prior to delivery, or when a fisherman delivers one trip's catch to more than one buyer. Also the number of days fished per trip vary.

Landings can be grouped by day, month, or season. California biologists are looking at boat-days as a unit of effort; however, the data appear to be of questionable value. Shortcomings of the data include: (1) time of soak unknown, (2) number of pots unknown, and (3) it is not known whether or not the boats are on delivery limits imposed by the buyer.

Fishermen Interviews. Fishermen interviews have been conducted during the first week of the crab season in California to obtain CPUE data for use in predicting the season's landings. Interview data (CPUE) from northern California have been collected throughout the season since 1965 and have been used to develop population dynamics information (see section on Stock Assessment). Information collected includes area and depth fished, pots pulled, time of soak, and pounds landed. The interviews were done on an opportunistic basis and the sample averaged about 25 percent of the total effort in Eureka and about 40 percent in Crescent City. To date this is the best fishery-based CPUE data available.

Voluntary Logbooks. A voluntary daily logbook system was initiated in Oregon in 1977. Information includes date, area and depth fished, soak time, number of pots pulled and number lost, pounds landed, and price. The system has not yet been evaluated, but if successful, this will provide excellent fishery data on those vessels participating in the program.

Recommendations

The State/Federal Dungeness Crab Study Team (Collinsworth et. al. 1976) felt that the number of pot lifts in a season would be a realistic measure of effort. However, no direct measure of pot lifts was available.

There are basically three data sources for acquiring pot lift data. They are: (1) revised landing receipts, (2) logbooks, and (3) fishermen interviews. One or a combination of these methods should be instituted to collect effort data.

Landing Receipts. The most straight-forward way of acquiring pot lift data is to require that the number of pots pulled be recorded on the landing receipt. Area fished is required on California landing receipts and it would be no more difficult to require that the number of pots pulled also be included, and possibly length of time fished. However, this would require full cooperation with the fishermen and the buyers and constant surveillance by the managing agencies. Additionally, statutory changes would need to be enacted in Washington.

Logbooks. Logbooks are in use in some other fisheries and can be either mandatory or voluntary; however, experience has shown that voluntary logs are often biased. Accurate logs can provide excellent data on not only CPUE, but also area and depth fished, gear lost, weather and oceanic conditions, and crab condition. A mandatory logbook system for the crab fishery would require an expensive program to edit logs, process data, and enforce compliance and would probably be unpopular with many fishermen. However, mandatory logbooks are now required in some other fisheries and the programs have been quite successful in acquiring good CPUE data.

Fishermen Interviews. Interview data can be a very effective way of obtaining effort data. An added bonus is that the personnel engaged in the interviews may also have the opportunity to collect some biological data. Also, personal contact with the fishermen may result in better rapport with fishermen and dealers.

When compared with the costs of instituting logbook systems, California biologists feel that interviewers could probably acquire catch-effort data more efficiently and cheaper. However, because of logistic problems brought about by the existence of more landing ports in Oregon and Washington, biologists from those states feel that fishermen interviews would not be an effective way of collecting CPUE data. Interviews should be done on a statistically random basis for all ports and dealers throughout the season. A sufficient sample would probably be around 25 percent of the total effort.

STATISTICS AND HISTORICAL DATA

Statistical information needs change in response to new developments and management policies. Considerable improvement in statistical data has resulted with increased use of ADP equipment for fishery management and planning decisions.

Statistical data is a major limitation relative to the Dungeness crab fishery. The reliability of historical data relative to landing and fishing effort has been questionable and current data on potential and actual fishing effort is limited. Lack of adequate data in some cases is due to inadequate or excessively expensive procedures to obtain data. Lack of adequate historical data on stock size, fishing effort and similar factors seriously limits the reliability of estimation of net gains from changing management policies.

Review

A coastwide data system is currently being developed through a cooperative State/Federal effort. The purpose of this project is to provide more complete data and to develop procedures to provide information that is consistent and can be combined by State and Federal agencies where coastwide (or regional) data is needed for fisheries management. A trial coastwide data system for developing Dungeness crab data was developed through a subcontract to Sea Scan International, Inc. This produced data related to fishermen's opportunity costs including revenue per delivery by species and boat length for those boats landing crab during the 1971-72, 1972-73 and 1974-75 seasons.

Williams and Richards (unpublished) provide the following additional information relative to statistical data:

1. Current expenditures to provide statistical data.

2. Improvements needed and estimated costs to provide adequate statistical data for fisheries management.

3. Added cost specifically associated with fisheries management to control fishing effort.

The views of the fishery administrators in areas where effort control programs have been implemented were summarized by Williams and Richards. It was agreed generally that a good statistical base is necessary for appropriate fishery management discussions even if policies are not intended to control fishing effort.

Recommendations

High priority should be given to improving statistical information pertaining to biological, economic and social factors. Improved information will benefit decision making regardless of the objectives of management policies.

STOCK ASSESSMENT

A number of techniques have been used to predict legal crab abundance and to forecast landings with varying degrees of success. Winnor (1966) concluded that sea surface temperature during the crab's larval period could be used to predict future landings off central California. Unfortunately, his work could not be evaluated because of the collapse of the crab fishery in that region. Lough (1975) stated that by using climatological data, crab landings could be predicted four years in advance. Thus far, his predictions have exceeded actual harvest by a factor of 2 to 5 times.

The most promising methods for crab abundance prediction are those based on preseason cruises (Heimann, personal communication), CPUE studies based on fishermen interviews (Gotshall, in press [a]), and the ratios of sublegal to legal crab (Stefferud 1975).

Review

Preseason Cruises. The California Department of Fish and Game conducted preseason pot and trawl cruises in central California (San Francisco area) and northern California (Eureka-Crescent City area) from 1963 to 1975. These surveys have been discontinued following the sale of the research vessel NB Scofield. Survey procedures were not standardized in early years, but recent surveys have utilized a standardized sampling plan for trawls and crab pot sets along predetermined transects.

Heimann (personal communication) fitted a weighted least square regression to Eureka and San Francisco pot catch data and calculated 90 percent confidence limits. The catch estimate for the 1975-76 season in Eureka was 15.2 million lbs.; the 90 percent confidence limits ranged from 18.2 million lbs. to 6.6 million lbs. Actual landings were approximately 17 million lbs. However, the 17 million lb. landing may not accurately indicate the relative abundance of crabs since considerably more could have been landed had there been greater market demand. Also, a substantial but unknown amount of California-caught crab was landed in southern Oregon ports.

Eureka preseason data were plotted against Oregon and Washington data. The plots show promise; however, further data and analysis are needed.

Fishermen Interviews. Fishermen interviews have been conducted during the first week of the crab season at San Francisco for 12 years and at Eureka and Crescent City for 11 years to gather CPUE data (lbs. of legal crab per pot pull) during the first week of the fishery. The CPUE is used to predict the season's landings based upon the relationship between first-week CPUE and season's landings based upon the relationship between first-week CPUE and season landings in past years. Although a mathematical relationship has not been worked out, California biologists feel that this provides a good indication of what the season landing will be. The relationship between first-week CPUE and season landings will be studied further and will be used to predict landings in lieu of preseason surveys.

