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AN ECONOMIC STUDY OF A COMMON PROPERTY PROBLEM: THE DUNGENESS CRAB FISHERY ON THE WASHINGTON COAST

by

Lee Edward Erickson

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Economics)
in The University of Michigan
1975

Doctoral Committee:

Professor Harvey E. Brazer, Chairman
Professor G. Robinson Gregory
Professor Lester D. Taylor, University of Arizona
Professor Sidney G. Winter, Jr.

DEDICATION

To the memory of my grandfather, Llewellyn Evans (1882-1975), who never admitted that there was anything he could not do, and was seldom proved wrong.

ACKNOWLEDGMENTS

This study has had the attention, cooperation and support of the Washington Department of Fisheries (WDF), and through them the National Marine Fisheries Service (NMFS) from the beginning. This not only has made the study possible, but makes its chances of actually influencing policy greater than for most dissertations. Some preliminary work on this dissertation was reported in a paper written in July 1973 for these agencies.

While many people have been helpful a few deserve special recognition: At the Olympia office of the WDF Charles E. Woelke and Cedric Lindsay who commented on earlier drafts of some parts of this paper, and Dorothy Bunn and Arno D. Stautz who were helpful in providing data. At the Aberdeen laboratory of the WDF Herb C. Tegelberg and Charles D. Magoon whose experience as biologists working with the fishery was helpful in expediting this work. At the Seattle office of the NMFS John Gharrett and especially Jack A. Richards who provided helpful comments and encouragement. Wesley Silverthorne working in both the Aberdeen laboratory and the Olympia office of the WDF for the State/Federal Management Program for Managing Dungeness Crab provided useful comments

and help in keeping informed about developments in the fishery while this dissertation was being written, although this group decided to continue the work I had begun using somewhat different methods. John Harville helped to keep me informed regarding the activities of the Pacific Marine Fisheries Commission in this area.

The Statistical Research Lab at the University of Michigan deserves thanks for their help through and with the use of their statistical computer program, MIDAS.

The members of my dissertation committee, especially the Chairman, Harvey Brazer, provided helpful comments on earlier drafts of this work.

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GLOSSARY OF TERMS USED

X	total stock of fish available to be caught by this fishery at a point in time
$\dot{X}$	rate of change of the fish stock per unit time
$F(X)$	function describing natural growth of the fish stock as a function of the size of this stock
Y	total yearly catch by the fleet fishing the stock, X
K or E	total number of vessels (or other unit of effort) fishing the stock, X
P	price which fisherman receives for fish
W	cost of inputs per unit of effort
$C(Y,X,K)$	costs of fishing per year as a function of catch, stock of fish available, and number of vessels fishing
C_1	rate of change of costs as the catch rate, Y, changes, i.e. the marginal costs
C_2	rate of change of costs as the fish stock, X, changes, i.e. the stock externality
C_3	rate of change of costs as the number of vessels, K, changes, i.e. the crowding externality
λ	Lagrangian multiplier used in solving a comparative static constrained maximization problem. It may be interpreted as the marginal value of the fish stock.
$\dot{K}$	rate of change of the extent of effort per unit time
δ	factor of proportionality

e	base of natural logarithms, 2.71828
ρ	discount rate used to convert future costs and revenues to their present value
t	time
F'	first derivative of F
F''	second derivative of F
$G(X,E)$	production function which gives the catch rate, Y, as a function of the stock, X, and the amount of fishing effort, E
k	K/X
$g(k)$	$G(X,K)/X$
g'	first derivative of g
Hamiltonian,H	In solving a calculus of variations type problem, the function whose maximum and minimum occur at the same values of the dependent variables as the integral being maximized or minimized.
Calculus of Variations	The study of the theory of maxima and minima of definite integrals whose integrand is a known function of one or more independent variables and one or more dependent variables and their derivatives, the problem being to determine the dependent variable so that the integral will be maximum or a minimum.
Transversality Conditions	In calculus of variations, the conditions generalizing the fact that the shortest line segment joining a point to a curve must be orthogonal (in two dimensional space this means perpendicular) to the curve at the point where the line meets the curve.
γ	auxiliary variable used similarly to a Lagrangian multiplier which in this case may be interpreted as the marginal value of the fish stock; also the catch tax
$\dot{\gamma}$	rate of change of γ over time
β	profit per unit of effort

$Y^*(E)$	sustainable yield curve
$Y^{**}(X)$	catch locus
π	total fleet profits
α	a constant
T	license fee or tax on effort
$\dot{E}, J(\beta)$	rate of change of E over time, or entry rate

CHAPTER I

DESCRIPTION OF THE PROBLEMS

I-A. Introduction

The west coast Dungeness crab fishery is beset by problems which are inherent in most fisheries. Catches and revenues have both seasonal and cyclical fluctuations, the average return to labor and capital is low compared to U.S. manufacturing, and there is excess effort due to the common property nature of the resource. State management of the fishery was instituted many years ago to protect the species from extinction through predation by man, but limitations on the amount of fishing effort employed were avoided. Instead closed seasons and legal prohibitions were used to protect crabs during their soft-shelled period, and size limitations and prohibition of harvest of females were used to protect the ability of the population to reproduce itself. Management of the fishery has been complicated by having the fishery extend across several political jurisdictions. A description of the fishery appears in the second section of this chapter.

Regardless of anything that is done to improve the efficiency of the fishery, and hence the return to

effort employed, or to solve the problem of coordinating seasons among political jurisdictions, the problems caused by the common property nature of the fishery will remain. It is in the nature of common property resources that at the point where an optimum amount of other resources is devoted to a production process which uses this common property input, rents accruing to the ownership of the common property resource will be divided among users of the input in proportion to its use. However, these rents cannot be capitalized into the cost of the resource to its users as would be the case with privately owned inputs. Rather, they will be interpreted as profits by individual firms since everyone owns the common property resource and hence no one owns it. Thus additional effort will be devoted to this production process until all rents are dissipated. Average revenues will then be equal to average costs, but these average costs will not include capitalized rents to ownership of the common property input. Any increase in real revenues per unit of effort in a fishery will induce entry of additional effort into this fishery until all profits and rents are dissipated again. No one firm has any incentive to economize in the use of the common property resource or to invest in the future stock of this resource, because anyone who does not take all he can today will

find that someone else will take it before tomorrow. The common property nature of the resource requires that effort be controlled by the management agency in a way which does not restrict fleet efficiency. The relationship between the common property problem and other "market failures" is considered in the first part of Chapter II.

Economists first recognized these common property problems in fisheries about twenty years ago. The fisheries economics literature which has developed since then is summarized in the second part of Chapter II. This deals mainly with discussion of the problem and the search for a theoretically optimal solution. While some of the "optima" devised are more elegant than they are applicable in practice, these models provide a useful structure for considering these problems. Only in the last five years or so has any attempt been made to quantify the benefits of the policy changes necessary to achieve the optimum. These estimates of excess effort have ranged from 30 percent to nearly 90 percent of the total value of the catch in the fisheries studied.

This wide variation in estimates of the percentage of effort which is redundant indicates that there may be considerable room for better estimates. Policy makers such as legislators have little reason to listen

to our policy recommendations until we can be more definite concerning the benefits of stepping on some toes politically to enact the necessary policy changes. Effort limitations which do not restrict the fishing efficiency of the fleet are rare, but note the fairly recent attempts in the British Columbia and Alaska salmon fisheries.

The extent and value of excess effort in Washington's coastal crab fishery are estimated in Chapter III. The fisheries economics theory reviewed in Chapter II is applied here, and a method for estimating the extent of excess effort is devised and exercised. A new method of estimating costs of fishing and therefore of placing a value on redundant effort is then tested. This method of looking at entry and exit response to changes in revenue per unit of effort is based on commonly available data whereas other methods require special extensive surveys of fishermen who may be hard to find during the fishing season and reluctant to reveal the details of their businesses to the extent that they know them. This method is faster and cheaper to apply and is not necessarily less accurate in practice than extensive surveys, because it focuses on just that to which fishermen react as opportunity costs. While the extent of excess effort fluctuates in the same way that landings do, it is estimated that over $3 million could have been

saved in both the 1972 and the 1972-73 Washington coastal seasons by optimum effort management.

This method of estimating costs works well for recent years on the Washington coast, but it is less successful for other jurisdictions of the Dungeness crab fishery. The remainder of Chapter III is devoted to improving the explanation of entry behavior. The addition of the rate of change of fleet revenues is a key factor here indicating that many fishermen do not wait for higher revenues per unit of effort to materialize before entering the business but rather anticipate these changes to some extent.

In Chapter IV one of the standard assumptions of fisheries economics models is tested. It is generally assumed that the fishery being studied is small enough that the size of landings in this fishery does not affect the market price for this species. Time series data suggest that there is cause to doubt the validity of this assumption at least for the Dungeness crab fisheries in California and on the Washington coast. Analysis of cross sectional data for the 1972 and 1972-73 seasons in Washington corroborate the finding that price and quantity are not independent on the state level or, indeed, even on the port level. Hence any estimate of excess effort, which is based on the standard fisheries economics theory, such as those given in

Chapter III, should be considered ballpark estimates. Therefore, the possible added accuracy of survey data on costs is of questionable value until this assumption of price and quantity independence is relaxed in the optimization models summarized in Chapter II. Indeed, this is the area where attention should next be focused in fishery economics: modeling the social optimum as distinct from the monopoly optimum when price cannot be assumed to be constant within the fishery under consideration as landings in that fishery change.

Chapter IV also shows how prices rise during the season as the catch per unit time declines. Prices are shown to be lower further north along the coast when adjustments for variation in other variables are made; this is due to transportation costs to the prime market in California. The market is also shown to be quite concentrated in the sense of few buyers and processors of crab on the Washington coast.

Chapter V provides policy alternatives and recommendations and summarizes other conclusions of this study. This work has had the attention, cooperation and support of the Washington Department of Fisheries, and through them the National Marine Fisheries Services, from the beginning. This not only has made the study possible, but makes its chances of actually influencing policy greater than for most dissertations.

I-B. The Dungeness Crab Fishery[1]

The Dungeness crab, Cancer magister, is fished commercially from the Aleutian Islands in Alaska to the San Francisco Bay area in California. The common name of this crab came from a small fishing village on the Strait of Juan de Fuca in Washington where the first commercial fishing for this species occurred. This is the only commercial crab species in the State of Washington.

While these crab are caught commercially in salt water inlets and bays such as San Francisco Bay and Puget Sound, most of the catch is taken in the Pacific Ocean itself. For example, in Washington the total catch averages about 10 million pounds annually of which only about 1 million pounds is caught in Puget Sound. About 80 percent of the total catch was reported to have been taken more than three miles from shore or by Indians in the 1972 season in Washington, although this may be an artifact of the lower tax rate on these landings. In addition, very few boats which fish for crab in Puget Sound also fish for crab elsewhere in Washington; less than 10 percent of the Puget Sound crab vessels also fished for crab off the Washington coast in the 1972 season. While crab caught in Puget Sound are substitutable on the demand side for Dungeness crab

caught elsewhere, management policy proceeds on the view that the Puget Sound and coastal crab fisheries are distinct largely because the Puget Sound crab molt earlier. San Francisco Bay is similarly treated separately from the California coastal fishery.

The standard device for catching Dungeness crabs is called a crab pot. This is a cylindrically shaped trap made of stainless steel wire mesh over an iron frame. Each pot weighs 90 to 140 pounds, is 3-1/2 feet in diameter, and costs about $50 including lines and buoys. The weight depends on the expected storm activity in the area of normal use. These traps are baited with squid, razor clams or fish scraps, placed on the sea bottom, and the location marked with a buoy(s) attached with line(s). Crabs enter through funnel-shaped openings in the side of the pot as they are attracted by the scent of the bait. Exit via the entrance opening is prevented by a trigger device, although smaller exits are provided to allow sub-legal size crabs to escape. Prior to the 1930's ring nets were the accepted technology for catching crabs. This technique is much more labor intensive and is now only very seldom used.

Figures I-1 through I-11 are photographs of the fishing equipment and its operation. Figure I-1 shows the harbor at Westport, the largest port for crab fishing vessels on the Washington coast. The forest of poles



Figure I-1.--Harbor at Westport.

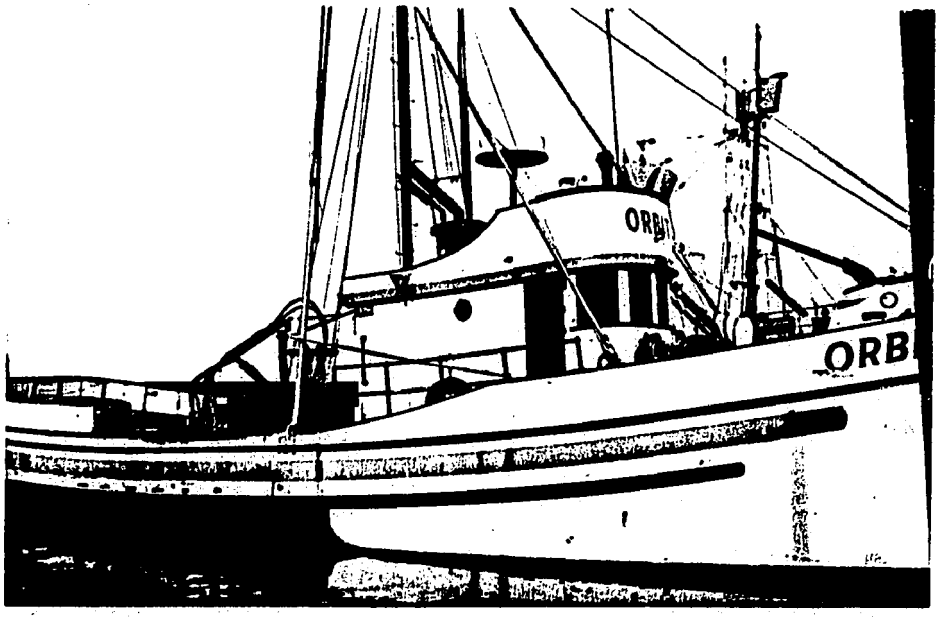

Figure I-2.--Typical crab and salmon troll vessel.

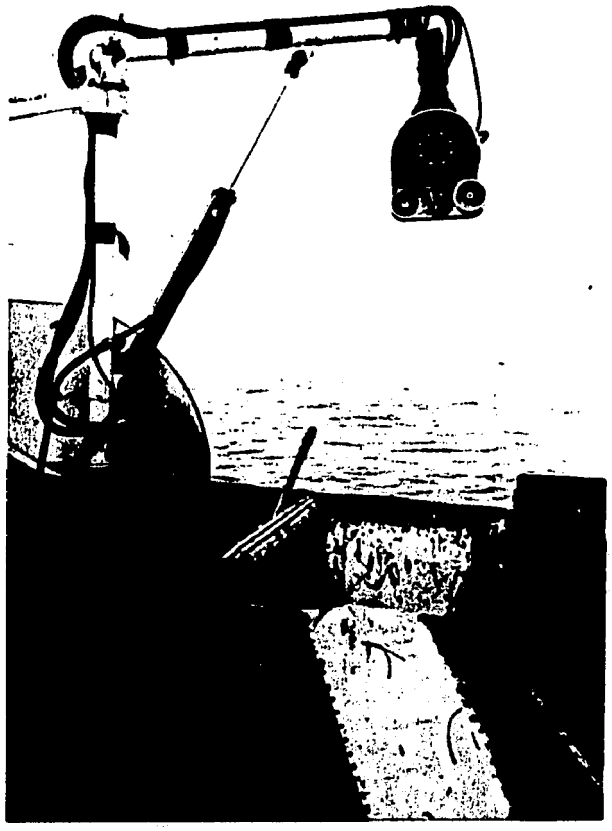

Figure I-3.--Power block used to lift crab pots.

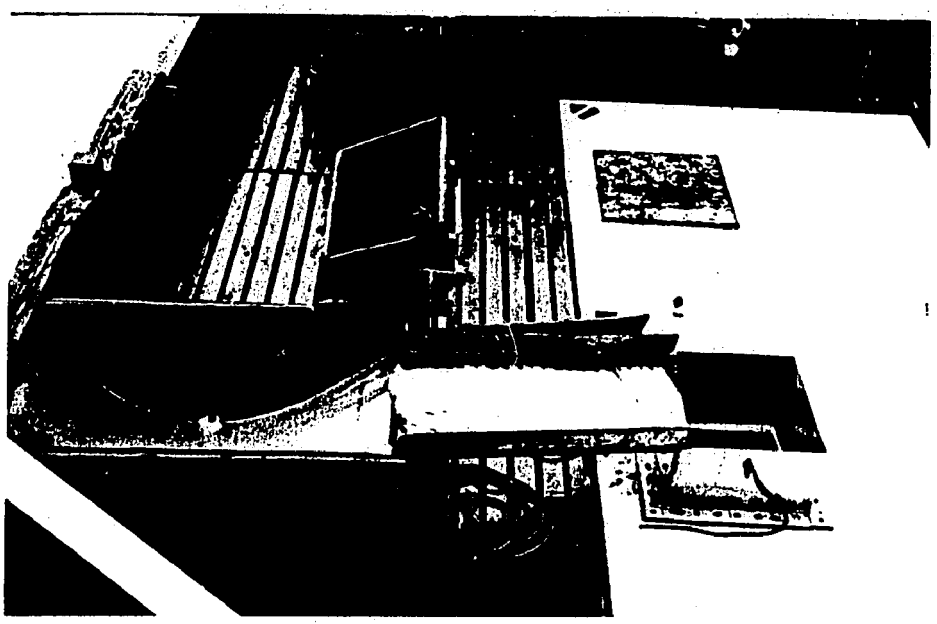

Figure I-4.--Sorting bin, ramp and live tank.