Gotshall (in press [a]) used crab fishermen interviews throughout the season in northern California to determine CPUE. The data were used to estimate the abundance of legal sized crabs with 95 percent confidence limits and to estimate mortality rates. Population estimates for northern California ranged from 2.4 to 16.7 million lbs. during 1966-67 to 1971-72 with harvest rates ranging from 63.2 to 87.3 percent.

Sublegal to Legal Crab Ratios. Stefferud (1975) worked on the hypothesis that the ratio of sublegal males to legal males caught in small mesh crab traps without escape ports was equal to the ratio of the crab harvest the following season to the crab harvest of the current season. This method of prediction fairly accurately estimated season landings at Newport but vastly underestimated season landings at Astoria. The Newport and Astoria predictions were used to project total Oregon landings. Actual harvest for the 1973-74 and 1974-75 seasons were respectively 10.3 and 22 percent above predicted harvests.

The main problems encountered with this method were: 1) crabs tend to segregate by sex and size, and 2) fishing effort is unevenly distributed throughout the fishing area. Because of these problems, the experimental ratios are not entirely reflective of the total population. Also, the formula used to predict landings lacks sophistication and should be modified as more data are collected.

Recommendations

There is no need for additional preseason crab abundance data under the present Dungeness crab management programs. However, management programs based on quotas and/or allocations between different user groups will require better information on the distribution and abundance of Dungeness crabs than is now available. Also, assessment of M.S.Y. and O.Y. under P.L. 94-265 would require better stock assessment than is presently done.

The three methods reviewed here do not give total population, but are used either to predict season landings based on past performances or to estimate the legal population after the season is over. All three methods show promise and should be pursued further. It may be found that a combination of preseason surveys, the Stefferud technique, and CPUE studies will produce reliable preseason estimates of season crab landings.

Modeling of the fishery to determine population is thwarted by our inability to accurately age crab and would require the capability to sample the total population so that relative strengths of year-classes can be made. Therefore it is not recommended that modeling of the fishery be pursued.

INTERFISHERY CONFLICTS

There are basically two causes of conflicts between crab fishermen and other fishermen. These are: (1) gear conflicts, and (2) incidental catch and damage of crab by trawlers.

Gear conflicts are, for the most part, a minor problem between crabbers and trawlers, salmon trollers and salmon gillnetters. Conflicts occur when crab pots are fished in areas where trawl, troll, or gillnet fisheries are occurring, resulting in lost and/or fouled fishing gear.

Incidental catch and damage of crab by trawlers occurs when trawlers fish in areas where crab are present. The potential for trawl damage to crabs, particularly to softshell crabs, ovigerous females, and juveniles, is considerable but the extent of the damage is unknown. In California, trawling is prohibited within three miles off the shore in most areas. This closed area is largely for the purpose of limiting trawl damage to crabs as well as to decrease gear conflicts between crab fishermen and trawlers.

Review

Gear Conflict. No studies have been conducted on the extent and nature of gear conflicts in California; however, conflicts have occurred on different occasions and meetings have been held with fishermen in an attempt to solve the problem. Gear conflicts with trawlers are most likely to occur during the beginning of the crab season when the crab fishery starts out in deeper water. However, since the crab fishery is rarely beyond 30 fm. depth, and since California law prohibits trawling inside three miles in most areas, the conflict is minor. There are rarely any fishery conflicts during the winter since trawling is in deeper water and salmon season is closed. Conflict with salmon trollers occurs in spring and early summer and is most serious in years when significant crab fishing activity continues beyond spring. However, crab fishing effort is usually at a low level when salmon season opens. Conflict with the trawl fishery is insignificant during spring and early summer since the crab fishery is in shallow water well inside three miles.

No studies have been conducted in Oregon on the extent of the problem; however, the conflict is judged to be minor. The seasonal pattern of the conflict is the same as that found in California. Oregon does not have a three-mile trawling closure, but this has not significantly added to the gear conflicts. Most conflicts with trawlers and trollers have occurred in the Columbia River area.

No studies have been conducted on gear conflicts in Washington and the problem does not appear to be significant. As in Oregon and California, the problem is seasonal and occurs mainly during late summer when crab fishing coincides with salmon trolling, and gillnetting. Washington does not have a three-mile trawl closure but most trawling is done offshore in deep water so there is little conflict with trawlers.

Incidental Catch and Damage of Crabs by Trawlers. A review of the problem is given in the Phase I Completion Report (Collinsworth et. al. 1974). Reviewed in the report were studies by Cleaver in Puget Sound during the 1940's in depths ranging from 5 to 60 fathoms, a 1947-48 study by the Fish Commission of Oregon (Anonymous 1949) in depths from 20 to 80 fathoms off Astoria, and Washington Department of Fisheries observations made in 1970-71 in the Strait of Georgia. In all, 1,925 crabs were observed. These studies indicate that perhaps 4 to 5 percent of the crabs caught by trawl boats are injured and/or killed. Oregon is conducting a short-term study of 1976 trawl logbook data to pinpoint areas of potential conflict but results are not yet available.

Observations were made in 1975-76 to determine the incidental catch and mortality of Dungeness crabs by groundfish trawls in Skagit Bay, Washington (Washington Department of Fisheries, unpublished). A total of 1,445 crabs were taken in four tows on three different days. The ratio of male to female crabs examined was 2:3; "observed" mortality for all male crabs was 5.6 percent; "observed" mortality for softshell male crabs was 12.0 percent.

Actual crab mortality may be somewhat higher than these values indicate. Coastal crab studies have shown that handling softshell crabs under ideal conditions can result in from 15 to 20 percent mortality. These studies have also shown that as high as 57 percent mortality can result from softshell crabs being dropped on the deck of a vessel. Since this procedure does resemble the release of a bottomfish haul on deck, it is safe to assume actual softshell crab mortality by trawl is substantially higher than that observed.

Recommendations

Gear Conflicts. Because of the infrequency of gear conflicts under normal conditions, there is no real need for additional information to manage under extended jurisdiction. If certain areas have recurring conflicts, these areas might warrant special studies.

Incidental Catch and Damage of Crabs by Trawlers. To manage under the concept of optimal yield, any wastage of the resource due to fishing practices should be evaluated and dealt with. An adequate assessment of the affects of trawling on Dungeness crab will require the following data:

1. Estimated total crab catch by trawl boats by season and area.

2. Distribution patterns of crabs (including softshells, ovigerous females, and nursery areas) and location of major trawl fishing areas should be examined to determine the extent trawling takes place on important crab areas.

SAVINGS GEAR

There are two types of savings gear that are applicable to the Dungeness crab fishery. These are escape rings and destruct devices.

Escape rings are required in Washington, Oregon and California to allow for the escapement of small crabs. Benefits from escape rings include: (1) handling mortality to sublegal males and females is reduced; (2) injury to small crabs resulting from fighting is reduced; (3) loss from cannibalism is reduced; (4) sublegal crabs are able to escape from lost pots; and (5) less time is required for the fishermen to sort the catch. California now has a 4¼-inch escape ring requirement while Oregon now requires 4-3/8-inch rings. Washington will require 4-3/8-inch escape rings in 1979, and now requires a 4-1/8-inch escape ring.

Another form of savings gear being considered are destruct devices that will permit the escapement of crabs from lost pots after a period of time. Field observations indicate that lost pots will continue to fish for crab, but the magnitude of crab loss is not known. However, it is known that pot loss is significantly high and therefore crab loss from lost pots could be quite substantial. The use of a device that would allow crabs to escape from lost pots would eliminate much of this loss of resource.

Review

Escape Rings. A thorough discussion of escape rings is given in Section VI of the Phase I Completion Report. The following information except where noted is taken from that report.

Length-Width Measurements. The smallest opening through which a crab can crawl is about equal to its length, which is the smallest dimension of a crab. Measurements of 2,814 male crabs (1,814 California, 1,000 Oregon) showed that a 6¼-inches male crab has a length very close to 4-3/8 inches (Dahlstrom 1975; Jow 1961). Measurements of 436 female crabs in California showed that female crabs are proportionally longer.

Oregon data were presented as a scatter diagram with a line fitted to the points by eye. No mathematical expression for the relationship was given; however, the fitted line closely matched that calculated for California.

Length-width measurements were taken for 297 male Dungeness crabs ranging in width from 150mm to 169mm taken in the ocean near Willapa Harbor, Washington (Washington Department of Fisheries, unpublished).[2/] Although a mathematical relationship was not calculated, visual examination of the data indicates that the linear regression closely approximates that observed for California crabs. However, there was much greater scatter in the data points than found in California length-width data.

Escape Opening Experiments. Jow (1961) presented data from several experiments done in California between 1955 and 1959. Comparisons were made with pots with no openings, two 4-inch ports, or two 4¼-inch ports; pots with one 4-inch, one 4¼-inch, or one 4½-inch port; and pots with one 4-inch, two 4-inch, two 4¼-inch, or two 4½-inch escape ports.

In Washington, theoretical escapement through 4, 4¼, 4-3/8, and 4½-inch diameter escape ports was calculated based on the length-width measurements, and it was found that 4¼-inch ports would theoretically retain all male crabs 159mm (6¼ inches) and larger, whereas 4-3/8-inch ports would theoretically allow some crabs as large as 165mm (6½ inches) to escape (Washington Department of Fisheries, unpublished).[2/]

The summary of findings is as follows:

1. Male crabs of 6¼-inch width have a length close to 4-3/8 inches.

2. Pots with escape ports of 4, 4¼, and 4½ inches in diameter will catch approximately the same number of legal crabs in California.

3. The larger the escape opening, the more efficient the release of sublegal male and female crabs is.

4. In actual fishing operations some legal crabs may escape through an escape port of 4-3/8 inches in California and Oregon.

---

[2]Not contained in Phase I Completion Report.

5. Preliminary data indicate that there may be some loss of legal crabs through escape rings of 4-3/8 inches in certain areas off Washington.

Destruct Device. Information on the loss of Dungeness crab due to lost pots was first reviewed by the State/Federal Dungeness Crab Program Study Team and Scientific Committee and was presented in the request for proposal for development of an escape mechanism (destruct device) for Dungeness crab pots. This same information is included in the report "Discussion on Crab Mortality Associated with Certain Fishery Practices" by Stewart (1976), prepared for the State/Federal Dungeness Crab Management Program.

Extent of Gear Loss. It has been estimated that an average of 10 percent of crab pots may be lost each year; however, Tegelberg (1974) estimated that 23 percent (9,545 pots) were lost or destroyed off Washington during the 1973-74 season.

Extent of Crabs Lost. Demory (1971) reported that of 140 pots found abandoned in Oregon in 1970, 117 were retrieved containing 3,629 crabs (91 percent legal males, 6 percent sublegal males, 2 percent females, 1 percent dead). Dahlstrom reported in 1975 that nine pots were recovered after being lost from three months to four to five years. Two pots believed out four to five years were badly corroded and unfishable. The remaining pots contained 90 live crabs of which 73 were legal males. Most (83 percent) crabs had heavy carapace pitting, presumably resulting from long confinement. Empty carapaces and cannibalized crabs were also found.

High (1976) conducted four experiments to determine whether Dungeness crab could escape from standard pots. Pots having closed escape rings and with functional triggers allowed escapement of 21 percent of the large and 67 percent of the small crabs after 74 days. Study results indicate that (1) escapement was directly related to the availability of escape openings and (2) triggers are an effective means for reducing escapement.

Development of Destruct Devices. Odemar et. al. (1975) present results from tests designed to develop a suitable material for use in a destruct device for lobster traps. Laboratory tests of material were made for five types of aluminum wire and rod, three diameters of steel wire, and three degradable plastics. They were looking for a material that would last from four to six weeks.

Aluminum wire and welding rod lasted 29 to 58 days; 28 gauge steel wire failed after 48 days (heavier wire had not parted after 79 days); and the degradable plastic 50/50 Copolymer/DL-Lactide parted after 36 days. All other materials tested were intact after the 79-day test period.

Subsequent testing of aluminum wire under fishing conditions resulted in the wire disintegrating after three days, or lasting as long as three months, depending on whether or not the traps were treated to inhibit electrolysis.

The California Department of Fish and Game now requires that on crab traps used south of Point Conception one of the following destruct devices be used[3/]: (1) 24 gauge (.028 inch) bare metal clamps ("J" clamps or cage clamps) to hold panels of traps together; or (2) panels be held together by cotton twine, 21 thread or less.

Humboldt State University is presently conducting a Sea Grant-funded study to develop a destruct device for Dungeness crab pots. One device they are testing consists of two plastic bars approximately three inches long riveted together with a bimetallic rivet. Two bars riveted together would be used to block an escape opening large enough to allow all crabs to escape. When the rivet corrods through, the two bars would swing free, thus creating an escape opening. They are also testing a plastic/bimetallic device to be used as a lid latch.

The devices are being designed so that the length of time the device would hold could be varied by the choice of material used. Results of the research is expected to be available in late 1977.

Recommendations

Escape Rings. No fishing tests have been made with escape rings of 4-3/8-inch diameter. However, crab measurements and fishing experiments strongly support the use of 4-3/8-inch escape rings in California and Oregon. Washington observations indicate that Dungeness crab in some areas off Washington may be proportionally shorter than those in other areas of the west coast. It may,

---

[3]Crab and lobster traps used in southern California are constructed of 2 X 4-inch steel wire mesh and the crab fishery is for cancer crab species other than Dungeness crabs.

therefore, be appropriate to vary the size of escape rings by region. Actual fishing tests with 4-3/8-inch escape rings should be conducted to determine the relative effectiveness of 4¼ and 4-3/8-inch escape rings and to determine the magnitude of resource savings that could be realized by going from 4¼ to 4-3/8-inch escape rings. Such tests may be necessary to convince fishermen of the need for 4-3/8-inch rings.