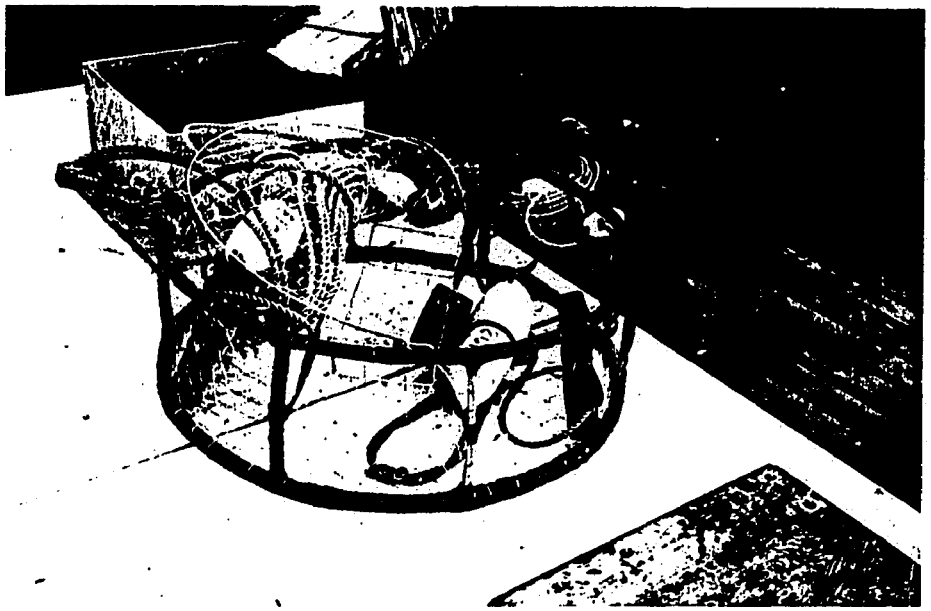

Figure I-5.--Crab pot.

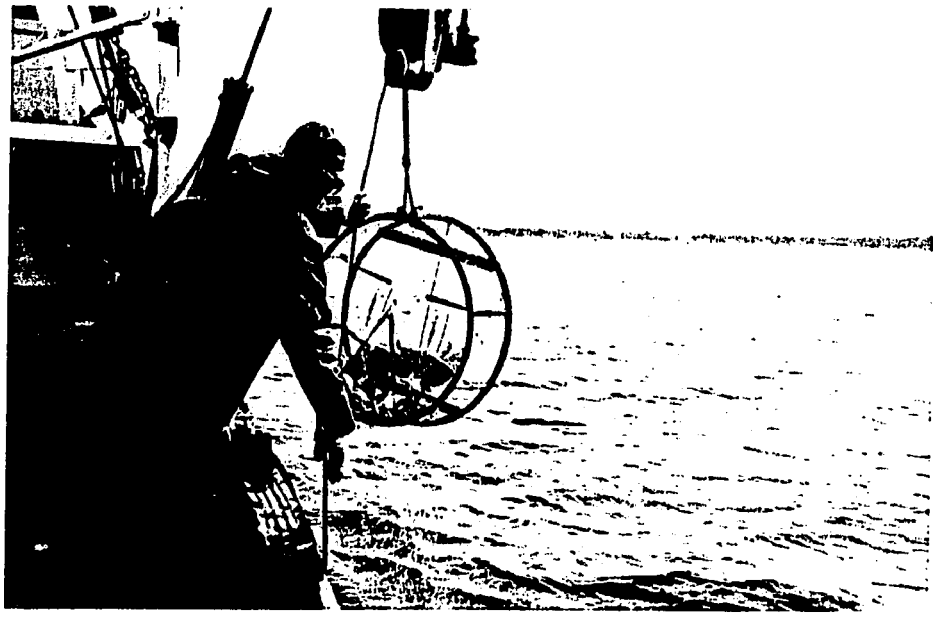

Figure I-6.--Raising the crab pot.

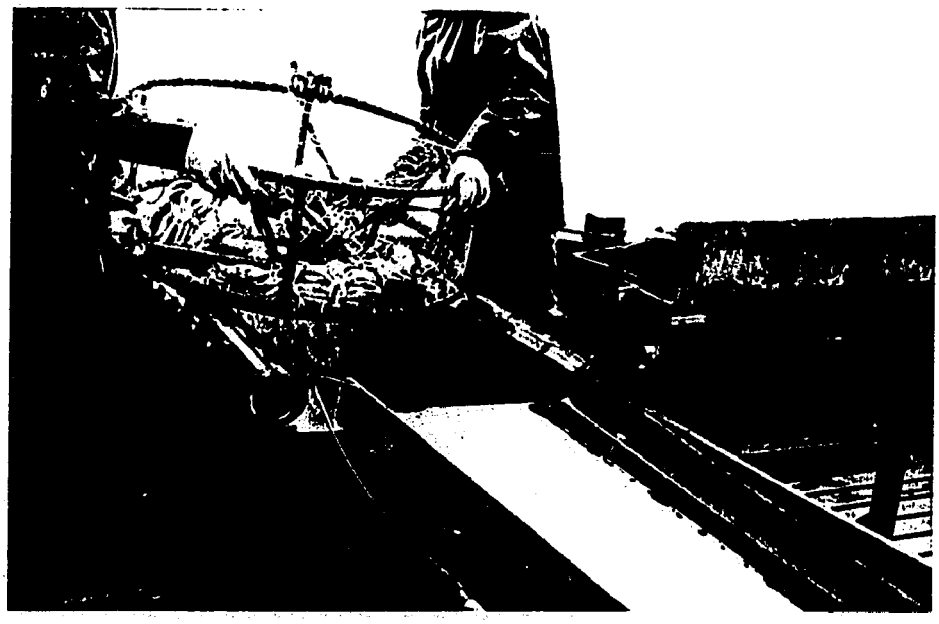

Figure I-7.--Crabs ready to be emptied into sorting bin.



Figure I-8.--Emptying crabs into sorting bin.

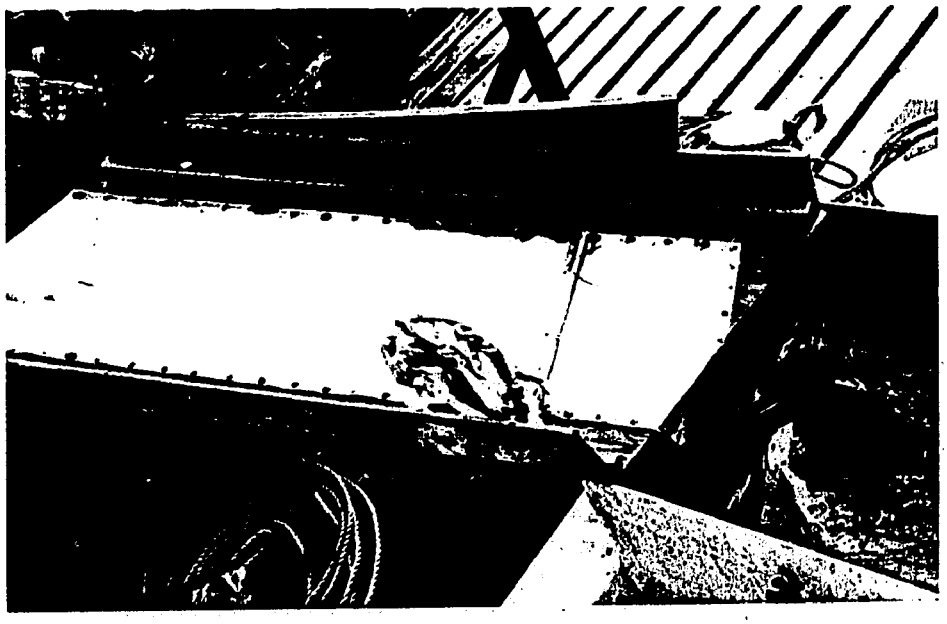

Figure I-9.--Crab sliding into live tank.

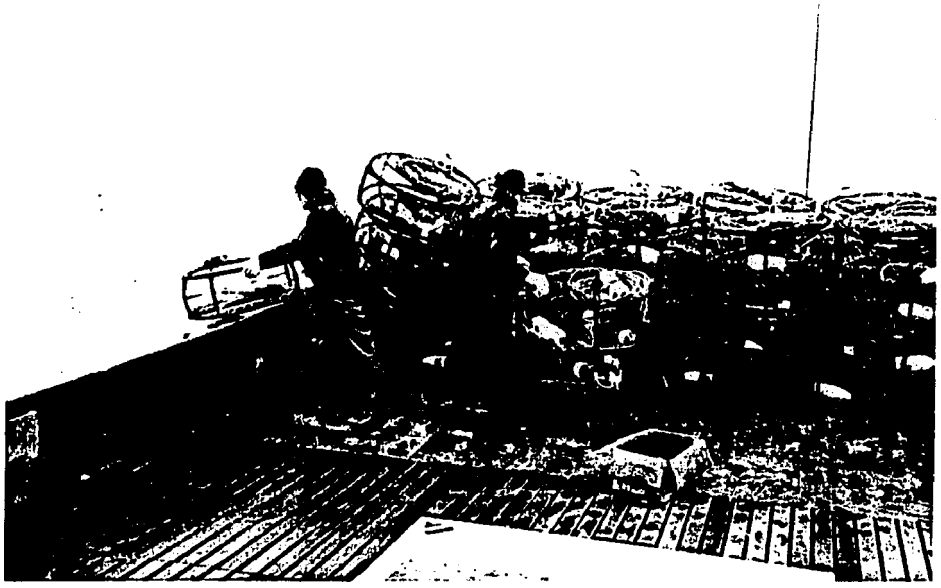

Figure I-10.--Baiting and resetting crab pots being moved to a new area.



Figure I-11.--Placing a crab pot in a new ocean location.

attests to the importance of the salmon trolling fishery. Figure I-2 shows a typical vessel which would fish for crab in the winter and troll for salmon in the summer. Figure I-3 shows the power block or winch used to raise the crab pots from the ocean floor. Figure I-4 shows the other equipment which is specialized to crab fishing: a sorting bin, a ramp down which crabs slide into the live tank, and a stand where bait boxes are kept. Figure I-5 is a close-up of a standard crab pot. Figures I-6 through I-9 show the harvesting operation: raising the crab pot, emptying it into the sorting bin where females and undersize crabs are discarded back to the ocean, and crabs being slid down the ramp into the live tank. The last two photographs, Figures I-10 and I-11, show the process of baiting and resetting the crab pots when they are being moved to a new area. If they were to be reset in the same area, the emptying, sorting and rebaiting process would occur at the side of the boat near the power block as the vessel moves to pick up the next pot.

The legal commercial size for Dungeness crabs in Washington is 6-1/4 inches (158.75 mm) caliper measure across the back of the shell in front of the points while the legal size for sport purposes is 6 inches. Only males may be taken, although few females attain the size of legal males anyway. This size restriction

protects the ability of the species to reproduce itself in spite of heavy fishing pressures, since males are polygamous and they mature a year or more before reaching legal size. Legal size is generally attained during the fourth year after assuming the adult form.[2] Figure I-12 shows the size of males and females at various ages as adapted from the work of Cleaver.

The growth of Dungeness crabs in shell width up to legal size has been outlined by Fred C. Cleaver[3] and others.[4] Research thus far has emphasized growth in shell width rather than weight, which is more important to the fishery. Therefore these shell width estimates must be translated into growth in weight by means of a width-weight relationship. Such a relationship has been estimated and is shown in Figure I-13. Note that weight is approximately a function of the cube of width; this is typical of such biological relationships. Unpublished data from January to July 1970 samples by the Washington Department of Fisheries coastal laboratory were used for estimating this relationship. These samples were taken for another purpose, but the relationship is suggestive of what a systematic investigation may find. Figure I-14 was then constructed using this relationship and Cleaver's report on growth in shell width. From this figure we see that during the last molt which brings male Dungeness crabs above the minimum

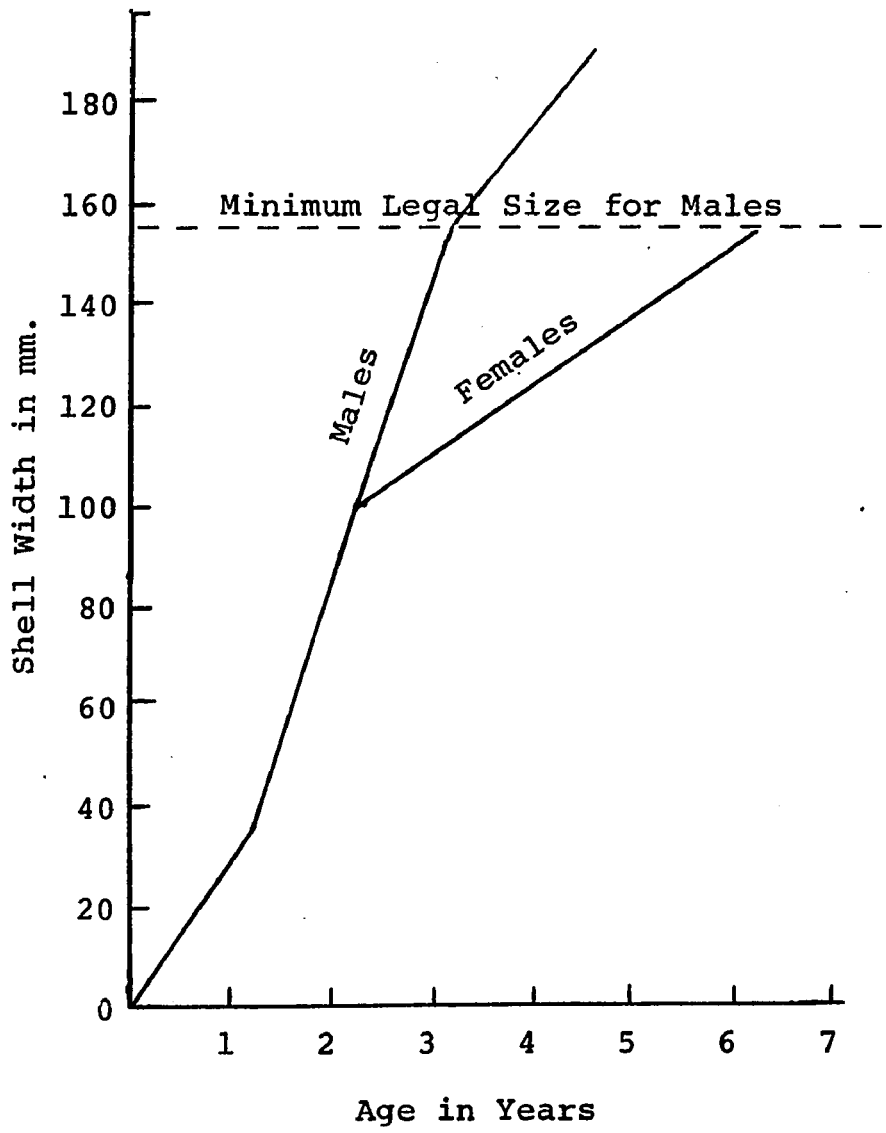

Figure I-12.--Age versus shell width of Dungeness crabs (adapted from Fred C. Cleaver).

$$LN\ (weight) = -9.0405 + 3.0589\ LN\ (width)$$
$$(-17.379)\quad (30.348)$$

$$or\ weight = 0.00012\ Width^{3.0589}$$

$$N = 112,\ R^2 = 0.893$$

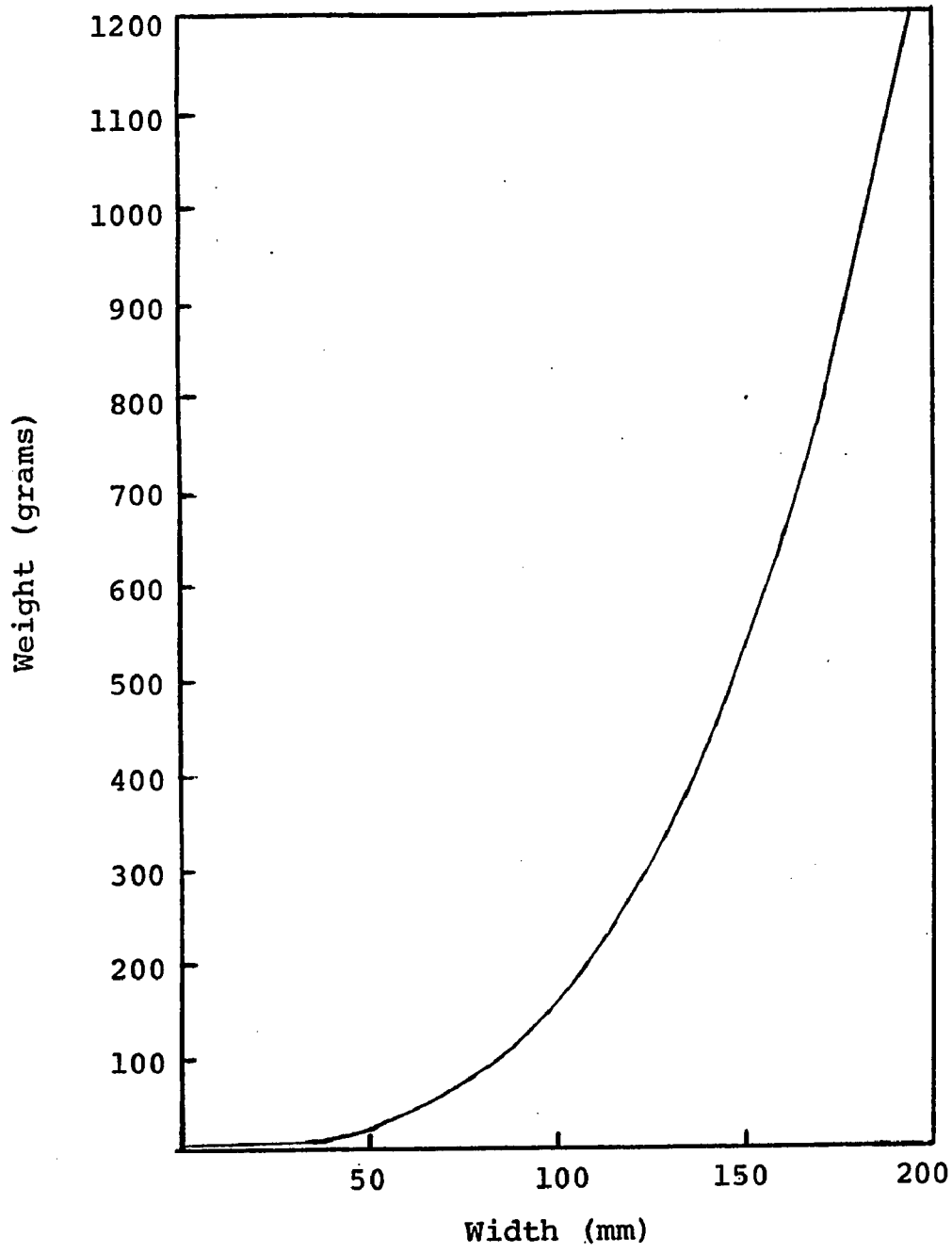

Figure I-13.--Width versus weight of male Dungeness crabs.