Destruct Device. Additional information on the number of traps fished and the number lost would allow for a better assessment of the magnitude of the problem of lost pots. Additional work on the development of a destruct device should be delayed until after the results of Humboldt State University's work are available.

RECREATIONAL FISHING

The Phase I Completion Report contains a section on recreational crab fishing in California, Oregon and Washington. Additional information on the California recreational fishing is given by Gotshall (in press [b]). For the most part, the recreational harvest takes place in bays and estuaries and accounts for roughly one percent of the total commercial take.

Review

Washington. Crabbing along the Washington coast is primarily limited to Willapa Bay, Grays Harbor, and ocean beaches north of the Columbia River and at Kalaloch. Peak utilization was estimated at less than 60 people in Willapa Bay and less than 50 people per day along ocean beaches. Even though catch statistics are not available, the Washington coast recreational fishery is considered minor compared to the Puget Sound recreational fishery and probably accounts for no more than one percent of the annual coastal commercial harvest in Washington.

Oregon. Most recreational fishing occurs within the 16 principal estuaries in Oregon and relatively little crabbing is done along ocean beaches.

A 1971 survey of 16 Oregon estuaries estimated that from March 1 through October 31 nearly 190,000 legal male crabs were taken from 15 estuaries. This take exceeded the commercial take from estuaries during the entire season by 80,000 crabs; however, the recreational take was only one percent of the total ocean and bay commercial landings for the 1970-71 season.

California. The California recreational fishery takes place in Monterey Bay, San Francisco Bay, Humboldt Bay, Crescent City Harbor and in the ocean off Bodega Bay and Trinidad.

Gotshall (in press [b]) gives estimates for recreational catch and effort for Humboldt Bay for 1964-65 and Crescent City Harbor during the 1965-66, 1966-67, 1967-68 seasons. The estimated recreational catch amounted to 0.08 to 0.4 percent of the commercial take during the study. No other data are available.

Recommendations

Data are not available to fully assess the magnitude of the recreational fishery on the resource. However, since all available information indicates that the recreational take is no more than one percent of the total crab landings, immediate further assessment of the recreational fishery is considered presently unnecessary.

MIGRATION AND MOVEMENT

An understanding of the migration and movement patterns of the Dungeness crab is necessary to evaluate the potential impact of management options on the different crab fisheries. The contribution to the fishery by the different segments of the resource found in shallow or deep water as well as the movement patterns of crabs along the coast need to be considered in developing management plans. Also movement and migration patterns bear on determination of unit stocks and therefore on management planning.

Review

Stewart (1974) has reviewed the published information on movements of tagged Dungeness crabs along the Pacific coast from British Columbia to California. In nine separate studies more than 28,000 crabs have been tagged and released in ocean and bay waters. Of these more than 7,000 crabs were recovered that provided useable information on movements. Stewart gave a general summary of the results of these studies summarized as follows:

1. There is no definite pattern to coastal movement of crabs. In some local areas there has been a tendency for tagged crabs to move predominately in one direction but on a coastwide basis it appears movements are more random in nature.

2. Crabs do not move in any significant number between major fishing areas. Tagged crabs have traveled distances of more than 100 miles, but most recoveries have been made within a few miles of the release site.

3. There appears to be some onshore-offshore movement, with crabs tending to move inshore in the spring and summer and offshore in the fall and winter. However, it is not clear what percentage of the population may move or how extensive this movement may be coastwide.

4. Crabs move in and out of bays and in some cases from bay to bay, but the rate at which this interchange occurs is not known.

5. Crabs tend to move freely between the waters of each state in the California-Oregon border area and the Oregon-Washington border area, indicating a single population occurs in each area.

6. Data are not available to evaluate movement patterns of crabs found in deep water (50 fathoms or more).

Recommendations

Available data on movements of Dungeness crabs appear to be adequate for present policies. Additional information on onshore-offshore migrations and how they may vary with abundance level would be useful to evaluate such questions as whether a delay in the season opening would result in a greater pot loss as has been suggested by the State/Federal Dungeness Crab Study Team in their Phase I Completion Report (Collinsworth et. al. 1974).

MARKET CHARACTERISTICS

An adequate understanding of market characteristics is necessary to evaluate changes in management policies that increase the quality or quantity of product available, impact on geographic areas or sectors of the fishing industry, and to evaluate the effectiveness of the market system at all levels in achieving the desired resource allocation.

Information is needed regarding factors affecting price-quantity relationships. Future product demand also needs to be projected. These projections require information relating to the influence of competing products such as other species of crabs, production of Dungeness crab in other areas such as Alaska, and information regarding consumers tastes, incomes, and population changes. It may also be necessary to identify demand factors for specific types of Dungeness crab products.

If the supply of Dungeness crab is determined only by availability of stocks, then market information is not essential to predicting production. However, there is substantial disagreement about the level of harvest and to the extent that the annual catch is influenced by market prices, then market information is essential to predicting the impact of policy changes on total production.

Review

Existing market information is adequate only relative to general conditions. The importance of competing products (e.g. Tanner crab), competing geographical areas (e.g. Alaska), or importance of changing income levels and similar factors are not adequate. The relationship of price changes to annual variation in catch levels needs further study. Not enough information is available concerning market characteristics such as types of market outlets or the geographical or other factors influencing the use of this product.

Existing marketing information also is inadequate to explain ex-vessel price determination, the importance of the "Christmas" market, or to predict future market characteristics and price levels.

Much of the available information regarding marketing characteristics is related to specific areas, outdated, or inadequate. Wix (1967) made the following observations regarding the market for Dungeness crab:

1. A stable demand for Dungeness crab existed from 1956 through 1965 that may be attributed to the relationship with king crab that existed at that time (i.e. expansion of king crab production probably restricted interest in Dungeness crab).

2. Dungeness crab probably benefited from the markets created by king crab.

3. The demand for crab may tend to be responsive to promotional activities.

4. Over 67 percent of Oregon's Dungeness crab is sold in California markets.

Lewis (1973) estimated . . ."the price elasticity of current demand for Oregon Dungeness crab computed at the mean annual yield of 8.5 million pounds is -0.5" . . . (i.e. an increase of 1 percent in the total quantity of crab landed will cause price to decrease by 0.5 percent). Lewis estimated that the maximum revenue for the Oregon fishery was reached at 12.6 million pounds and that effort levels were not useful above this maximum amount based on the situation during the 1970-71 season.

Collinsworth et. al. (1974) estimated net gains from season changes associated with meat yields and pot loss. They also considered handling mortality, opportunity costs and market demand although no values were estimated for these factors. It was pointed out that some processors believed the "Christmas" market to be very important while others disagreed and almost totally discounted this factor.

Erickson (1975) developed a description of the market structure that prevailed at selected Washington ports and assessed the impact of effort control on this market structure. He also considered the relationship between Dungeness crab fishing and processing and that of other fisheries. He concluded that the principle variables affecting Oregon prices were prices in Washington and California and purchasing power in California and the U.S.

Erickson (1975) concluded that ex-vessel prices for Washington and Oregon are usually derived from California markets. Other things being equal, an increase in landings in California by one million pounds causes the price there to drop by 0.34¢ per pound in that year. For every 1¢ increase in California prices the price in Oregon will be higher by 0.87¢ and the price in Washington by 0.37¢. Landings in Alaska have an important negative impact on the price in Washington.

Collinsworth et. al (1976) considered the ex-vessel market demand curve for Dungeness crab. Their work was based on secondary data sources. They assumed that a constant difference between ex-vessel and consumer level demand will exist over time and estimated the demand relationship at the ex-vessel level only. A linear demand function was estimated. This was estimated by regressing the 3-state weighted average real ex-vessel price of Dungeness crab against the per capita catch from the three states, the Alaskan catch of Dungeness crab, the Alaskan catch of king crab, and the Alaskan catch of snow crab.

Recommendations

The information available on market demand needs to be improved for fishery management decisions even though the major variables seem to be identified and their general importance is indicated. More precise data would be useful particularly to estimate the magnitude of benefits with potential changes in management policies. The importance of the California market in determining prices in Washington and Oregon, demand for specific crab products, and additional information to improve industry marketing decisions is needed. An assessment of future demand conditions is needed to meet the data requirements associated with extended jurisdiction.

Adequate demand information also is needed if fishing effort is controlled, in order to estimate potential net benefits. An adequate understanding of market conditions also is needed to estimate the effect on total revenue if some of the available stocks are not harvested during years of abundant stocks. This is interrelated, however, with information needs regarding natural mortality, social characteristics, relationship to other fisheries, and impact on consumers. This type of management might reduce cyclical production patterns and could conceivably benefit both producers and consumers.

Information also is inadequate regarding market forces that determine ex-vessel prices and the relationship of these prices to changes at wholesale and consumer market levels. Price changes at the consumer or wholesale level may not be reflected adequately in ex-vessel prices due to market imperfections.

Additional study of characteristics related to market structure and the effectiveness of market prices in providing appropriate resource allocation decisions and research to identify factors affecting product demand are the most critical areas where additional information is needed.

SOCIAL CHARACTERISTICS

The nature of information relating to social characteristics required by the concept of fishery management for optimum yield has not been fully developed and information requirements will likely change as this evolves. It is not even clear what type of social characteristics managers will want to include.

Liao and Stevens (1975a) found that the relationships between profit and the sociological variables that they considered were not statistically significant for either crab or noncrab fishing enterprises. The sociological factors they considered were years in commercial fishing, years as skipper, age of skipper and years of formal education.

Social issues that seem likely to be of major importance include total and seasonal employment opportunities, shifts in income between industry sectors and geographic areas, impact of changes in the local and regional economic base, and social changes that are interrelated with changes in the economic base. Due to the seasonal nature and apparent lack of good employment alternatives for many

resources used in the Dungeness crab fishery the net gain from some management alternatives may be seriously reduced. Since much of the catch in this fishery usually occurs during a few weeks in the winter there may be little net gain if effort is controlled by regulations unless alternative types of employment exist for resources used for processing and fishing. This depends on whether total fishing effort would be reduced over time if availability of Dungeness crab fishing is restricted or if programs to restrict effort simply result in greater seasonal unemployment.

The State/Federal Dungeness Crab Study Team considered social issues in general, but neither adequate information nor adequate guidelines indicating the type of social characteristics were available for fishery management decisions.

Review

More precise guidelines are needed to indicate:

1. The type of social information that should be included in fishery management decisions.

2. Procedures to provide this information in a useable form since it may not be possible to express all factors in quantitative or dollar terms.

3. Type of management information system that will provide maximum information to a complex group decision making procedure with highly divergent interests among the members of the decision making group.

Guidelines and procedures used in domestic water resource planning and management may provide a useful base for modification or expansion to develop evaluation guidelines and procedures. This seems to be the most critical and immediate requirement.

The relationship of social characteristics to nearly all other types of information requirements also is important, both in development of information and in its use. An interdisciplinary approach is probably essential to provide adequate information. Difficulty in identifying all factors and inability to quantify many important variables will require special consideration particularly with reference to the management information system that is used. Relating social conditions to fishery management decisions may tend to reflect value judgments of decision makers and add to the difficulty of reaching acceptable solutions.

Available information is inadequate to determine how management changes in the Dungeness crab fishery will affect the economic or social structure of local or regional communities.

Recommendations

The most pressing research need is development of guidelines indicating the type of information to be included, the type of management information system to be used (particularly with reference to nonquantifiable or only partially identified data) and recommended procedures for data development.

CONTRIBUTION TO ECONOMIC ACTIVITY

The importance of fishing activity to local and regional economic needs must be considered since many management decisions may affect the seasons or geographic areas where landings are made, labor or other resource use and similar factors.

Review

County studies relating fishing activities to local and regional (i.e. county) economic bases are available for Oregon (Oregon State University). Statewide studies are available for Washington (University of Washington), although information relating to the fishing sector is poorly identified in the Washington model. Research planned at Washington State University (by Professor Glen Petrie) will develop specific information relative to salmon fishing. The results of this research are expected to be available by about 1979. These studies are useful to indicate the general importance of fishing to local and regional economies, but do not provide information regarding the specific impact of the Dungeness crab fishery. Models indicating the contribution of different economic sectors to regional economic activity are available from the U.S. Department of Commerce (generally for metropolitan areas). Although these regional models aggregate fishing with agriculture and forestry some separation may be possible with special computer programs.

Although the above models provide some useful information indicating the contribution of fishing in general to economic activity, very little information is available indicating the specific economic contribution of Dungeness crab fishing.

Recommendations

Models are needed that indicate the contribution of Dungeness crab fishing to economic activity and employment, particularly for local areas. The impact of likely policy changes on economic activity including geographic areas, seasons and sectors of the fishing industry affected should be analyzed as completely as possible.

ALTERNATIVE USES FOR PRODUCTION RESOURCES

The value of resources used for fishing and processing if employed in producing an alternative product is a fundamental information requirement in evaluating benefits from fishery management based on effort control. Even with more traditional management procedures, this information is useful, since policy decisions often affect the type of resources used and their earnings (e.g. large compared to small vessels, mobility of fishing effort, concentration of landings, etc.)