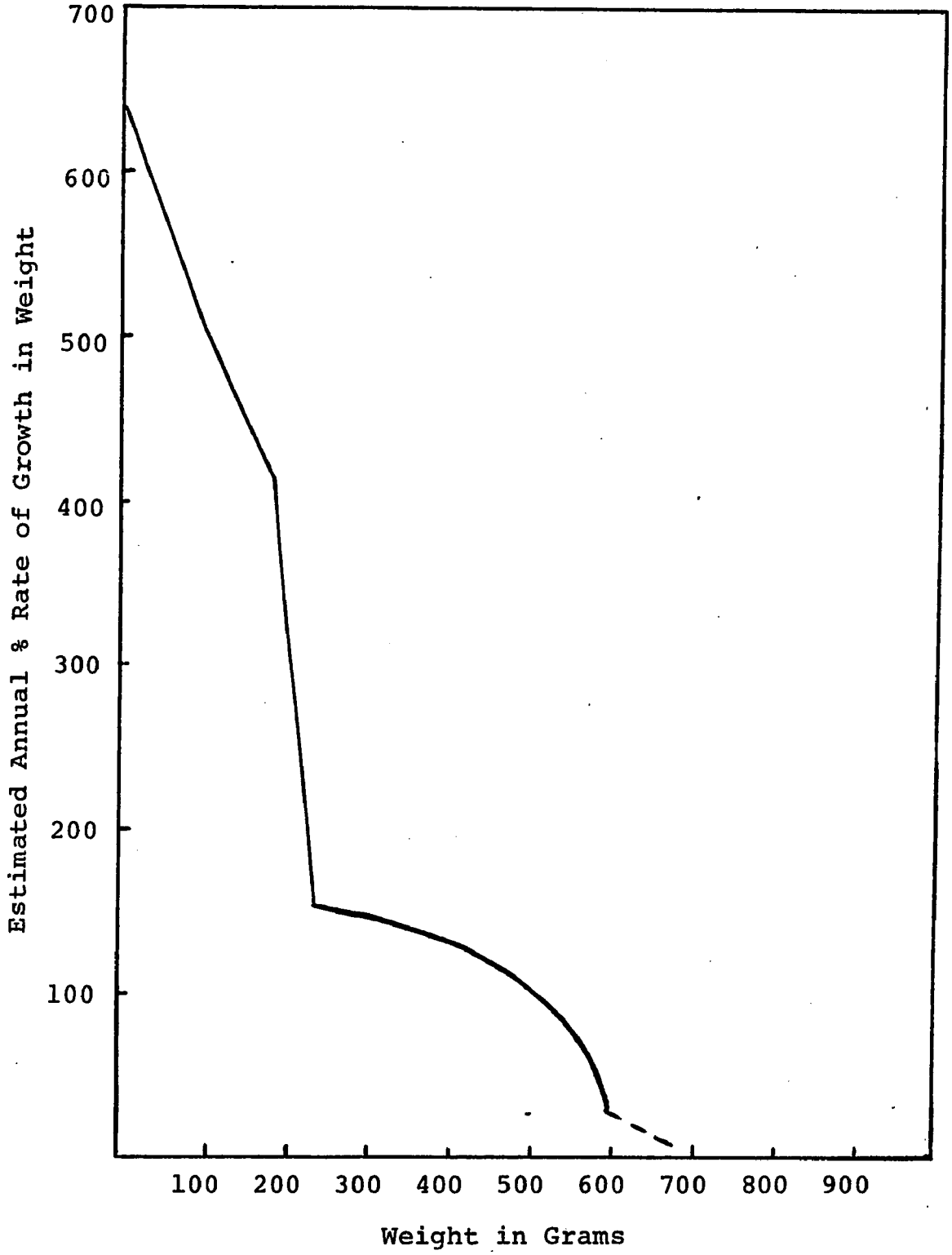

Figure I-14.--Estimated growth rate of male Dungeness crabs.

legal size they are growing at a rate of about 33 percent per year in weight. This growth rate is declining rapidly and little is known about the growth rates of these crabs once they enter the fishery. Molts are thought to occur six times a year during the first year, five times in the second year, twice in the third and once in the fourth year which brings them above the legal minimum size. After the fourth year, molting may occur less than once a year and may not be regular; the rate of growth above legal size is not at all well known. Few Dungeness crabs have been observed in the commercial catch larger than 8 inches;[5] little more is known about natural mortality of legal size crabs, or any size for that matter. Crabs in the commercial catch average a pound and a half to a pound and three-quarters and yield about five to seven ounces of meat.

Both growth and natural mortality of crabs in the fishery are ripe for further biological research, and some is proceeding. This research has been stymied by problems of developing a tag which would stay with the crab rather than the shell during molting. The evidence available as presented in Figure I-14 suggests that the minimum legal size at capture is close to the optimum and a bit low if anything. There is not sufficient knowledge at present to recommend more than further study, however, especially for growth and natural

mortality of crabs above the current legal size. It will subsequently be assumed here that the size limit has been set optimally.

The evidence on growth of female Dungeness crabs is very sketchy indeed. What is known is summarized in Figure I-12 and should be regarded as tenuous at best. Females grow about as fast as males until they reach sexual maturity at about two years. Thereafter females grow less rapidly than males as much of their energies go into producing eggs. Those females which live to grow larger than the legal size for males are at least six years old and are growing very slowly at that point even assuming annual molting for these older females. As noted for males over four years old, however, these older females may well molt less than once a year and may not molt on as regular a schedule as younger crabs do. If this is the case, they would be even older and growing more slowly at the time they reach the minimum legal size for males.

Unless their egg production capacity is necessary to insure the ability of the crab population to reproduce itself, these old females may actually be a detriment to the fishery. They compete for food with younger males which produce more meat and younger females which may produce more eggs. There is not enough evidence on the growth of females by shell width, let alone meat weight,

and their reproductive capabilities to recommend a minimum size limit for them. It seems clear that such a size limit would be an improvement over the current total prohibition against harvesting females of any size.

This is not so clear to many, however. Some recent unpublished research indicates that older females do still contribute to the reproductive capacity of the fishery. For this reason and primarily due to the opposition of processors, the management agencies have no present plans for further study of the possible harvesting of older females. The processors fear that there would be pressure to accept all crabs at the same price although the females contain less meat and it is harder to remove this meat from them.

Tagging studies have indicated that most (80-90 percent) of the legal size crab available in a given season are landed by the fishery during that season.[6] This means that each year's catch represents a given year class in the population, namely four year old males. Therefore, fluctuations in the propagation and survival of young crabs in a given year class show up directly in the size of the commercial catch when the males enter their fourth year.

These fluctuations in the size of the annual commercial catch are great. The catch in Washington has

varied from 3.5 million to 18 million pounds within the last twenty years. Other states have been subject to similar fluctuations in catch and availability as is shown in Figure I-15. A ten year cosine cycle was found to explain more of the variation in landings over time in Washington, Oregon and California than any other regular sine or cosine cycle. (See Appendix Tables.) Nevertheless, this ten-year cycle plus a time trend "explained" only 55 percent of the variation in landings in Washington and less in Oregon and California. Biologists believe that the causes of these fluctuations in Dungeness crab landings in the Pacific Coastal states are largely biological.

In a dissertation just completed at Oregon State University, R. Gregory Lough[7] reports that environmental conditions during the critical larval period explained 60-70 percent of the variability in crab landings at some ports four years later. In particular, February precipitation at southern Oregon and northern California coastal stations four years earlier was the environmental variable most highly related to crab landings in northern Oregon and southern Washington ports. Low ocean surface salinity caused by heavy rains during February reduces the size of the year class that is later harvested as four year old males. It may well be that what tends to have a ten year cycle is rainfall

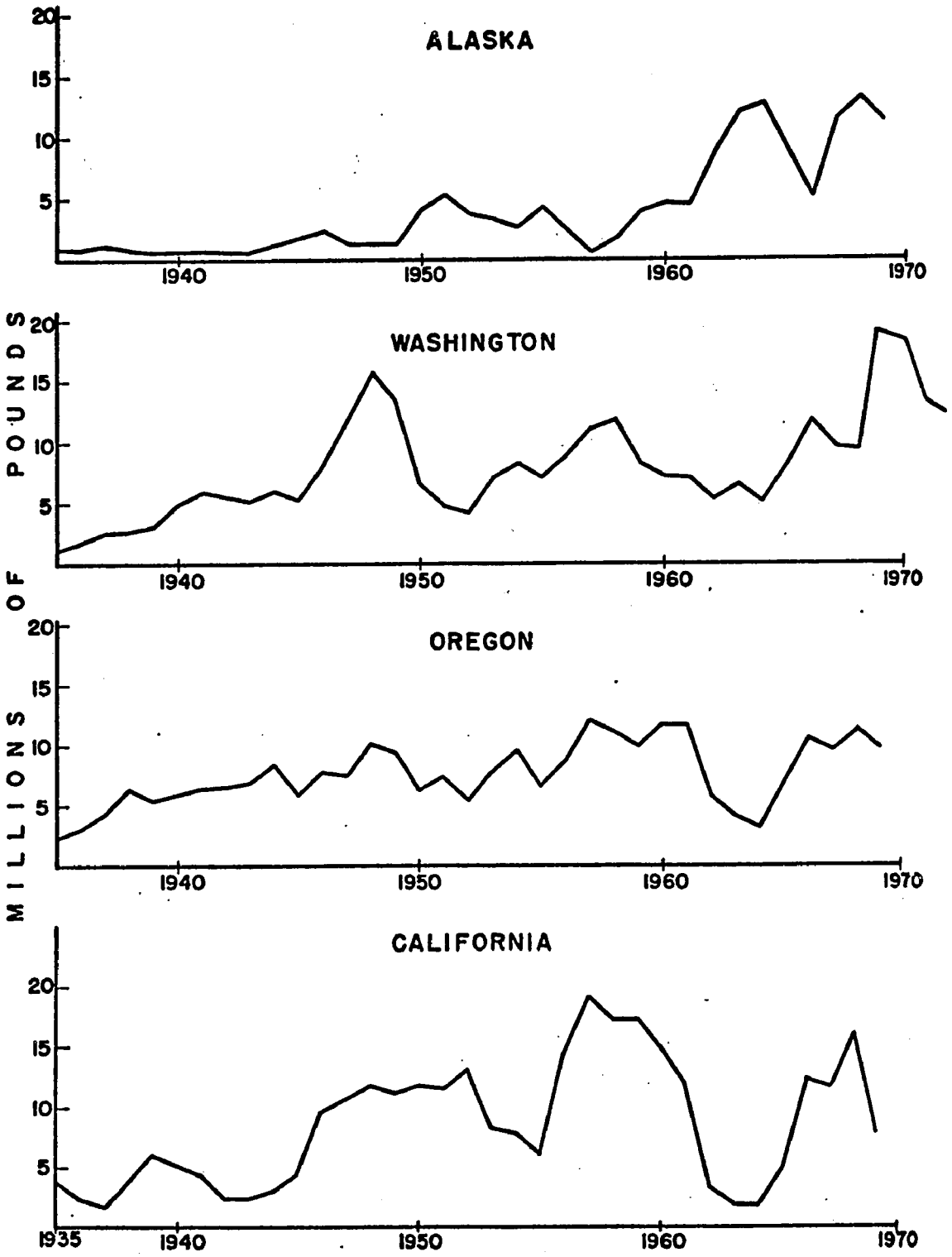

Figure I-15.--U.S. Dungeness crab landings by state, 1935-70.

levels along the Pacific coast. In addition, these natural fluctuations may be magnified because small crabs form part of the diet of larger crabs, and because the percentage of the legal size crab taken each year, although it is always large, may be inversely related to the size of the year class.

Landings in Alaska have been growing in recent years as prices have risen in response to increasing real incomes, a declining cycle of availability of Dungeness crabs in Washington, Oregon, and California in the early 1960's and again currently, and the declining of the Alaskan King crab fishery following the rapid depletion of an essentially virgin population in the 1950's and 1960's. Thus the catch in Alaska represents an increasing proportion of the available legal size Dungeness crab there.

Fluctuations in catch cause fluctuations in revenue and return to effort which in turn lead to large scale entry and exit of effort in this fishery. The difficulty of predicting average revenues per unit of effort increases the risk involved in a business which is already riskier than most due to lack of a stable production function. Inputs of an individual firm are only one factor determining fishing success or failure for that firm. Other important factors are the percentage of soft-shelled crab in the available population at the

time, how much of the season's catch has been caught and the size of the available population for that season, how much effort others are devoting to the fishery, and the density of one's own and others' inputs relative to the available population in the location chosen to fish, as well as some random factor.

It may be that fishermen like this risk in the sense that if they were presented the same expected return but a more certain one elsewhere, they would not take it. Average returns to fishermen's time and capital are notoriously low and this fishery seems to be no exception as we shall see in Chapter III. Other reasons for the lack of mobility in the face of low returns may be few opportunities for alternative employment and simply a preference for the life of a fisherman. All of these factors affect the real savings which could be made by shifting some of the resources currently devoted to fishing into other activities. It is another strength of the method of cost estimation tested in Chapter III that it takes these factors into account automatically. Survey methods must make a special effort to be careful in estimating opportunity costs of time and nonmonetary benefits of a preference for fishing as opposed to simply the wage bill.

In addition to being subject to annual fluctuations in natural availability which are to some degree

cyclical, the Dungeness crab catch is also very seasonal. In the coastal regions the molt which brings four year old males into the fishery occurs in the late fall (October to December). This molting occurs a month or so earlier further south along the Pacific Coast and during the summer in Puget Sound. After shedding the old shell, the thin pliable new shell under it expands rapidly as the tissues become saturated with water. While the new size is attained quickly, it takes a month or more for firm meat to replace water and for the shell to harden. During this period the crabs are more susceptible to predators and handling mortality in commercial capture. Since much of the weight of these soft-shelled crabs is water, the meat yield is less per crab if it is harvested in this soft-shelled condition than if one waits for it to fill its shell with firm meat. Because of greater handling mortality of discarding soft-shelled crabs captured and low meat yield of keeping them, total meat yield from a given available population of crabs can be increased by waiting for them to achieve a hard-shelled condition. For these reasons management agencies have attempted to maintain a closed season during the soft-shelled period for the majority of the crabs. Because the molting, and therefore the attainment of good meat condition, occurs somewhat earlier in warmer southern waters, this has led to

conflicts among the states involved in the coastal Dungeness crab fishery.

Since the last peak of crab availability occurred in 1969 and 1970, boats from California and Oregon have come north after catching the legal crab in their own states as soon as possible after the late fall molt. This forced Washington to open its 1972-73 season December 1, 1972 rather than January 1, 1973 so as to give their local residents first crack at the available crab even though their condition in December may not be as good. Only 4 percent of the 1972 crab landings in Washington were made by nonresidents, but crab caught off Washington's coast and landed elsewhere (primarily Astoria, Oregon) were estimated at 15-20 percent of Washington's crab landings in 1972. Who gets to fish the crab first and the meat yield of the crab at the start of the season are particularly important because most of the season's catch is taken in the first two months of the season, and the catch per week often declines from the first week of the season.

A minority of dealers argue that they can police the condition of the crab taken themselves without any seasons set by the states. There are indications, however, that when crab condition is poor some dealers may discount the weight that is credited to a fisherman (rather than the price) because the dealers are anxious

to be the first on the market and to have a larger share of the market even if it means a smaller total catch. Most dealers recognize this manifestation of the common property problem and join fishermen in wanting some season(s) set by the states. Arguments continue over how the season(s) should be set. The two most popular alternatives seem to be December 1 or January 2 for the whole coast.

The season-opening question is one that has been discussed since anyone can remember. Only recently, however, has there been much interest in study rather than simply discussion of the problem. A systematic study of season-opening dates would need to weigh the benefits of having some fresh crabs available earlier, but in poorer condition on average, versus the alternative of landing more usable crab meat at a later time. If the present season dates are not optimal, then some changes could be made which will increase the total value of the crab catch. One must be careful to note that unless the total costs of landing, processing, and marketing the annual crab catch do not also increase, a total revenue increase may still not be optimal. As long as there are no effective limitations on entry of additional effort in crab fishing, however, one must expect the benefits to fishermen of implementing optimum season dates to be dissipated through such entry.

This is not to say that it is unwise to bother solving the problem of coordination of seasons across political boundaries. The benefits to fishermen of such action would remain potential benefits except in the very short run, however, unless some entry limitations can be introduced. Even a moratorium on new licenses, such as has just been introduced in the Washington salmon trolling fishery, could help us move closer to the optimum by holding actual effort constant while the optimum catch and effort could be increased by solution of the multiple political jurisdictional problems.

Without some action to solve the common property problems, the benefits of arriving at optimum season dates, or anything else which would help existing crab fishermen have higher average incomes for that matter, will be dissipated through additional entry into crab fishing. This fact increases the urgency of getting on with work on this more fundamental problem, which is also the problem that has been central in the theoretical work which has been done in fishery economics.

Footnotes

[1]See T. H. Butler, "Growth and Age Determination of the Pacific Edible Crab, Cancer Magister Dana," Journal of the Fisheries Research Board of Canada, Vol. 18, No. 5 (September 1961), 873-891; T. H. Butler, "A Bibliography of the Dungeness Crab, Cancer Magister Dana," Technical Report No. 1, Fisheries Research Board of Canada (February 1967); Fred C. Cleaver, "Preliminary Results of the Coastal Crab (Cancer Magister) Investigations," Biological Report No. 49A (Seattle: Washington State Department of Fisheries, April 1949), 47-82; Herb C. Tegelberg, "Crabbing in Washington" (Olympia: Washington State Department of Fisheries, March 1972); and R. Gregory Lough, "Dynamics of Crab Larvae (Anomura, Brachyura) Off the Central Oregon Coast, 1969-1971" (unpublished Ph.D. dissertation, Oregon State University, 1974).

[2]Cleaver, loc. cit. See also Tegelberg, loc. cit.

[3]Cleaver, loc. cit.

[4]Butler, loc. cit.

[5]Cleaver, loc. cit. See also Tegelberg, loc. cit.

[6]Cleaver, loc. cit., p. 64.

[7]Lough, loc. cit.

[8]Cleaver, loc. cit.

CHAPTER II

THEORETICAL STRUCTURE

II-A. The Common Property Problem Related to Other "Market Failures"

Recognizing what the common property problem is not should help to clarify what it is. There are many problems which arise in trying to apply the standard competitive model to the real world. These "market failures" where governmental intervention is necessary to make the economy work as well as the standard model says it can are increasingly evident. These situations may be classified under two major headings: (I) Economies of scale which can lead to imperfect market structures or public ownership, and (II) Externalities or problems of incompletely defined private property rights. The latter heading may be further classified into (A) Public or collective goods problems, and (B) Problems which have been referred to as ownership externalities or common property problems including (1) Pollution, (2) Congestion, and (3) Intertemporal externalities in common property, open access resources of which fisheries are a prime example.

All of these problems lead to a divergence between price and social marginal cost at the market equilibrium. While the effects are similar, the causes and the possible

extent of the welfare loss differ. (I) Economies of scale lead to a divergence between price and social marginal costs when the minimal optimal scale of production is large relative to the market size, i.e., when the volume of output at which a firm can achieve the lowest average total cost per unit given existing technology is large relative to industry sales. Only a few firms would be needed to produce the total industry's sales, and the fewer the number of firms the closer each firm comes to viewing the downward sloping industry demand curve as its own. Profit maximizing firms will set marginal revenue equal to marginal cost, but price will exceed marginal revenue because the firms' demand curves are downward sloping. Because some people are willing to pay more for an additional unit of output than it costs to produce, production should increase to be socially optimal; but there are no private incentives to do this. Therefore, extreme cases, where average costs decline up to industry output, are termed "natural monopolies" and the government attempts to regulate such industries directly or to take them into public ownership. If the state does either, it is faced with the problem of how to charge a price which is equal to marginal cost and still covers all fixed costs. It cannot do both in such cases except perhaps in a very long run sense where the costs of expanding

capacity should be included in the long run marginal cost of providing more units of output.

(II) When some unpriced part of one entity's production or consumption enters directly into the production or consumption function of some other entity, the unpriced byproduct is called an external effect. A positive external effect leads to underproduction or consumption of the good which generates the externality, while a negative externality causes overproduction or consumption of the good through a divergence between private and social optima. When the good being produced or consumed is the same as the externality which is jointly generated, the good is termed a public good. (See Bator,[1] and Mishan.[2]) Note that the external effect may be negative: what is a "public good" to some people can be a "public bad" to people with different tastes; what is national defense for some people may at times look like national offense to others also taxed to finance it.

A pure public good costs nothing to provide to additional persons once it is provided to someone and, in fact, cannot be denied to others. Few goods are universally public in this sense; national defense is probably the closest and most commonly cited. Many more are publicly or collectively consumed within a limited group or geographical range, such as radio and television

programs, for example. Note that public goods may be privately produced, and vice versa; for example, radio programs are usually privately produced but are publicly consumed at least within a limited geographical area, and electricity is often publicly produced but is privately consumed. Generally, however, public goods are publicly produced, because they would not be produced at all or only in less than socially optimal quantities by the private sector. Since no one can be excluded from consumption of a pure public good once production for someone's consumption has occurred, revenues cannot be gathered through a pricing mechanism. Radio and television programs are usually financed through the provision of advertising of private goods in conjunction with the program, but most public goods must be financed by taxes. Where pricing of publicly produced goods is possible these are examples of what governments believe to be "natural monopolies." Where user charges provide only part of the revenues necessary to finance the publicly produced goods and services, it must be thought that all benefits do not accrue to those who could be excluded through the price mechanism or that income redistribution toward those consuming these goods and services is itself a public good.

The concept of external effects has a long history. It was first noted by Marshall, but was not really

noticed by the profession in general until the developments by Pigou[3] and Knight.[4] Pigou refers to external effects as existing when there are "uncompensated services" or "uncharged disservices."[5] Pigou's example of the external diseconomies which factory smoke imposes on neighboring businesses and homes is probably the most frequently cited one. Pigou also notes examples of external economies ranging from city parks to scientific research.[6] The general principle that taxes and subsidies can be used by governments to solve these problems is also noted here.[7] Knight identifies the source of the problem as the absence of "the most essential feature of competitive conditions," namely the "private ownership of the factors practically significant for production."[8] Ellis and Fellner refer to the problem as the "divorce of scarcity from effective ownership."[9] Scarce goods are treated as if they were free because they are not privately owned and hence carry no market price as a rationing device, although to society they do have a positive shadow price.

Among the modern literature some emphasize the spill-over costs or benefits which external effects of production or consumption entail; others emphasize the lack of complete private property rights which leads to these externalities. (For the "property rights" literature, see Furubotn and Pejovich,[10] Demsetz[11] and

Alchian and Demsetz.[12]) At least some of those taking the "property rights" approach believe that this alternative way of looking at the same problem is a superior and more general theory.[13] While it is useful to be aware of both causes and effects, this extreme view appears self-serving.

Coase[14] showed that disregarding transaction costs, and income or wealth distribution effects and the resulting changes in consumption patterns, the composition of output is independent of the structure of property rights. While this is true, some take this as evidence that there is really no problem; bargaining will solve everything. But as has been forcefully argued by Mishan[15] both transactions costs and wealth effects are often significant. In the standard pollution example of a smoke nuisance transactions costs are significant because many damaged parties must get together to bargain with a few or single polluter(s). Where large damages are imposed on people, say by airport noise, a large proportion of their incomes would have to be devoted to paying airlines to reduce noise if the companies were legally allowed to create this noise otherwise. Because incomes are finite this can lead to people being willing to pay less to prevent pollution than they would have to be paid to allow it. In the extreme case pollution which endangers health and

therefore life has a value which is bounded by the injured parties' finite wealth if they must pay to avoid the damages, whereas there may be no amount of money which could induce them to allow the pollution. Thus more pollution may result where people must pay to prevent it than where they must be paid to allow it; the locus of liability significantly may affect the equilibrium composition output.

Until very recently the distinction between pollution, congestion, and the problems involving overexploitation of common property natural resources such as open access fisheries was not recognized. All these problems were grouped together by Ellis and Fellner.[16] Bator[17] called them ownership externalities and similar to Meade's unpaid factor case.[18] The "property rights" people still confuse them;[19] such is the penalty for their "more general" theory.

Rothenberg[(20)] has pointed out the distinction between pollution and congestion: crowding is said to exist when there are negative externalities generated by persons engaging in an activity which reduce other persons' enjoyment or productivity of engaging in the same activity. Thus additional users of a highway can cause congestion or crowding externalities which reduce other people's ability to use the same highway for the same purpose.

In contrast, pollution is said to exist when there are negative externalities generated by persons engaging in an activity which reduce other persons' enjoyment or productivity of engaging in other activities. Auto traffic generates emissions which may be unpleasant and/or unhealthy for pedestrians. The distinction between congestion and pollution is the difference between competing users and competing uses of scarce resources.

The study of open access or common property resources as distinct from other externalities problems began about twenty years ago with Gordon's article on fisheries.[21] This literature is summarized in the second part of this chapter. But these problems were not critically compared to congestion and pollution externalities until very recently.[22] Of course, congestion externalities are present in open access resources such as fisheries when boats and gear in the same fishery get in one another's way. Also pollution type externalities exist when there are gear or boat conflicts between different fisheries. However, the major difficulty in open access resources which prevents the equation of price and social marginal cost at the competitive equilibrium is the existence of positive rents at the socially optimal level of output which cannot be capitalized into the cost of the open access resource to its users. In an ordinary competitive equilibirum

where all inputs are owned by their users, the price will be equal to average costs including capitalized rents to scarce factors (according to Knight or to marginal costs excluding such rents according to Pigou). However, in a common property case such as an open access fishery the rents which should accrue to ownership of the common factor are not included in the average costs to which price becomes equal at equilibrium. Instead, the rents which exist at the socially optimal level of output in the common property case are viewed as profits by the firms because they cannot be capitalized into the cost of the factor. Because a greater share of these rents (profits) can be obtained only by producing a greater share of the output, these rents induce the entry of additional resources into the industry. Thus these rents act as a negative user cost by which potential entrants adjust their perceived real unit costs in making an entry decision. This entry stops where price equals average costs excluding rents to ownership of fishing rights and these rents have been dissipated through higher costs. Additional resources have been artificially attracted into the industry because the average cost to which price becomes equal does not include the normal capitalized rents to one of the scarce factors, namely, the fish.

All three of these ownership externalities cases involve too much output and too many inputs devoted to the activity. But their causes and the magnitude of their potential effects differ. In the pollution and congestion cases the causes are the failure of the economic actors to consider the spillover costs on other uses and users of an open access resource respectively. In the common property case it is an intertemporal externality caused by the nonappropriability of rents to ownership of the resource prior to the use of the resource.

The welfare loss in the common property case is bounded; the maximum welfare loss is the producer's surplus or rent available at the optimum output. The welfare loss in the congestion case is also bounded because the congestion externalities act to inhibit additional entry which would cause further congestion. In the pollution case, however, the welfare loss is not bounded; the seriousness of the externality has no effect on the equilibrium level of output.[23]

As with most problems the history of the common property problem is much longer than its study. The transition in Europe from the open fields and community property of the medieval manor system to the current system of ownership and use is the oldest well documented case of dealing with this problem.[24] In the United States common oil pools in the Southwest have led to the

incomplete solution of prorationing programs governing how fast anyone may pump oil. The use of forests and grazing lands in the early American West is another good example of the over-exploitation of natural resources that occurs when free and open access is allowed to resources whose ownership would involve rents if exclusion could be applied prior to use. The U.S. Forest Service and the Bureau of Land Management are now charged with management of these public resources so as to avoid these excesses. Part of the typical solution involves charging fees for the use of these public resources so that they are no longer "open access." Most fisheries have not yet followed suit, although the theoretical literature on fishery economics to which we now turn is rather extensive.

II-B: Fisheries Economics Theory: "Conservation is Essentially an Investment Decision."[25]

Vernon Smith[26] has criticized the fisheries economics theory that came before him on several grounds. Two of the most important criticisms have been that the model was not a dynamic model and that it did not allow for the possibility of species extinction. While Smith's contributions generally bolster the theory with modern mathematics, a closer examination of the work done prior to this is necessary to put his criticisms in perspective.

While as noted in the first part of this chapter there was some earlier recognition by economists of the importance of property rights to the idealized solution of the perfectly competitive model,[27] biologists generally worked alone on the problems of fishery management until the 1954 article by H. S. Gordon.[28] He showed that the market mechanism under competitive conditions fails to provide proper allocation of resources in fisheries because ownership of the fish is not established until the fish are captured. It is each fisherman's haste in attempting to establish ownership over as much of the catch as possible that forces the total catch and effort above competitive levels. The model first used by Gordon to show this assumes a relationship between equilibrium fish population and sustainable landings, combines this with a cost function and graphically derives the competitive equilibrium. This has been later termed a static analysis in the sense that it deals with the equilibrium, but in the modern language of dynamic models it is a steady state solution. Profits are constrained to be zero so that there is no entry or exit, and catch is constrained to be equal to the natural growth rate of the population. This latter assumption is so common to the biological literature that came before Gordon that it can be missed in the article if one is not looking carefully for it. This competitive solution is then compared to the social optimum which Gordon derives by assuming that the fishery is managed by a single profit

maximizing owner. The profit maximizing solution is socially optimal because it is assumed that the output of this one fishing ground has no impact on the price of fish. This assumption is tested for the Dungeness crab fishery in Chapter IV of this paper.

Perhaps a clearer derivation of these results is found in Gould.[29] Following Schaefer[30] the biological data are presented as growth rate of the fish stock dependent on the size of the stock rather than equilibrium population as a function of sustainable catch as in Gordon[31] and Scott.[32]

The equation system describing competitive steady state equilibrium in a fishery is thus

$$\dot{X} = F(X) \tag{1}$$

$$Y = G(E,X) \tag{2}$$

$$F(X) = Y \tag{3}$$

$$PY = WE \tag{4}$$

where X is the fish stock, F(X) is the time rate of change of the fish stock due to natural growth, Y is the annual catch, E is a composite variable for fishing effort, P is the price of fish and W is the cost per unit of effort. Both P and W are assumed constant to this fishery. From (1)-(3) a "sustainable yield curve" is derived

$$Y^* = Y^*(E) \tag{2'}$$

which is then combined with (4) to give the catch and

effort which solve the system. This is shown graphically on Figures II-1 and II-2. Figure II-1 shows the natural growth curve (1) with the production function (2) for different levels of effort superimposed. Above X_3 and below X_1 catch exceeds natural increase and the population will decline. Between X_1 and X_3 the natural growth rate exceeds the catch rate and the population will increase. Thus where the production function for a given level of effort cuts the natural growth curve from below, this is a stable equilibrium population and catch; but where the production function cuts the growth curve from above, the equilibrium is unstable. The "sustainable yield curve," $Y^*(E)$, shows in Figure II-2 the catch and effort combinations which give stable biological equilibria in Figure II-1. This sustainable yield curve does not vary gear selectivity as does the eumetric yield curve discussed on page 49. In Figure II-2 the sustainable yield curve is combined with the cost condition (4) to determine which of the biological equilibria is a competitive economic equilibrium in the sense of no entry or exit.

Note that in Figure II-1 the highest effort level for which the sustainable yield is positive is E_2. Thus if an effort level greater than E_2 were sustained, the population would go to extinction. This means that the

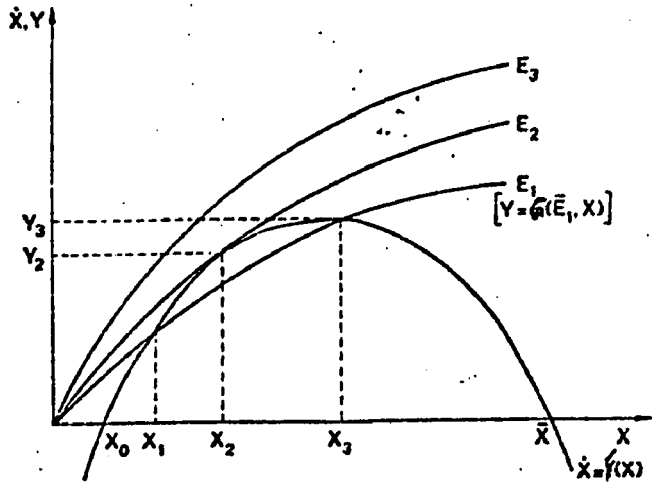

Figure II-1.--Deriving the sustainable yield curve.