Review

Erickson (1974) evaluated entry and exit response to changes expected in net revenue per unit of effort. Although all expected costs become implicitly related with this procedure, opportunity costs for other uses of resources employed in the crab fishery also are included by fishermen deciding to enter or exit from the crab fishery. A similar procedure was followed by Collinsworth et. al. (1976). These studies indicate how fishermen view earnings prospects in crab fishing compared to other fishing or nonfishing activities.

Liao and Stevens (1976a,b) evaluated the relationship between crab fishing and other fishing activities for the 1971 and 1972 seasons and provided general information relative to fishing and nonfishing opportunities. Some of the conclusions from this research were:

1. Salmon - tuna - crab fishermen received an average annual net return of $11,680 from crabbing and $4,096 from salmon and/or tuna fishing.

2. Physical characteristics of the vessel were significantly correlated with profits in noncrab enterprises. No correlations between profit from crabbing and physical characteristics of the boat were significant.

3. Specialized salmon fishermen who worked outside the fishery (85 percent of them) spent on the average about eleven months in nonfishery employment in 1972.

4. Only about 20 percent of the crab, drag and salmon-tuna/crab fishermen worked outside the fishery in addition to fishing.

Collinsworth (1976) provided information that is more specific relative to seasonal opportunities. Based on data generated by the coastwide data system contract he concluded that "for at least the first four months of the coastal crab season, given the current structure of the market, there are few fishing alternatives for the majority of the fishermen." In the short run, Collinsworth concluded "that the opportunity cost of fishing Dungeness crab prior to the opening of the salmon season is very nearly zero." However, this situation may not be true in the future if market demand conditions, fishing technology, or institutional conditions change.

Available information suggests that crab fishing is a major component of the total fishing activities of the firm (i.e. vessel owner) and competes favorably with both fishing and nonfishing opportunities as judged by entry into crab fishing. Although available knowledge is based on data that has important time and geographic area limitations and small sample size, it does suggest that the average crab fishing enterprise is important relative to the profit prospects for the fishing firm (i.e. all types of fishing).

Recommendations

Much more information is needed relative to the adequacy of nonfishing opportunities. More research is needed to determine the importance of the Dungeness crab fishing enterprise to the total earnings of the fishing firm (i.e. including all types of fishing activities). Averages may obscure the importance of crab fishing to many fishermen and the importance of crab fishing may vary substantially for different seasons.

INFORMATION NEEDED FOR EFFORT CONTROL

Prerequisite information for fishery effort management policies include: data concerning allocation of initial property rights, means to transfer or maintain property rights, and enforcement and administrative activities.

Review

Information is generally adequate relating to the theoretical justification for effort control and the nature of benefits expected with this type of fishery management. Christy (1973) has identified economic efficiency, biological effectiveness, equitable distribution of benefits and political feasibility as necessary criteria for evaluating alternative effort management programs. Erickson (1974) provides a good review of the literature dealing with this topic, and a bibliography of relevant literature was prepared by the State/Federal Dungeness Crab Study Team. The Study Team also described the potential usefulness of each kind of effort control as it might be applied to the Dungeness crab fishery.

Lewis (1973) surveyed Oregon crab fishermen to determine their interest in effort management programs. This involved a mail questionnaire to which he estimates that 79 percent of the crab vessel owners responded. Of these respondents, 89 percent believed that too much gear was fished in Oregon during the 1971-72 season and 85 percent said that some program should be implemented to control the amount of fishing effort.

Erickson (1975) estimated that of 45,595 pots actually employed in Washington during the 1972 season only 16.2 percent of that effort was really required to land the harvestable surplus. For the 1973 season, Erickson (1975) estimated that 10 percent or less of the pots actually employed were required. The State/Federal Dungeness Crab Study Team's estimate for optimal effort (Collinsworth et. al. 1976), however, was considerably higher than that estimated by Erickson (1975) and was stated as follows:

> *the maximum level of net economic benefits from the Dungeness crab fishery would be obtained with a three-state combined average effort level of 60,150 pots. At this level of effort, the average annual catch would be 24,820,604 pounds, and the net economic benefits, excluding administrative costs, would be $7,812,074 annually (at November 1975 price levels). Without some form of effort management, it has been estimated that the average effort level in the 3-state fishery would be 123,168 pots, approximately double the optimal level. The average annual yield would be 24 percent lower at 18,749,032 pounds, and the net economic benefits would drop by 88 percent to $931,404 annually. The potential*

gain in net benefits due to effort management is the difference between the maximum net benefits and the unregulated net benefits; that is, $6,880,670 annually. The actual gain in benefits achieved by any real effort management program would be less than the potential gain due to imperfect regulation of effort, administrative costs, and transitional costs to displaced individuals.

The estimated optimum reduction in fishing effort varies substantially based on projections of these two studies. The Study Team pointed out that there is "the possibility of considerable error in the estimate of the potential benefits due to effort management." One reason for this is the severe lack of information regarding estimates of stocks and the extent that these stocks should be landed in peak years of production. The Study Team committed substantial effort to estimating the sustainable harvestable surplus and probably has provided the best possible estimates given present information. Considerable variation will exist in estimates of optimum effort levels, however, due to value judgments concerning the extent that peak production years need to be harvested, which economic sector should receive the greatest concern in developing management policies, and whether some excess effort may be desirable due to lack of reliability of estimating procedure.

Although there may be disagreement about the functional relationships or estimating procedures used, interest in effort control seems to be adequately documented. However, unless alternative opportunities exist for the major resources that are displaced a combination of seasonal changes and effort management may provide more effective and acceptable management policies. Information related to social impact and political feasibility have been evaluated far less adequately than economic efficiency or biological effectiveness. The impact of alternative policies on income distribution and social conditions has not been evaluated adequately.

If effort is limited by establishing individual catch quotas, the precision and timeliness of estimated harvestable stock and landing statistics need to be improved if effort level is controlled near the optimum amount relative to economic efficiency.

Information available now indicates the general impact of alternative procedures to control effort and measure the benefits that might be achieved. The magnitude of estimated benefits is probably unreliable, but little can be done to improve this given present estimates of harvestable stocks, market conditions, fishing costs, and industry structure.

Little information is available regarding potential benefits from various combinations of management procedures (e.g. tax or license fee plus buy-back). Information is lacking also regarding potential benefits from changing seasons to other more traditional forms of management in combination with effort control.

Recommendations

Highest priority should be given to determining potential benefits from implementing management plans that may not provide optimum economic efficiency at least in the short run, but may result in a more acceptable social impact including acceptability to the fishing industry. This will require consideration of several types of information such as alternative types of employment for resources, social impacts and similar data. The Study Team recommended that:

> *it would not be appropriate to make a final decision at this time on whether or not to implement an effort management program. However . . . the question is well worth pursuing further and such efforts would produce a more clear-cut recommendation. If the question is pursued, however, it should be done in the context of the multi-species fishing vessel operating under extended jurisdiction.*

ENFORCEMENT AND MANAGEMENT COSTS

Enforcement and management costs must be taken into account in estimating the net benefits of effort management. These costs will vary with alternative fishery management policies.

Review

The Study Team's estimated net benefits were exclusive of management and enforcement costs due to early termination of their research. Williams and Richards (unpublished) summarized estimates by state agencies of these costs. The estimates were based on experience in agencies (including Canadian) that have implemented similar activities and the views of state personnel with

experience in these areas. The basic cost categories which were identified included allocation and maintenance of the license limitation on catch-quota system, prediction of harvestable stocks, landing statistics, enforcement, buy-back programs, general administration and resource management. State agencies estimated costs for present programs, for improved management without effort control and for management programs with effort control. These estimates need to be viewed as only approximations but represent the best data available.

Recommendations

More precise estimates of administrative and enforcement costs are needed for policy changes that are considered likely to be implemented. Available cost information are only rough estimates and more refined data should be developed.

COSTS AND EARNINGS

Cost and earnings information are needed to evaluate the impact of policy decisions (e.g. the impact on large vs. small vessels or mobile vs. local vessels). This information also is needed to determine the importance of the Dungeness crab fishery to the total annual net earnings of the vessel.

Information is generally available (although not adequately summarized) regarding gross earnings or value of ex-vessel landings. Information regarding the contribution of the crab fishing enterprise to the net earnings by the firm, information on fishing costs, information on fishermen net earnings and trends in net earnings are generally inadequate.

A survey by the Study Team provided information to estimate fishing costs, net earnings and relationship to income from other fisheries. However, the response rate to this survey was low and consequently additional study is needed.

Review

Although the Study Team and Erickson (1975) used a method that did not require cost and earnings data to estimate the magnitude of potential benefits from effort control, more precise estimates of these potential gains may be possible with adequate cost and earnings data.

Cost and earnings data are necessary if management policy changes are to take into account the potential impact on different vessel sizes or geographic areas. Cost and earnings data also are needed to indicate the relative importance of Dungeness crab fishing to potential earnings by the fishing firm.

Recommendations

High priority should be given to research to estimate net earnings associated with Dungeness crab fishing. This will indicate whether potential unemployed resources resulting from effort control would be likely to continue fishing or if over time these resources would exit from this industry. This information also is needed to project the impact of alternative policies on different sectors of the fishing industry and geographic areas.

PROCESSING EFFICIENCY

Current fishery practices that concentrate landings in a short time period probably reduce economic efficiency and potential employment benefits. This problem is less serious for processors who can use their facilities for other products, such as bottomfish, although even in this case concentration of landings in a short season may reduce efficiency.

Review

The results of a survey of processor's attitudes by Bribitzer et. al. (1973) found that:

> *Since most of the landings occur in a short time, processors must either impose limits (which may result in fishermen selling elsewhere) or utilize their full capacity for only a small part of the season, often with idle capacity for a considerable time. More uniform landings over a longer period may improve yields (i.e. reduce amount of softshelled crab), increase total revenue and provide better use of facilities for most processors.*

Although the existence of some processing inefficiency seems certain, the magnitude of this problem has not been measured adequately.

Recommendations

Studies are needed to determine the importance of processing inefficiency due to management policies and to measure the potential benefits from alternative management policies.

CONCLUSIONS

Our primary assigned task was to review available management information with respect to the requirements of P.L. 94-265. It immediately became obvious that such an evaluation would depend heavily on the data needs of the particular management plan chosen by the Council's Crab Management Planning Team. However, in general, after review of Sections 301 (Standards) and 303 (Contents of Fisheries Management Plans) of the Act, we conclude that the information available will generally meet the Act requirements. However, Subsection 1, Section 303, concerning possible Indian treaty rights if any needs further attention. Subsection 3, Section 303, concerning maximum sustainable yield and optimum yield could be problem areas, especially if it is deemed that these require stock assessment. It is our view that direct stock assessment as such is not a high priority need for good management of the Pacific Coast Dungeness crab fishery, especially if effort management is not implemented, and possibly not then.

However, the Act clearly calls for designation of the allowable allocation available for foreign fishermen, if any. That requirement in our judgment may call for stock assessment including estimates of total population and mortality or exploitation rate. Available information is inadequate for that task and would need to be augmented by new research studies as recommended in the "Discussion Section" of this report. OY assessment would also necessitate considerable improvement of our socioeconomic data base.

Biological Data

Information and data relative to crab life history and management has been collected for many years along the Pacific Coast. In general, this information is extensive and covers much of that needed. The major areas of weakness or need are as follows:

1. Better data on fishing effort (CPUE).

2. Better data for stock assessment.

3. Better data on natural mortality rate and exploitation or fish mortality rates are needed.

4. Better information on the cycle of crab abundance is desirable; however it is probable that only a long time series data base will fill this need.

Socioeconomic Data

Less effort has been expended on collection of socioeconomic information than on biological data for the Pacific Coast Dungeness crab fishery. Data needs and collection methods need special attention. Major needs for socioeconomic data are:

1. Better economic information on alternative fishing and nonfishing employment opportunities if effort control is considered. These would include both human and capital resources.

2. Improvement of costs and earnings data for fishermen and processors.

3. Additional marketing information.

4. More information on the contribution of the crab fishery to the net earnings of fishermen and the economic and social structure of coastal communities.

We believe this report will be useful to the Pacific Regional Management Council's Dungeness Crab Management Planning Team, and recommend they use it and the basic data we reviewed in drafting the management plan for this fishery.

REFERENCES CITED

Anonymous. 1949. Drag boat damage on crabs. Fish Comm. Oregon Res. Briefs 2(1): 9.

Anonymous. 1972. Statement on Coastal Dungeness crab for Fisheries Int. Comm., Wash. State Leg. Wash. Dept. Fish.

Anonymous. 1975. Criteria for coastwide crab condition sampling. Pac. Mar. Fish. Comm. Scientific Comm. and State/Federal Dungeness Crab Management Program Study Team. Proc. rept. 5 p.

Bribitzer, C., F. Walgenbach, and J. Richards. 1973. Pacific coast Dungeness crab. A preliminary report on processor attitudes toward crab management. 17 p. Unpublished report.

Butler, T. H. 1951. The 1949 and 1950 tagging experiments in the Graham Island crab fishery. Fish. Res. Bd. Canada, Pac. Prog. Rept., No. 89, pp. 84-87.

_____ 1960. Maturity and breeding of the Pacific edible crab, Cancer magister Dana. J. Fish. Res. Bd. Canada, 17 (5), pp. 641-646.

_____ 1961. Growth and age determination of the Pacific edible crab, Cancer magister Dana. J. Fish. Res. Bd. Canada, 18 (5), pp. 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.

Christy, F. T. Jr. 1973. Alternative arrangements for marine fisheries: an overview. Resources for the future. Washington, D.C. 91 p.

Collinsworth, D. W. 1976. Dungeness crab fisherman's opportunity costs. Unpub. rept., 5 p.