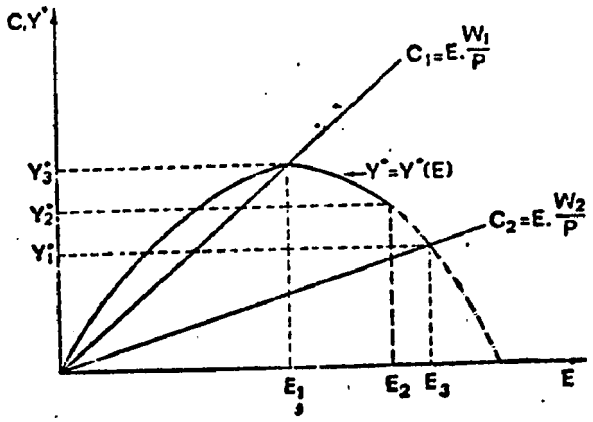

Figure II-2.--Determining competitive equilibrium catch and effort.

sustainable yield curve in Figure II-2 is discontinuous at E_2 and zero for effort above this level.

Gould[33] uses equations (1)-(4) to demonstrate the possibility of extinction in another way. He combines (2) and (4) to get a family of Y**(X) curves and then combines these with (1) and (3) to solve the system for the steady state values of X and $\dot{X}$. This is shown graphically in Figures II-3 and II-4. Figure II-3 shows a family of production functions in (Y,E)-space for various levels of the fish stock, X, and the zero profit condition (4). Where the production function crosses the zero profit line this gives the catch level for which the fishery is in equilibrium for the given fish population. From all of these catch-population pairs comes the "catch locus" shown in Figure II-4:

$$Y^{**} = Y^{**}(X) \qquad (2'')$$

There is a different position of this catch locus corresponding to different values of W and P. As P rises and W falls the catch locus shifts toward the origin. Where the catch locus lies to the right of the natural growth curve for all positive $\dot{X}$ as depicted by Y_2^{**}, the fishery is not sufficiently profitable to warrant exploitation. Where the catch locus lies to the left of the natural growth curve for all positive levels of $\dot{X}$ and X, the fish population will be driven to extinction by the fishery,

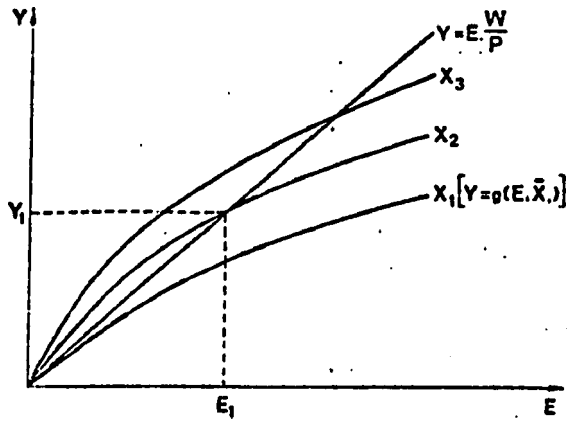

Figure II-3.--Deriving the catch locus curves.

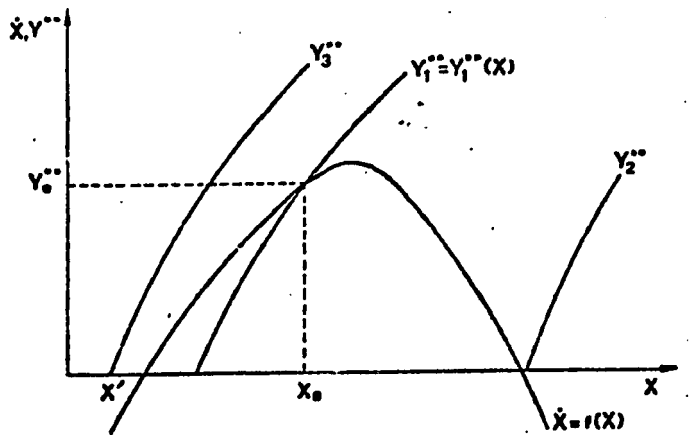

Figure II-4.--Exploring the possibility of species extinction.

although the fishing operations would cease at a positive population, X'.

Gordon[34] was not as specific about the upper range of the sustainable yield curve since he does not show the curve declining at high levels of effort, but neither does he specify a eumetric yield curve. The eumetric curve (see Beverton and Holt[35]) is composed of sustainable yield curves derived for different mesh sizes or other gear characteristic which allows variation of the minimum size or age of fish at capture. The envelope of the sustainable yield curves for all different minimum sizes at capture is the eumetric yield curve and describes the highest catch per unit of effort locus which can be attained by optimal variation of minimum size at capture simultaneously with effort. To follow the eumetric yield curve is to take into account the external effects of each fishing firm changing the minimum size of fish it captures as the total fleet effort changes. Individual firms have no incentive to do this in the absence of centralized management, or specific regulations encouraging it, so there is no reason to suppose that the competitive industry is ever on the eumetric yield curve except by accident.

Turvey[36] views the optimization process as composed of two suboptimizations. Suboptimization of mesh size with effort constant implies an increase in catch but

effort may increase or decrease depending on whether the demand for the fish is elastic or inelastic. Suboptimization of fishing effort with mesh size constant will decrease the amount of effort employed in the fishery but may increase or decrease the catch depending on whether the marginal social product of fishing effort is negative or positive. So moving from the competitive equilibrium to the optimum optimorum has an indeterminant effect on catch and effort.

Scott[37] makes it clear that while the early work in fisheries economics used a static or steady state model, this is not because it was not recognized that an appropriate solution to the problem involved maximization of net present value of the fishery over time through an optimum time path of landings considering the stock externality, i.e., the effect of catch on population in future periods. It was even recognized that the optimum did not necessarily involve any stationary population or sustainable catch. The maximization of current returns was only a short run objective when the sole owner or management authority could not count on being able to manage the fishery over time.[38] The possibilities of extinction of the population and of an unstable equilibrium with cycles of high and low catch years under the competitive solution were also noted by

Scott.[39] It seems clear that the problem was understood at that time better than the mathematics of the dynamic models necessary to model it. Summaries of this early work are found in volumes edited by Turvey and Wiseman[40] and Hamlisch.[41] Increasingly, the work of biologists such as Beverton and Holt,[42] Schaefer,[43] and Dickie[44] on growth rates versus population density, natural mortality versus age, and eumetric yield curves was incorporated into the economic theory.[45]

The model as presented by Turvey[46] is worth a closer examination as an illustration of the backward bending supply curve in fisheries, although it is simply another way of presenting equations (1)-(4). The upper part of Figure II-5 shows the hypothesized relationship between the fish population and the annual catch which this stock can maintain year after year. (This is a combination of equations (1) and (3).) The virgin population is OF where recruitment just offsets natural mortality. As fishing begins, the sustainable catch increases as fishing mortality replaces natural mortality and fewer fish are competing for available food stocks leading to an increased recruitment rate. For each level of the fish population in the upper part of the diagram there is a supply curve in the lower part of the diagram which shows the fishing costs given this fish population. (This adds a form of equation (2) to the combination of (1) and (3).) Only

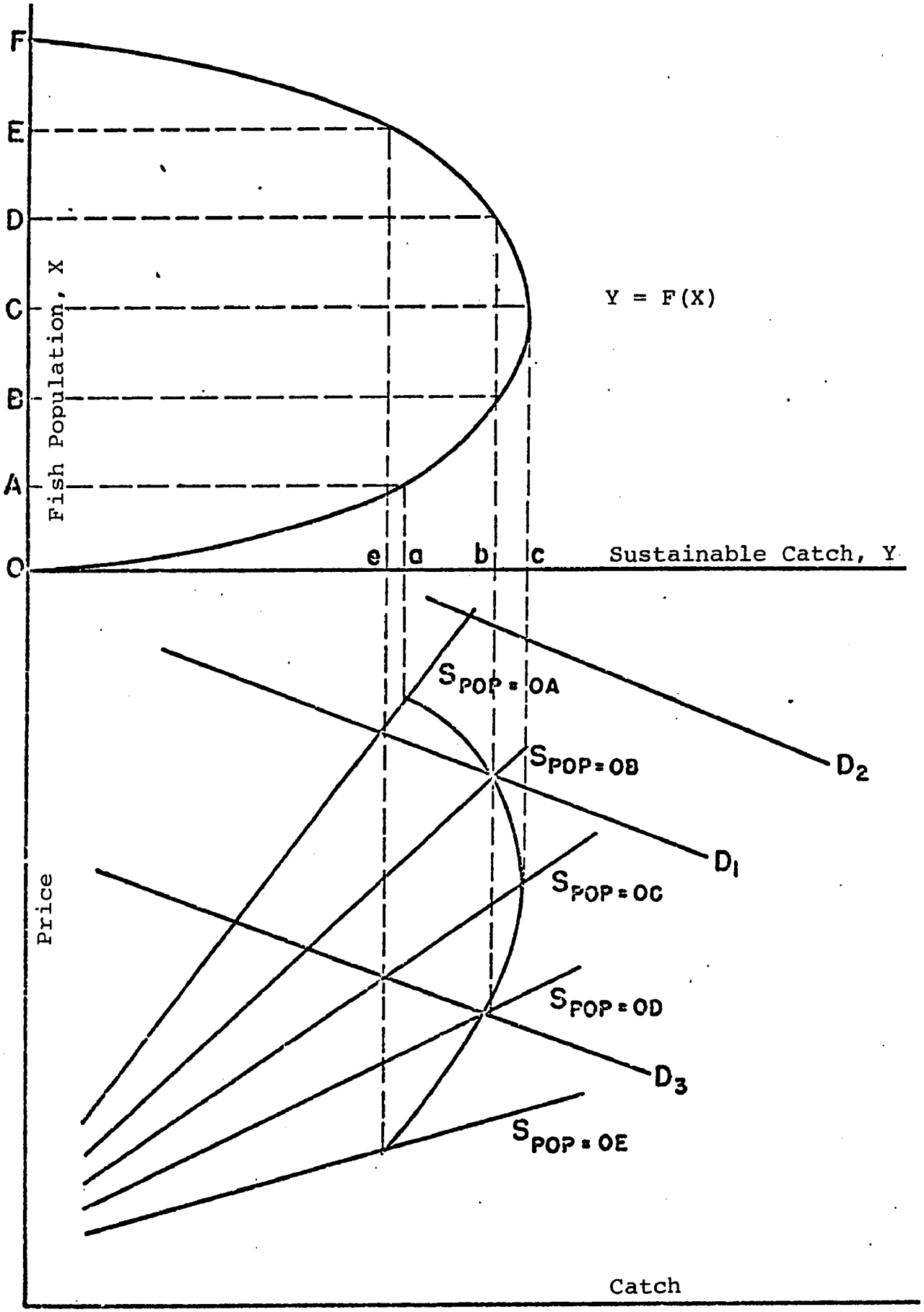

Figure II-5.--Static fisheries optimization model after Turvey.

one point on each supply curve corresponds to a sustainable catch at the given population level; the locus of these points is the long run supply curve for this fishing industry. If the industry demand is given by D_1, this is consistent with a fish population, OB, and a sustainable catch, Ob; note that this same catch is also consistent with a larger fish population, OD, which gives lower fishing costs. Although the additional effort is not needed to take a larger catch, the higher price resulting from D_1 will attract more resources than the lower price at D_3 unless management agencies interfere to restrict entry. If demand is large enough compared to the ability of the fish population to reproduce itself, as in D_2 or whaling, for example, effort sufficient to lead to extinction of the population can result. Only for fish stocks greater than OC and demand levels such as D_3 will the private competitive market lead to an equilibrium without more resources being used than would be necessary if the fish stocks had not already been depleted.

Crutchfield[47] adds that the low returns to fishermen are due to the near monopsonistic position of fish buyers in any given port (few dealers buying from many fishermen) as well as the dissipation of all economic rents, which might otherwise accrue to ownership of fishing rights, through excessive entry of effort into the fishery. In Turvey and Wiseman,[48] Crutchfield notes that the

same result in terms of resource allocation which is achieved through sole ownership or management agency incentives could be achieved through monopsonistic waterfront markets although the distribution of wealth would differ. This is noted again in Crutchfield and Pontecorvo.[49] However, it is also observed that "even though in many fisheries the degree of buyer concentration is high, the results to be expected from monoposony or effective collusive oligoposony are rarely observable."[50] An assessment of the extent of monoposony in the Washington coastal Dungeness crab fishery is given in Chapter IV.

Crutchfield and Zellner[51] review this early theory and give an algebraic derivation. In addition they formulate a model of port pricing with both fresh and canned demand for fish, and then test this model for the case of the Pacific halibut fishery.

Smith's main contribution[52] has been to couch the fisheries model in the language of dynamic mathematical models. However, his main results still refer to the steady-state solution, which makes one wonder why he should make such a big point of contrasting his steady-state solution of a "dynamic model" with earlier steady-state solutions to "static models." While it is an advancement to use phase diagrams rather than verbal reasoning to describe disequilibrium behavior, Smith stops short of deriving the optimal time path of catch, population and

effort which would make his model truly dynamic. While Smith may have contributed less than some claim, his model is worth closer scrutiny.

Smith postulates the following equation system as a behavioral model of a competitive fishery (There are some notational changes in this and other models so as to have a uniform system of notation.)

$$\dot{X} = F(X) - Y \tag{5}$$

$$\dot{K} = \delta\pi = \delta(PY - C(Y,X,K)) \tag{6}$$

$$P = C_1(Y,X,K) \tag{7}$$

where $\dot{X}$ is the net rate of growth of the fish stock and need not be zero except in equilibrium, K is the number of vessels or firms and a measure of capital investment, δ is some positive coefficient of entry/exit rate. In his 1969 version, Smith allows different rates for entry and exit of capital; still he notes that the equilibrium relations, $\dot{X} = \dot{K} = 0$, presuppose instantaneous output adjustment in accordance with firm profit maximization as given by (7).

Equation (5) is a combination of (1) and (3) given previously; (4) is another form of (6) in the stationary state; and (7) is the usual condition for profit maximization. Note that instead of incorporating the stock externality into the production function as in (2), Smith uses the cost function, C(Y,X,K). This gives rise to the

difference noted by Smith[53] that while the standard model has a cost function that is linear in the effort measure and a yield (and revenue) function which has a negative second derivative with respect to the effort measure, his model has a linear revenue function with output dependent only on the number of vessels and a backward bending cost function due to the external effects. In the stationary state equations (5)-(7) become

$$F(X) = Y \tag{3}$$

$$PY = C(Y,X,K) \tag{4'}$$

$$P = C_1 \tag{7}$$

In contrast to the competitive fishery Smith has the sole owner or manager maximizing $PY - C(Y,X,K) + \lambda (F(X) - Y)$ giving the necessary conditions

$$F(X) = Y \tag{3}$$

$$P - C_1 = \lambda \tag{7'}$$

$$P - C/X - C_3/Y = \lambda \tag{8}$$

$$C_2/F' = \lambda$$

where C_1 is marginal cost, C_2 is a negative stock or intertemporal externality, and C_3 is a positive crowding externality.

To get the competitive industry to act like the sole owner or manager Smith concludes that one must impose a catch tax of C_2/F' per unit of Y harvested and a license

fee of C_3 per unit of K employed in the fishery. The two taxes are required here because Smith has tried to dispense with the assumption of a single effort input other than the fish stock. In other models the catch tax can always be combined with the license fee to be either a single catch tax or a license fee because of the form of the production function assumed. If (2) is combined with Smith's model,[54] two taxes would no longer be required.

The notion that an appropriate catch tax or license fee could make the competitive industry behave in a socially optimal manner was recognized prior to Smith's work.[55] However, the correct magnitude of the tax(es) had not been calculated. In practice it (they) still cannot be calculated due to lack of data.

The question of choosing the appropriate minimum size of fish at capture has been treated by Turvey[56] and Smith[57] following the biological discussion of eumetric fishing by Beverton and Holt.[58] Turvey suggests that selecting the appropriate mesh size (or other measure of gear selectivity) always increases the catch but may increase or decrease effort depending on whether the demand elasticity for the fish in question is greater or less than one. Similarly, suboptimization of effort with mesh size constant will lower effort but may increase or decrease catch depending on whether the marginal social product of fishing effort is negative or positive. Turvey is careful to note that

these are steady state results comparing the competitive with the new equilibrium; short run effects may differ so that the discount rate used becomes important. Smith[59] says that in addition to the taxes suggested in his 1968 article a tax on mesh sizes different from the appropriate size should be levied and that the tax rate should be high enough to force everyone to use the appropriate mesh size; the distinction between such a tax and a regulation requiring everyone to use a given mesh size could only be in the size and timing of the penalty for noncompliance.

While Smith's formulation is an improvement over previous presentations of the same basic ideas, it is still a comparative statics model. Profits are maximized at a point in time subject to a zero rate of change of the fish stock in question. A truly dynamic model should maximize profits over time with fish stocks free to change as is optimal.

Quirk and Smith[60] attempt to build such a dynamic model. They compare a competitive general equilibrium model with two outputs including fish, and one generalized input plus the fish stock to an optimization of this system by centralized management.[61] Of course, to be able to use optimal control theory they assume perfect information about the future. On the other hand they assume that each of the firms ignores the effect of their own or

their competitors' actions on the price of fish or the resource stock. Then there is some confusion regarding whether it is each firm or the industry maximizing profits over time. There is no condition that the rate of entry or exit be equal to zero in the competitive equilibrium as there was in Smith[62] and in one form or another in the previous theory; later in their paper they introduce this as a special case. Only the stock externality is considered here, i.e. possible crowding or mesh externalities considered by others are neglected. As a result of this and the reverting to include (2) to capture the stock externality rather than including it in the cost function there is only a single catch tax required to get the competitive industry to behave as the centralized management or sole owner would. This catch tax differs from that obtained by Brown[63] in a more convincing, although less ambitious, dynamic formulation, because Quirk and Smith neglect the change in the necessary conditions for the social optimum which Arrow[64] notes is required when using an infinite time horizon.

Brown[65] has the central manager maximizing (There are some notational changes made to standardize notation.)

$$\int_0^\infty (PY - WE)e^{-\rho t}$$

subject to

$$\dot{X} = F(X) - Y \tag{5}$$

$$Y = Xg(E/X) \geq 0 \tag{2'''}$$

where $g(E/X) = G(E,X)/X$ and $Y = G(E,X)$ is linear homogenous and concave. The appropriate current value of the Hamiltonian for this maximization is

$$H = ((Pg(E/X) - \frac{WE}{X})X + \gamma(F(X) - Xg(E/X)))e^{-\rho t} \tag{10}$$

The necessary conditions in addition to satisfying (5) and (2''') are

$$\frac{\delta H}{\delta\left(\frac{E}{X}\right)} = ((P - \gamma)g' - W)X \leq 0 \tag{11}$$

$$\dot{\gamma} - \rho\gamma = -\frac{\delta H}{\delta X} = -((P - \gamma)(g - (E/X)g') + \gamma F') \tag{12}$$

and the transversality conditions

$$\lim_{t \to \infty} \gamma X e^{-\rho t} = 0 \quad \text{and} \quad \lim_{t \to \infty} \gamma e^{-\rho t} \geq 0 \tag{13}$$

Sufficient conditions are satisfied by assuming that the production function is concave, $P > \gamma$, and the following concerning the growth of the resource stock, $F(X)$: $F' < 0$, $F'' \leq 0$, $F'(X^o) = 0$. A centralized management authority would thus choose the catch and effort which would satisfy the above conditions for this maximization problem.

Alternatively, the same results could be obtained from a competitively organized fishery if the management agency levies a catch tax of γ per unit of catch and a license fee or tax on effort employed in the fishery of

$$T = (P - \gamma) \quad (g - g'(E/X))/(E/X) \tag{14}$$

per unit of E/X employed. The catch tax, γ, is the marginal value of the resource stock. To show that the license fee (14) is required in addition to this catch tax, note that given the catch tax, effort will be devoted to the competitive fishery until

$$W = (P - \gamma)\ g(E/X)/(E/X) \tag{15}$$

because the average cost of production in the fishery will be equal to the marginal opportunity cost elsewhere. Impose a tax on the return to effort so that (15) becomes $(W - T)/(P - \gamma) = g(E/X)/(E/X)$. Solve for T using the return to effort as given by (11) in the social maximization model to get (14). If a tax on effort employed in the fishery were not required in addition to the catch tax, γ, then we would get $T = 0$. This license fee or tax on effort is zero when $g' = g(E/X)/(E/X)$, i.e. when the marginal return to effort is equal to the average return.

These two taxes may be combined into a single catch tax of $(\gamma + T/g(E/X)/(E/X))$ <u>or</u> a single license fee of

$T + \gamma g(E/X)/(E/X)$. As was noted earlier this simplification is possible because of the form of the production function assumed, i.e. (2), such that there is only one input other than the fish stock. In practice this would not be possible unless the production function happened to be of the fixed coefficients type. While there is some evidence of constant returns to scale[66], and factor substitution is probably slight in the short run, it is unlikely that the catch tax and license fee could be combined successfully in practice.

Biologists have traditionally advocated a maximum sustained yield (MSY) position as optimal for fisheries. Economists have argued that the economic optimum must lie at a point on the sustainable yield curve, $Y^*(E)$ to the left of the maximum where catch and effort are lower (see Figure II-2). The standard argument is that the MSY point would be optimal only if there were no production costs. However, Plourde[67] shows that as long as there is a positive discount rate, a maximum sustained yield program such as has traditionally been advocated by biologists is non-optimal even if there are no production inputs other than the fish stock. When production costs are introduced, the optimal steady state resource population is increased and catch is decreased just as one would expect.

As Brown notes[68] Smith's[69] omission of an interest rate results in a social maximum occurring at the point

of maximum sustained yield when there is no stock externality as long as the value of the resource stock is positive. This sort of error by omission is especially hard to excuse when committed by someone who makes such a point of claiming to be using a dynamic model whereas most people have used a static one.

One of the special cases considered by Quirk and Smith[70] is worth closer scrutiny because the simplifying assumptions of "mass contact rate" fishing technology and costs proportional to effort seem generally appropriate to many fisheries. The behavioral equations for such a competitive fishery are

$$\dot{X} = F(X) - G(E,X) \tag{5}$$

$$\dot{E} = J(\beta) \qquad J'(\beta)<0, J(0) = 0 \tag{16}$$

where

$$\beta = (PY - WE)/E = \frac{\pi}{E} \text{ and } G(E,X) = \alpha EX, \alpha \text{ a constant}$$

so that (5) and (16) become

$$\dot{X} = F(X) - \alpha EX \tag{5'}$$

$$\dot{E} = J(\alpha XP - W) \tag{16'}$$

From (5') and (16') the phase diagrams, Figures II-6 through II-10, are then derived.

Depending on the population size, X, and the extent of effort, E or K, for which biological equilibrium,

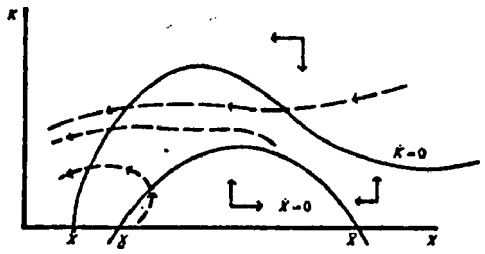

Figure II-6.--Species extinction.

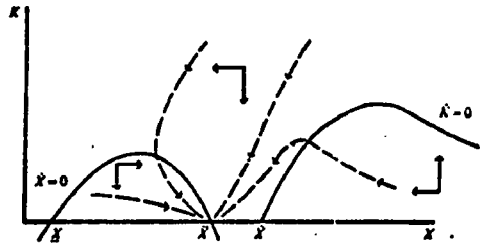

Figure II-7.-- Nonprofitable harvesting.

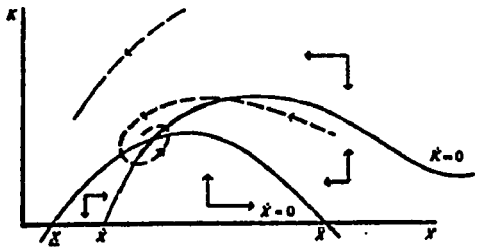

Figure II-8.--Fishing cycles.

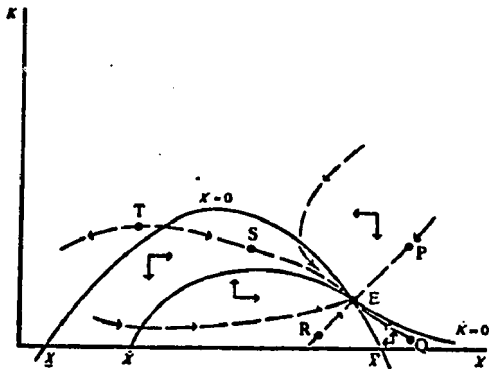

Figure II-9.--Stable, sustained yield harvesting.

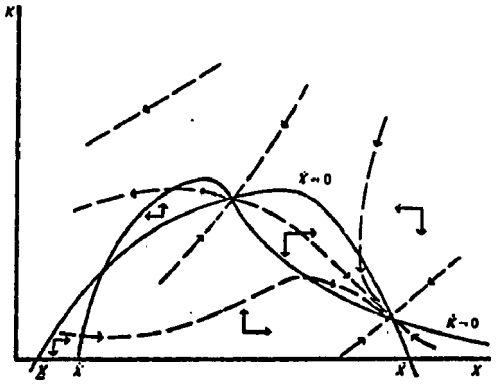

Figure II-10.--Multiple equilibria.

$\dot{X} = 0$, and economic equilibrium, $\dot{K} = 0$, occur one of these phase diagrams will be appropriate. The possibility of fishing cycles resulting from the interaction between biological and economic equilibrium conditions is especially interesting in view of the biologist's belief that the causes of such cycles for the Dungeness crab fishery are strictly biological. Their meaning it appears is that the $\dot{X} = 0$ curve is stochastic rather that deterministic and hence does not appear stable. Such movements in the curve may indeed be more important than the interaction of economic and biological factors illustrated in the phase diagrams. At a minimum such stochastic elements are a significant complication in estimating the equations of the system.

While there has been much written over the last twenty years on the theoretical optimum for management of a fishery resource, only recently has any work been done on quantifying the benefits of the shift in policy necessary to achieve the optimum. The first of these estimates was done in 1969 by Crutchfield and Pontecorvo for the Bristol Bay and Puget Sound salmon fisheries.[71] Other estimates have been made for the Georges Bank haddock fishery,[72] the California anchovy fishery,[73] the North Atlantic lobster fishery,[74] and others[75,76]. Estimates of the amount of redundant effort in present fisheries range from 30 per cent[77] to nearly 90 per cent.[78] The predictions of the theory that excess effort would be a chronic problem

for common property resources such as fisheries have proved true to a greater or lesser degree in all the fisheries studied thus far. We now turn to the case of the Dungeness crab fishery on the Washington coast.

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CHAPTER III

EVALUATING THE EXTENT OF EXCESS EFFORT

III-A. Applying Fisheries Economics Theory

As we have seen in Chapter II an unregulated competitive fishery employs more resources than are needed to catch and land the fish. Also the catch is larger in early years of the fishery than would be the case under optimal unified management so that extinction of the species may occur if demand is great enough. Species extinction could occur under optimal management, but this would be much rarer.

In the Dungeness crab fishery a minimum size limit was imposed by agreement between fishermen and management agencies early in the history of the commercial fishery. As discussed in Chapter I this size limit plus prohibition of harvest of females protects the species from extinction. The effect of these regulations on the shape of the sustainable yield curve is shown in Figure III-1. The shape of the resulting curve may be explained as follows: Starting with a virgin population and no fishing effort there is an initial range of increasing catch and effort as fishing mortality replaces natural mortality and pressure on food stocks, including in this

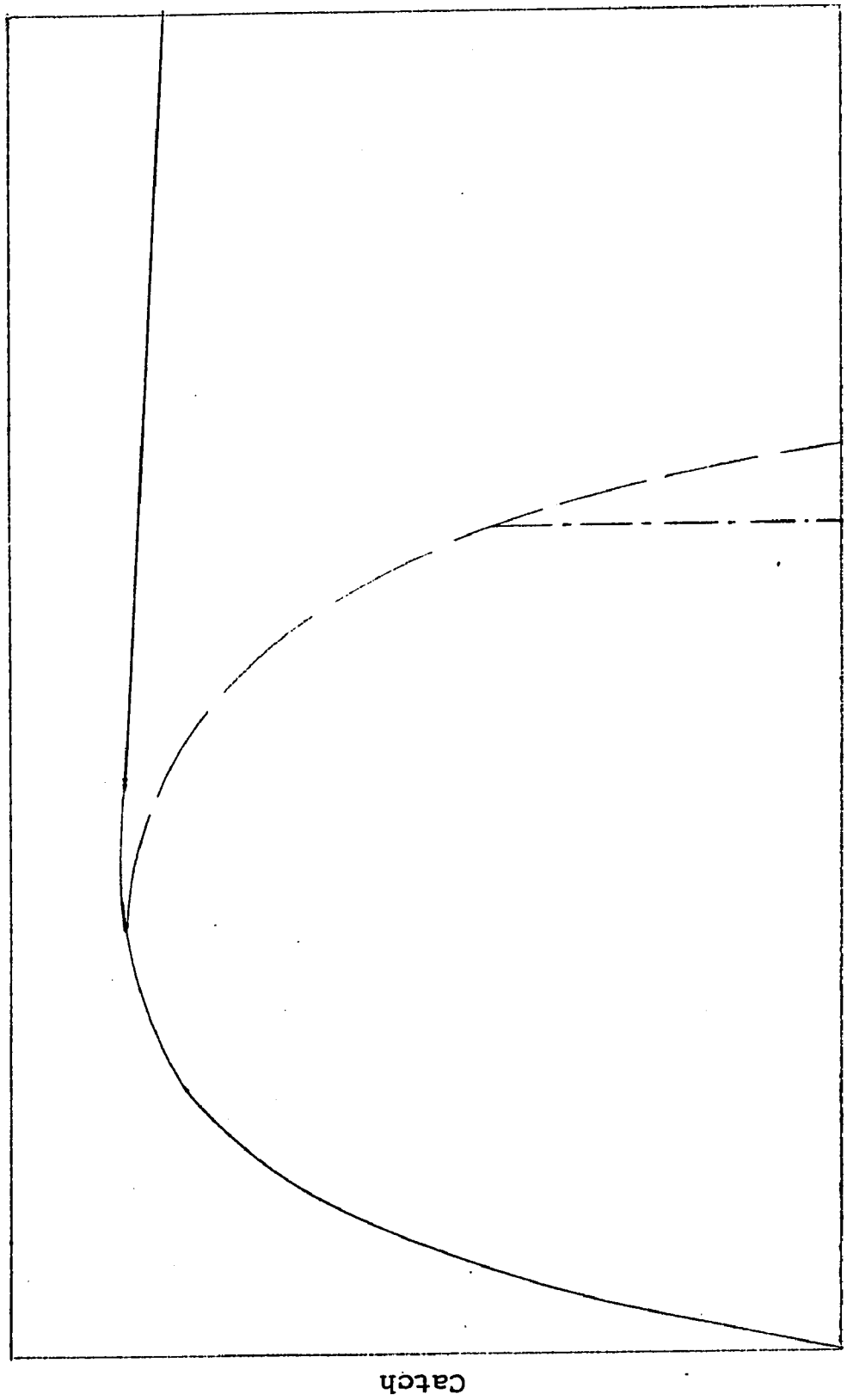

Figure III-1.--The effect of size and sex limits on the shape of the sustainable yield curve in the Dungeness crab fishery.

case cannibalism of very young crabs by older ones, is reduced. As fishing effort increases further fishing mortality eventually replaces natural mortality completely and all additional benefits of reduced pressure on food stocks are exhausted; this is called the maximum sustainable yield point (MSY). Beyond MSY additional effort would reduce the ability of the population to reproduce itself in future years and might eventually lead to extinction of the resource if effort is large enough. Recall that in Chapter II it was noted that beyond a certain effort level the sustainable yield curve goes discontinuously to a zero catch level.

In the Dungeness crab fishery biologists believe the effects of additional effort beyond MSY on the sustainable yield curve have been largely if not totally negated by the minimum size limit for males and the total prohibition against harvest of females. Whether these regulations result in the curve leveling off at the MSY catch or declining slightly after MSY but bypassing the discontinuous species extinction section of the curve, depends upon the impact that legal sized males have on the ability of the species to reproduce itself and the extent to which handling mortality and capture of crabs in soft-shelled condition increase with the amount of fishing effort. Clearly current regulations prevent species extinction, but they probably do

not prevent some decline in the sustainable yield curve beyond MSY. The same rush to establish ownership over a larger portion of the available population which leads to excess effort being employed in the fishery also causes some waste of haste: it costs more to do things more quickly. Beyond this there is a loss in total meat yield from a given population because crabs are harvested in soft-shelled or marginal condition more frequently and returned to the sea less carefully than would be the case if ownership of these animals, if and when they were later harvested, could be assured prior to their capture. Just like many common oil pools the faster the attempted rate of exploitation of the resource, the less total output resulting from it. (On the modeling of production from oil pools, see Kuller and Cummings.[5])

As noted in Chapter I the size limit is set at about the right size from the limited biological data available to assess the question. In Turvey's[1] terms suboptimization of gear selectivity is assumed to have been approximately accomplished by existing regulations; this is certainly more than can be said for many fisheries.

It is clear, however, that the problem of excess effort is a serious one in this fishery just as the theory reviewed in Chapter II suggests and as is observed in other fisheries. The issue this chapter

addresses is, "How much effort is redundant and how much could be saved by a change in management policies?"

The first step in answering this question is to get some measure of the capability of the current technology to catch Dungeness crabs. That is, "What would be the average catch per unit of effort if the productivity of the effort were not reduced by having excess effort employed in the fishery?" As noted in Chapter I the catch and, by inference from Cleaver's early work,[2] the availability of crab has varied widely over the years. Largely in response to this, the extent of effort and the catch per unit of effort have also varied. If the catch per unit of effort has been higher in the past than currently, then it could be that high again under similar circumstances.