Collinsworth, D. W.; S. W. Silverthorne, and N. E. Stewart. 1974. Phase I completion rept. - proposal for development of a state/federal fisheries management plan for the California, Oregon, and Washington Dungeness crab fishery. Pac. Mar. Fish. Comm. State/Federal Dungeness crab management program, Proc. rept. 163 p.

_____ _____ _____. 1976. Phase II completion report - proposal for development of a state/federal management plan for the California, Oregon, and Washington Dungeness crab fishery. Pac. Mar. Fish. Comm. State/federal Dungeness crab management program, Proc. rept. 104 p.

Dahlstrom, W. A. 1975. Summary of information on recovered lost traps. Calif. Dept. Fish and Game, Mar. Res. Region, proc. rept. 2 p.

Demory, D. 1971. Abandoned crab pots near Cannon Beach, Oregon. Fish Comm. Oreg. Shellfish invest. inf. rept. 70-6; 5 p.

Erickson, L. E. 1975. An economic study of the common property problem: the Dungeness crab fishery on the Washington coast. Unpub. Ph.D. thesis, Univ. Mich.

Gotshall, D. W. 1969. Port sampling at Crescent City - Brookings - Port Orford; November 1966 - October 1967. Pac. Mar. Fish. Comm., 20th Ann. Rept. for the year 1967, pp. 50-51.

Gotshall, D. W., and R. Hardy. 1969. Final report of port sampling, January 1966 - November 1968. Pac. Mar. Fish. Comm., 21st Ann. Rept. for the year 1968, pp. 28-31.

Gotshall, D. W. (In press [a]). Catch-per-unit-of-effort studies on northern California Dungeness crabs (Cancer magister). Calif. Dept. Fish and Game.

Gotshall, D. W. (In press [b]). Crab sport fisheries. Calif. Dept. Fish and Game.

High, W. L. 1976. Escape of Dungeness crabs from pots. U.S. Dept. Comm. Nat. Mar. Fish. Serv. MFR Paper 1184, Mar. Fish. Rev. pp. 19-23.

Jow, T. 1961. Crab trap escape-opening studies. Pac. Mar. Fish. Comm. Bull. 5, pp. 49-72.

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

Lewis, R. C. 1973. Preliminary economic analysis of management alternatives for limiting harvest by Oregon commercial fisheries. Fish. Comm. Oregon, proc. rept.

Lehman, C. (Unpublished manuscript). Phase I. Population dynamics. Part I. The migration and growth of Dungeness crab (Cancer magister) in southeastern Alaska. Typed rept. 21 p.

Liao, D. S., and J. B. Stevens. 1975a. Oregon's Dungeness crab fishery: an economic analysis of productivity and profitability. Oreg. State Univ. G.R. Spec. Rept. No. 441, 18 pp.

_____. 1975b. Oregon's Commercial Fishermen: characteristics, profits, and incomes in 1972. Oreg. State Univ. Circ. of information 649. 20 pp.

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

MacKay, D. C. G. 1942. The Pacific edible crab, Cancer magister. Fish. Res. Bd. Canada, Bull. No. 62, 32 p.

McMynn, R. G. 1951. The crab fishery off Graham Island, British Columbia, to 1948. Fish. Res. Bd. Canada, Bull. No. 91, 21 p.

Northup, T. 1976. Coastal Dungeness Crab study. Comm. Fish. Res. and Dev. Act, Project No. 1-114R, Segment 1. Wash. Dept. Fish. Ann. Rept. Feb. 3, 1975 - June 30, 1976.

Odemar, M. W., R. R. Bell, C. W. Haugen, and R. A. Hardy. 1975. Report on California spiny lobster, Panulirus interruptus (Randall), research with recommendations for management. Calif. Dept. Fish and Game. Rept. to Calif. Fish and Game Comm. 98 p.

Orcutt, H. G., R. N. Tasto, P. W. Wild, C. W. Haugen, and P. C. Collier. 1975. Dungeness crab research program - Report for the Year 1975. Calif. Dept. Fish and Game, Mar. Res. Admin. Rept. No. 75-12. 77 p.

Osborn, O. S. (Unpublished manuscript). Part II. A study of the growth and molt patterns of the adult Dungeness crab (Cancer magister) in southeast Alaska. Typed Rept. 17 p.

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.

Stefferud, J. A. 1975. Prediction of abundance of harvestable Dungeness crab (Cancer magister). M. Sc. Thesis. Oregon St. Univ. Corvallis. 39 p.

Stewart, N. E. 1973. Summary of Dungeness crab condition studies in Washington, Oregon, and California (tables and figures only). Pac. Mar. Fish. Comm., State/Federal Dungeness crab management program, Proc. Rept. 20 p.

_____. 1974. Movements of tagged Dungeness crabs. Pac. Mar. Fish. Comm., State/federal Dungeness crab management program, Proc. Rept. 19 p.

_____. 1976a. Memorandum to Dungeness crab Scientific Committee. Fleet mobility in Oregon.

_____. 1976b. Discussion on crab mortality associated with certain fishery practices. Pac. Mar. Fish. Comm., State/Federal Dungeness crab management program, Proc. Rept. ___ p.

Tegelberg, H. C. 1970. Dungeness crab study. Comm. Fish. Res. and Dev. Act. Proj. No. 1-52-R. Wash. Dept. Fish. Ann. Rept. Aug. 15, 1969 - June 30, 1970. Proc. Rept.

_____. 1971. Dungeness crab study. Comm. Fish. Res. and Dev. Act. Proj. No. 1-52-R. Wash. Dept. Fish. Completion Rept. for July 1, 1969 - June 30, 1971.

_____. 1972. Condition, yield, and handling mortality studies on Dungeness crabs during the 1969 and 1970 seasons. Pac. Mar. Fish. Comm. 23rd Ann. Rept. for 1970. pp. 42-47.

_____. 1974. Coastal Dungeness crab study. Comm. Fish. Res. and Dev. Act. Proj. No. 1-920R. Wash. Dept. Fish. Ann. Rept., July 1, 1973 - June 30, 1974. 28 pp.

Tegelberg, H. C. 1975. Memorandum concerning vessel mobility. Wash. Dept. Fish.

Tollefson, T. C. 1972. Letter to Senator Lowell Peterson, Legislative Interim Committee on Fisheries, Game and Game Fish. Aug. 18, 1972.

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

Weymouth, F. W. and D. C. G. MacKay. 1934. Relative growth in the Pacific edible crab, Cancer magister. Proc. Soc. Expr. Biol. Med. 31: 1137-1139.

Williams, R., and J. Richards. Unpublished manuscript. Administrative costs of programs to control fishing effort in the Dungeness crab fishery.

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, Mar. Res. Reg., Sacramento. M.R.O. Ref. No. 66-29. 14 pp.

Wix, J. R. 1967. Some economic considerations in Dungeness crab marketing. M.S. thesis, Oreg. State Univ. Corvallis, Oreg.