Care must be taken to insure that circumstances really are similar. Most importantly biological conditions affecting the size of the fish population must be held constant as they were in the construction of sustainable yield curves in Chapter II. Whenever the fish population changes due to changes in biological conditions, a new sustainable yield curve applies. As we have seen in Chapter I, fishery biologists believe that such changes are annual occurrences in the Dungeness crab fishery. So in this fishery at least we have a different sustainable yield curve each year. For this

reason any attempt to estimate anything more than an "average" sustainable yield curve from the time series data will fail here.

From biologists' statements that all available crab are taken each year and more effort would not produce more catch we can infer that at least the MSY level of effort is employed each year and that the catch level resulting from this effort lies on or above the sustainable yield curve. It could not lie above the curve because sex and size limits are said to prevent this year's catch from affecting future years' population. It follows that higher catch levels are evidence of higher population levels and of higher sustainable yield curves.

In the choice of an appropriate base year it is not always possible to find one where the catch and population levels were the same as in the current year. In such cases choice of a base year with a smaller catch and population will provide a minimum estimate of the current excess effort. This is because the effort necessary to catch crabs varies inversely with their density in an area which in turn varies with the size of the population. The possible catch per unit of effort is thus an inverse function of the population size. This procedure controls for the change in productivity of the gear which results from changes in the average density of available crab in the area where pots are set.

Having chosen a base year with population less than or equal to the current year, catch per unit of effort is compared in the two years. The catch in the current year could be taken with effort of not more than this current catch divided by the base year catch per unit of effort. This gives an estimate of the amount of effort which is required in physical terms to land the available catch. Less effort than this would mean some crab would not be caught and more effort would not land any more crab. Thus the MSY level of effort is estimated. This provides annual estimates which could not alternatively be provided by estimating the sustainable yield curve and then finding its maximum because as was noted earlier the time series of catch and effort combinations do not all lie on the same sustainable yield curve for this fishery. While there may well have been excess effort in any base year chosen and productivity of crab pots may have improved over the years since the adoption of this technology, this procedure provides a minimum estimate of the current extent by which effort exceeds the "required" or MSY level. If effort exceeds the MSY level, it will per force exceed the economic optimum level.

The estimated extent of excess effort over the MSY level will vary from year to year partly due to current changes in the actual extent of excess effort over the

MSY and economic optimum levels as the crab population and the actual amount of effort vary. The estimate will also vary due to similar fluctuations in the extent of excess effort in the base years chosen. There is no evident way of avoiding the problem of an unknown amount of excess effort in the base year. One can simply say that the estimate obtained is a minimum estimate of the extent of excess effort in the year being evaluated assuming that there was sufficient effort in the base year to take the available catch.

III-B. Annual Estimates of Excess Effort

To implement this procedure a measure of effort must be chosen. A composite measure would be preferred on theoretical grounds, because the catch per unit of such an effort measure would be insensitive to changes in the mix of inputs composing it. Such a measure was assumed in the theory reviewed in Chapter II. Unfortunately, neither historical records of such a measure nor data necessary for its construction are available. Data are available on the number of boats, fishermen and pots or traps employed in the fishery. As noted in Chapter I these pots have been the accepted gear used for catching Dungeness crabs commercially for about 40 years; their size and construction has changed little in that time. Both boats and fishermen are employed in

other fisheries at other times of year, but the pots have no other use. If one set out to build a composite effort index, the pots would clearly play a central role because of the mass contact nature of the technology. Given the crab population available, the catch per pot depends on the number of pots, the length of time each is left to fish or "soaking time," the frequency with which the pots are emptied, the location of the pot in question relative to the available crab population and to other pots, and the bait. These variables are only indirectly tied to the number of boats and fishermen in the fishery. Unfortunately data are available only on the number of pots used each year and not their "soaking time," etc. Data on the average catch per unit of effort measured in pounds per pot are available annually since this technology became accepted.

Looking now at the annual catch and effort data for the Washington coast as given in Table III-1 we see that the maximum catch per pot occurred in 1941 at 1260 pounds per pot. The catch in that year was just under 5-1/2 million pounds. If it is true that the catch in each year is the same proportion, i.e., nearly all, of the available crab population, it is valid to use this as the base year for all years in which the catch was greater than or equal to the 1941 catch. As noted in Chapter I the study which is commonly cited as evidence for the

TABLE III-1
CATCH, EFFORT AND ESTIMATED EFFORT REQUIRED FOR MSY IN WASHINGTON'S COASTAL DUNGENESS CRAB FISHERY

Year	Catch (Pounds)	Effort (Pots)	Catch/ Effort (Pounds/ Pot)	Estimated Pots Needed for MSY	Estimated Required as % of Actual Pots
1935	997,008	3,563	279.8		
1936	1,317,732	3,610	365.0		
1937	2,088,014	2,863	729.3		
1938	2,219,444	3,185	696.8		
1939	2,773,500	4,075	680.6		
1940	4,475,936	3,780	1184.1	3,780	100.0
1941	5,468,538	4,340	1260.0	4,340	100.0
1942	4,646,818	5,010	927.5	3,924	78.3
1943	3,841,300	5,375	714.7	≤3,780	≤70.3
1944	4,234,838	12,600	336.1	≤3,780	≤30.0
1945	3,406,020	10,750	316.8	≤3,780	≤35.2
1946	5,723,554			4,543	
1947	10,460,352	15,300	683.7	8,302	54.3
1948	13,923,448	22,100	630.0	11,050	50.0
1949	11,849,052	20,650	573.8	9,404	45.5
1950	4,245,122	16,450	258.1	≤3,780	≤23.0
1951	3,306,994	10,650	310.5	≤3,780	≤35.5
1952	3,349,130	10,300	325.2	≤3,780	≤36.7
1953	5,813,904	11,675	498.0	4,614	39.5
1954	6,643,560	18,300	363.0	5,273	28.8
1955	5,936,481	15,600	380.5	4,711	30.2
1956	8,245,164	18,225	452.4	6,544	35.9
1957	10,754,569	13,600	790.8	8,535	62.8
1958	11,465,735	14,900	769.5	9,100	61.1
1959	7,688,703	16,800	457.7	6,102	36.3
1960	6,108,953	21,585	283.0	4,848	22.5
1961	5,470,064	18,475	296.1	4,341	23.5
1962	4,385,908	17,550	249.9	≤3,780	≤21.5
1963	5,145,104	18,115	284.0	4,346	24.0
1964	3,599,076	17,965	200.3	≤3,780	≤21.0
1965	6,541,713	17,845	366.6	5,192	29.1
1966	10,772,960	17,275	623.6	8,550	49.5
1967	8,668,138	18,400	471.1	6,879	37.4
1968	8,521,746	19,524	436.5	6,763	34.6
1969	18,026,853	26,300	685.4	14,307	54.4
1970	17,161,645	34,000	504.8	13,620	40.1
1971	12,520,995			9,937	
1972*	9,286,498	45,595	203.7	7,370	16.2
1973*	4,332,392	42,161	103.0	≤3,780	≤ 9.0
1974*	3,630,260	31,580	115.0	≤3,780	≤12.0

Sources: Washington Department of Fisheries (WDF) and National Marine Fisheries Service (NMFS) records for catch and effort data.
*Seasonal rather than annual data.

belief that nearly all available crab are caught each year was done in 1947-48.[3] In 1947 the average catch per pot was about the same as in 1939 although the catch was much larger. While the low catch per unit of gear in the early 1930's probably reflects use of the old ring net technology, the change to the new technology was largely completed by the late 1930's. Thus 1940 and 1941 are probably about the earliest to reflect nearly all of the available population. The 1940 and 1941 catch per pot figures are probably high partly because people were just fully realizing the potential productivity of the new technology and partly because of the rapidly increasing alternative job opportunities at the end of the Depression and the beginning of World War II.

Using the 1941 experience as a standard only 7370 pots should have been required to take the 1972 season's coastal crab catch of 9,286,498 pounds in Washington. This number of pots is estimated to be "required" in the sense that any fewer pots would not enable the fishery to land as many pounds of crab. To the extent that there were more crab available in 1972 than in 1941, this is an over-estimate of the number of pots required to take the 1972 catch. Comparing the required number of pots to the 45,595 pots actually employed in the 1972 season we can see that only 16.2 percent of the effort employed was really required.

The same procedure could be used for 1973 or any other year to determine the number of pots required compared to the number actually employed. In the 1973 season the catch was only 4,332,392 pounds and a base year with a catch less than or equal to this should be chosen; 1941 will not do here. Indeed, most years of experience had landings greater than in the 1973 season and ones that did have lower landings were swamped with excess effort carried over from years of better fishing just as was the case in 1973. The best procedure here is to take the 1940 figure of 1184 pounds per pot with a catch of 4,475,936 pounds. Certainly no more effort should have been required to take the somewhat lower 1973 catch. Thus no more than 3780 pots should have been required in 1973, and probably less. Comparing this to the 42,161 pots actually employed in the 1973 coastal crab fishery in Washington we see that only 9 percent or less of the pots actually employed were required.

As the available crab population and the extent of effort employed in the fishery fluctuate over time the proportion of effort employed which is really required for MSY also fluctuates as is shown in Table III-1. This proportion tends to be higher when the available crab population is high and/or increasing and lower when it is low and/or decreasing. This will inevitably pose

problems for attempting to improve management of the fishery. Both the amount of effort required for MSY and the optimal amount of effort vary from year to year as do the differences between the actual, MSY, and optimal amounts of effort.

III-C. Cross Sectional Estimates of Gear Efficiency

In addition to the time series data on mean catch per pot for the fleet there is data on mean catch per pot by vessel in four recent seasons: 1968, 1969, 1970, and 1972. In each year in the time series, estimates of the total number of pots in the fishery were made by interviewing a sample of the vessels engaged in the fishery. Only in the four years cited have the detailed results of these surveys by vessel been available along with comparably detailed records of catch by vessel. The distribution of catch per pot by vessel for these four years has been explored to see whether there is enough stability of the basic distribution or systematic change in it to be able to infer anything about the years for which the detailed data were not saved. In particular, is the mean catch per pot used to calculate required effort the best figure to use or would some other point on the distribution be preferable?

Figure III-2 shows the distribution of catch per pot by vessel for 1968-70 and 1972 scaled by dividing by the

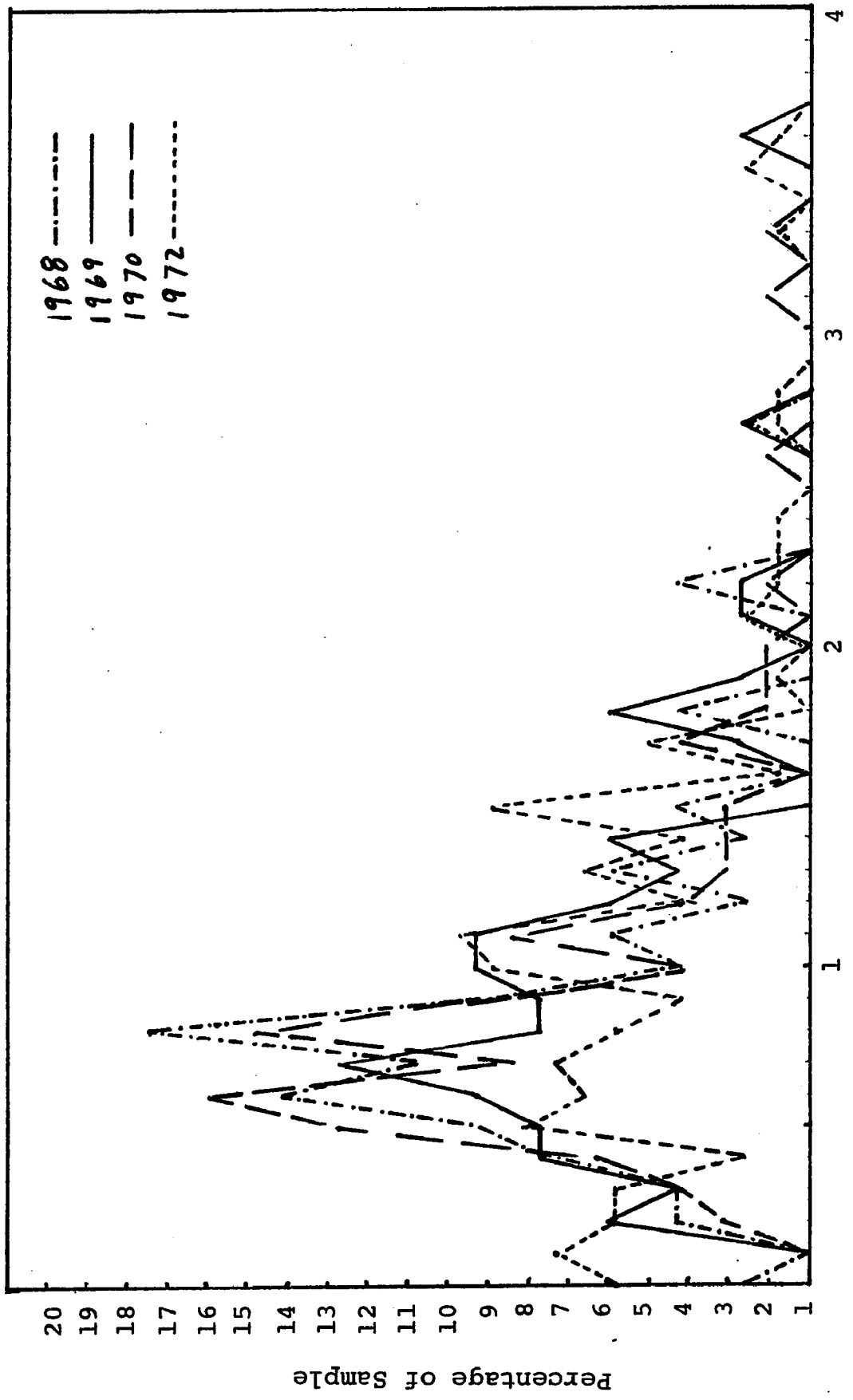

Figure III-2--Distribution of catch per pot by vessel for 1968, 1969, 1970 and 1972.

means of the respective distributions. From this it appears that the 1968-70 distributions may be the same but the 1972 distribution probably differs; this is confirmed by goodness of fit tests. All the distributions are positively skewed so that the median is always below the mean. Table III-2 gives the mean, median, standard deviation, third and fourth moments of these distributions. Table III-3 gives percentile levels for each distribution. This shows, for example, that 80 percent of the vessels caught less than 908.43 pounds per pot in 1968, 1255.30 pounds per pot in 1969, 717.68 pounds per pot in 1970 and 313.45 pounds per pot in 1972. Table III-4 shows these percentile levels as multiples of the respective means. Thus 80 percent of the vessels caught less than 1.48 times the mean catch per pot for all vessels in 1972 compared to 1.22 times in 1968. The percentiles at which the means occur are 70.49 in 1968; 58.33 in 1969; 69.15 in 1970; and 52.38 in 1972.

Comparing these distributions to theoretical distributions by means of goodness of fit tests it was found that the 1969 distribution may be termed a Gamma(3,1) and that it cannot be rejected that 1968 and 1970 are also Gamma(3,1) even at the 10 percent level. The 1972 distribution is not so easily characterized by a theoretical distribution, but a Chi-square(3) provides a better fit than a Gamma(3,1) or a Gamma(2,1). The 1972

TABLE III-2

DESCRIPTIVE MEASURES FOR THE 1968-70 AND 1972
DISTRIBUTIONS OF CATCH (POUNDS) PER POT BY VESSEL

	Mean	Median	Standard Deviation	Third Moment	Fourth Moment
1968 Season	745.31	573.80	848.68	3,311,100,000	19,253,000,000,000
1969 Season	972.05	871.36	612.73	381,210,000	966,850,000,000
1970 Season	594.96	462.07	482.00	337,000,000	744,520,000,000
1972 Season	211.97	203.18	158.35	4,957,100	3,209,300,000

TABLE III-3

PERCENTILE LEVELS FOR 1968-70 AND 1972 DISTRIBUTIONS
OF CATCH (POUNDS) PER POT BY VESSEL

Percentile	1968 Season	1969 Season	1970 Season	1972 Season
10	310.09	377.45	254.17	26.37
20	386.14	497.94	321.93	72.46
30	460.16	631.79	364.40	118.43
40	514.67	703.58	403.01	154.13
50	573.80	869.06	460.36	202.70
60	621.10	972.64	516.97	228.73
70	688.52	1085.60	606.39	266.58
80	908.43	1255.30	717.68	313.45
90	1109.70	1706.30	1039.20	365.96

TABLE III-4

MULTIPLES OF MEANS AT WHICH PERCENTILES OCCUR
FOR 1968-70 AND 1972 DISTRIBUTIONS OF
CATCH (POUNDS) PER POT BY VESSEL

Percentile	1968 Season	1969 Season	1970 Season	1972 Season	Average
10	0.42	0.39	0.43	0.12	0.34
20	0.52	0.51	0.54	0.34	0.48
30	0.62	0.65	0.61	0.56	0.61
40	0.69	0.72	0.68	0.73	0.70
50	0.77	0.89	0.77	0.96	0.85
60	0.83	1.00	0.87	1.08	0.95
70	0.92	1.12	1.02	1.26	1.08
80	1.22	1.29	1.21	1.48	1.30
90	1.49	1.76	1.75	1.73	1.68

distribution is flatter with more bunching near the low end than the 1968-70 distributions.

Although the distribution cannot be said to be stable from year to year, the changes are not random. Roughly the same forces that cause the difference in the means from year to year also cause the shape of the distribution to change. In the record catch year of 1969 those who would stop fishing their pots earlier in the season in a more normal year like 1968 continued to fish for a longer time because the fishing was good, i.e., the catch per pot was high. So the same forces which caused the high mean catch per pot in 1969 also reduced the positive skewness of the distribution somewhat. In 1970 the catch was nearly as great as in 1969, but entry of additional effort which depressed the average catch per pot also made it less profitable for marginal fishermen to continue fishing as long as they had in 1969. In 1972 the catch had declined to about the 1968 level after the record 1969 and 1970 catch years, but the number of pots employed had more than doubled. The 1972 catch was taken quickly and many boats either quit early or moved their pots to Oregon or Alaska looking for better fishing where they might at least cover variable costs. As the arena was vacated by those showing average catch per pot below the mean, more was left for those showing above average catch per pot. The combined effect was to

flatten the distribution considerably in 1972 as well as lowering the mean so that the positive skewness was largely eliminated.

Summarizing the results of the investigation of the distribution of catch per pot by vessel in recent years we see that the forces causing the mean to fluctuate also affect the nature of the distribution around the mean; in particular the extent of positive skewness is affected. The higher the mean the lower the proportion of effort employed which is redundant as shown in Table III-1. When this mean is highest the distribution may be best characterized as Gamma(3,1) and its mean occurs at about the 60th percentile. The closer the fishery is to having no excess effort, the closer the distribution is to a Normal(1,1). If much excess effort is eliminated by a large increase in the available crab population, then there are fewer marginal fishermen who quit before the rest of the fleet because they are not covering their variable costs. If excess effort were eliminated by auctioning of a limited number of fishing licneses, then marginal fishermen would be eliminated by not being able to bid as much for a license. (See Chapter V for more discussion of policy alternatives.)

What are the implications of this study of distributions of catch per pot by vessel for the determination of the extent of excess effort in a given year? Taking

the mean catch per pot in a base year selected to have no more available crab than in the year being evaluated, as was done earlier in this chapter, provides an acceptable measure of potential gear productivity. About 40 percent of the vessels probably could do better and 60 percent not as well for a typical base year where there is still some excess effort. As the extent of excess effort is reduced, closer to 50 percent of the vessels or firms could be expected to do better than the mean. It still seems best to take the mean catch per pot in the base year as the measure of expected productivity rather than some multiple of the mean or any other single value. It is also still best to regard the resulting estimate as a minimum estimate since reducing the extent of excess effort in the base year would raise the expected productivity of the gear and reduce the positive skewness of the distribution.

III-D. Value of Excess Effort

It would be well at this point to remind ourselves of the difference between the MSY and the economically optimal amount of effort. Figure III-3 reproduces the essential parts of Figure II-2. Note that physical rather than dollar units are used on the axes. Following the literature reviewed in Chapter II, constant returns to scale are assumed. Thus the "total costs"

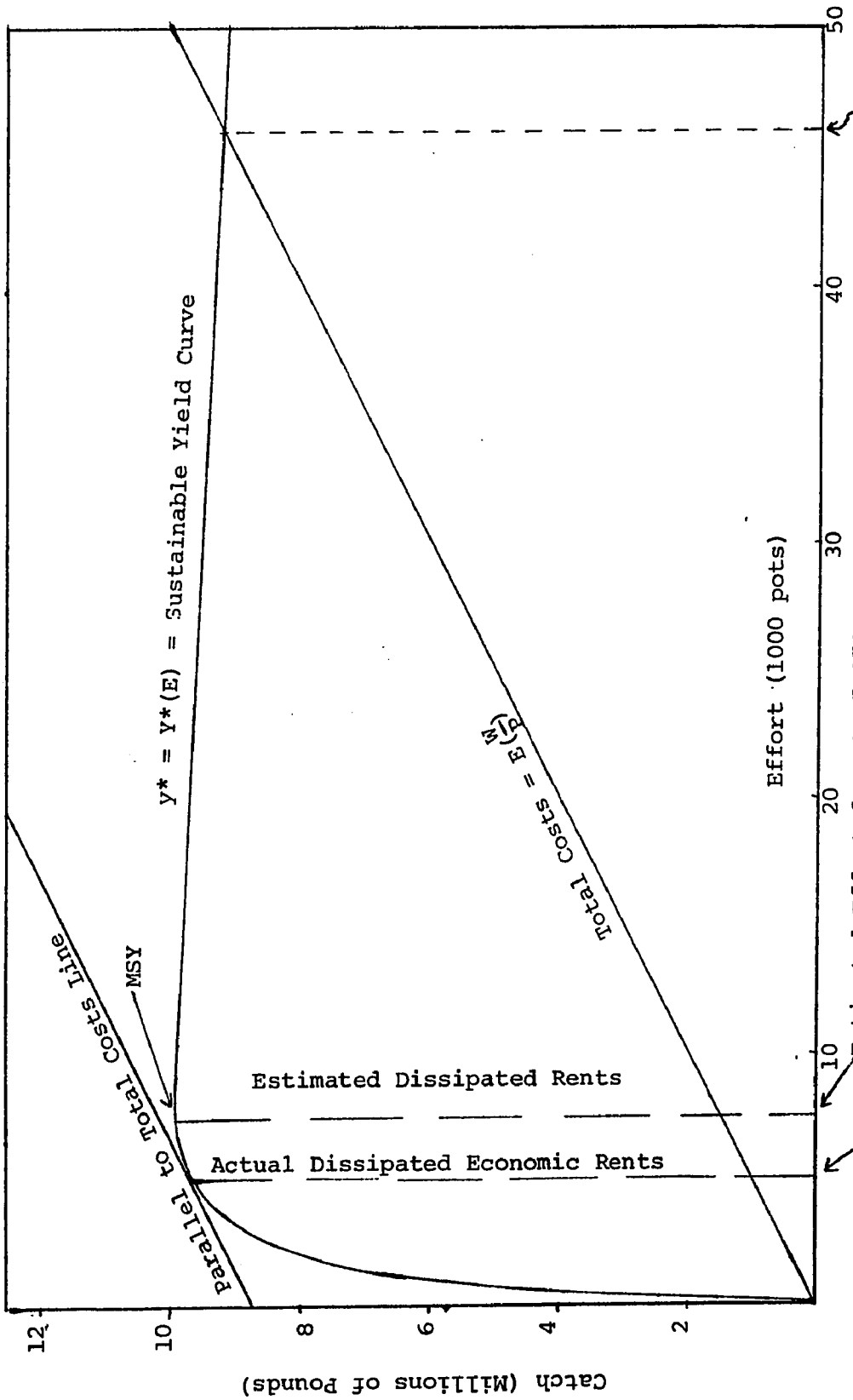

Figure III-3.--Estimating optimum effort and dissipated rents in Washington's coastal crab fishery in the 1972 season.

curve is given by a ray from the origin which is equal to the effort level times the ratio of costs per unit of effort and the price of crab to the fisherman. Recall that price is assumed not to be a function of the catch level in the fishery as defined because it is assumed to supply only a small portion of the relevant market. The validity of this assumption is tested in Chapter IV.

The sustainable yield curve is drawn for constant biological conditions comprising the ecological environment of this animal. The competitive equilibrium for this fishery is where the sustainable yield curve and the "total cost" curves cross. The MSY is the maximum point on the sustainable yield curve and involves less fishing effort than the competitive equilibrium. The economic optimum point is where the slope of the sustainable yield curve is the same as that of the "total cost" ray. This is where the marginal sustainable yield just equals the marginal ratio of costs to price of crab or the marginal revenues equal the marginal costs. This involves less fishing effort than would be required for MSY. Since it is the MSY level of effort that we have estimated in this chapter, the optimal amount of effort each year must be less than these estimates of effort "required for MSY" as shown in Table III-1.

Just how far the optimal effort level lies below the MSY level varies over time with the ratio of fishing costs to the price of crab. There is no direct information on changes in fishing costs over time. However, to the extent that costs have fallen in real terms over time due to changes in technology such as navigational equipment, the competitive equilibrium is moved further from the MSY level of effort and the optimum effort level is increased toward the MSY level. Increases in the real price of crab over time work in the same direction. As can be seen from Table III-5, prices have not been strongly trended in real terms, but some recent increase is observable. Optimal effort levels lie below MSY levels but are probably moving toward MSY levels over time, if anything. Thus the estimates of excess effort calculated here based on estimated MSY effort levels can be viewed as being minimum estimates which are probably increasingly accurate.

To translate the physical estimates of excess effort into dollar estimates of the resources which might be saved by optimal management of effort employed in the fishery, some estimate of the opportunity costs of these resources is needed. As a first approximation it was assumed that a competitive equilibrium existed in 1972, the first year evaluated, and that constant returns to scale prevailed. "Average revenues, and by assumption

TABLE III-5
REVENUES AND PRICES IN THE
WASHINGTON COASTAL DUNGENESS CRAB FISHERY

Year	Catch (Pounds)	Total Revenue (Dollars)	Price (¢/lb.)	Price/ CPI
1935	997,008	72,482	7.27	15.21
1936	1,317,732	101,202	7.68	15.90
1937	2,088,014	167,041	8.00	16.00
1938	2,219,444	107,421	4.84	9.86
1939	2,773,500	124,253	4.48	9.26
1940	4,475,936	218,426	4.88	10.00
1941	5,468,538	393,188	7.19	14.02
1942	4,646,818	365,240	7.86	13.84
1943	3,841,300	323,053	8.41	13.95
1944	4,234,838	308,720	7.29	11.89
1945	3,406,020	248,639	7.30	11.64
1946	5,723,554	761,233	13.30	19.56
1947	10,460,352	910,051	8.70	11.18
1948	13,923,448	1,461,962	10.50	12.53
1949	11,849,052	1,175,406	9.92	11.95
1950	4,245,122	478,161	11.26	13.44
1951	3,306,994	409,688	12.39	13.69
1952	3,349,130	444,361	13.27	14.35
1953	5,813,904	769,269	13.23	14.20
1954	6,643,560	883,020	13.29	14.20
1955	5,936,481	771,742	13.00	13.93
1956	8,245,164	941,925	11.42	12.06
1957	10,754,569	871,444	8.10	8.27
1958	11,465,735	1,145,459	9.99	9.92
1959	7,688,703	1,057,245	13.23	13.03
1960	6,108,953	921,115	15.08	14.63
1961	5,470,064	852,024	15.58	14.95
1962	4,385,908	874,742	19.94	18.92
1963	5,145,104	1,154,202	22.43	21.02
1964	3,599,076	832,195	23.12	21.39
1965	6,541,713	1,211,589	18.52	16.85
1966	10,772,960	1,524,350	14.15	12.51
1967	8,668,138	1,425,593	16.45	14.14
1968	8,521,746	1,553,415	18.23	15.04
1969	18,026,853	4,280,265	23.74	18.59
1970	17,161,645	3,450,210	20.10	14.86
1971	12,520,995	2,622,392	20.94	14.84
1972*	9,286,498	4,136,428	44.54	30.57
1973*	4,332,392			
1974*	3,630,260			

Source: Washington Department of Fisheries and National Marine Fisheries Service records for catch and revenue data.

*Seasonal rather than annual data

average costs, in the 1972 coastal crab fishery in Washington were about 39¢/lb. or $95/pot."[6] From Table III-1 we find that only 7,370 pots were estimated to be needed to take the MSY catch in 1972 as compared with the 45,595 pots actually employed. The excess effort of 38,225 pots would thus be valued at over $3.6 million in 1972.

While constant returns to scale may be a reasonable assumption,[7] there was actually significant entry in 1972 over the previous seasons and therefore the earlier assumption of a competitive equilibrium was not valid. This entry was probably due to the record catches of 1969-70 and rapidly rising prices in recent years. When entry is occurring, expected revenues must be above and therefore provide a maximum estimate of costs. However, actual revenues per pot were probably below what was expected due to the decline in crab availability.

A refinement of this earlier procedure is presented here. The percentage rate of change of the number of pots employed in the Washington coastal Dungeness crab fishery, i.e., the rate of entry or exit, since the mid-1930's was estimated as a function of average revenue per pot in the previous year. Then setting this percentage rate of entry equal to zero and solving gives a cost estimate, because expected revenues must equal expected costs when there is no entry or exit.

One would expect that entry/exit behavior would depend on expected profit in this business and the opportunity cost of resources used here. If one were to get a cost estimate by surveying fishermen one would probably get a measure of dollar outlay and not opportunity cost. The most important divergence between dollar outlay and opportunity cost on a year by year basis is the return to fishermen's time. In this fishery each crewman typically gets 10 to 15 percent of the catch as his wages. Because the catch fluctuates with natural abundance of crab, this wage bill could be considered a decent measure of opportunity cost only over a several year sample. Even then there would be the problem that some fishermen do not have significant employment alternatives even at much lower wages than their long run average in fishing. To determine the opportunity cost of fishermen's time by direct attack on that issue would be a sizeable chore in itself.

The method used here avoids these problems of estimating opportunity costs to which survey methods are prone. Rather than asking fishermen what they think these opportunity costs are, this method observes what they have done in response to fluctuating revenues. The most important assumption involved is that opportunity costs are stable from year to year at least compared to the fluctuations in revenues.

Simple as this procedure may seem now, it has not been tried before, and it is hard to over-rate its importance to empirical work in this field if it works even tolerably well. Data on catch and value of catch at the ex-vessel level are typically available for a fishery if any data are available. Some measure of the amount of gear and effort is necessary to speak of the concept of excess effort, and some measure of effort is generally available on a historical basis. But cost data are just not available in almost all cases. This means that an extensive survey of fishermen is seen as generally required at present. This limits the frequency of these studies because research money is limited, and it is difficult to get action required to solve the common property problem in a particular instance without first having a study to assess the benefits of doing so for this case.

In addition to reducing the time and money costs of studying fisheries, this method has the advantage of focusing on just those costs which could be saved by exit of excess effort from the fishery in question. Thus there is no need to know precisely what opportunities are available to fishermen excluded; if few opportunities are available at a comparable wage, then the opportunity costs will be demonstrated to be low and estimated

benefits from the policy change would be low just as they should be.

The results of this analysis for the Washington coast are shown in Table III-6. (Note that in this and later tabulations of equations the form of the equations is linear in the units specified in the column headings.) During the 1960's the fit is surprisingly good (R^2 = 0.954, DW = 1.96) especially considering that the period is so short and that during most of this period neither variable was strongly trended. This may be partly due to industry revenues not changing rapidly either; as we shall soon see the rate of change of industry revenues is ordinarily an important variable. Just being close to equilibrium for the system may also contribute to the good fit in this period. For the 1950's and 1960's taken together the relationship is still good (R^2 = 0.762, DW = 1.57) and the cost estimate of $57.74 per pot is only somewhat more than the $55.61 estimate for the 1960's alone. (All cost estimates are adjusted to 1957-59 dollars using the Consumer Price Index (CPI).)

Over the entire period since the mid-1930's the cost estimate is not much higher at $61.22, but the explanatory power of the single variable and hence the confidence in the cost estimate is worse (R^2 = 0.389, DW = 1.74). For the Depression and World War II years the relationship is not good at all. This is probably

TABLE III-6

ENTRY BEHAVIOR AND COST ESTIMATES FOR WASHINGTON'S COASTAL DUNGENESS CRAB FISHERY*

Per Cent Rate of Entry	Constant	Previous Year's Revenues/Effort (Dollars/Pot)	R^2 (DW)	Implied Cost Estimate in 1957-59 Dollars	Time Period	Number of Observations
ENTRYWN	-3.6229	0.065149 (11.262)	0.955 (1.96)	$55.61	1961-69	8
	-3.0314	0.052505 (7.1531)	0.762 (1.57)	$57.74	1952-70	18
	-1.6737	0.027337 (4.4428)	0.389 (1.74)	$61.22	1935-70	33
	-0.18881	0.0035577 (1.2703)	0.119 (2.24)	$53.07	1935-51	14

*t-statistics are in parentheses below the coefficients here and in later tabulations of equations unless standard errors are specified.

because the fishery was expanding after the introduction of the new technology in the 1930's and the degree of excess capacity was much less than in later years where the fit is better, i.e., the system was further from equilibrium and the explanatory variable(s) may not have a linear relationship with entry over a wide range away from the equilibrium. In spite of these difficulties the cost estimates fall generally in the $55 to $60 per pot range (all in 1957-59 dollars).

In Table III-7 these estimated costs are translated into 1972 and 1973 dollars using the Consumer Price Index. These figures are then used to place a value on the estimated excess effort in these two most recent seasons. We see that nearly $3-1/4 million could have been saved in the 1972 season and nearly $3-1/2 million in the 1973 coastal Dungeness crab fishery on the Washington coast alone. These potential savings from policy changes which would lead to proper management of the extent of effort employed in the fishery are expressed in 1972 and 1973 dollars respectively.

Comparing total revenues with estimated total costs we see that in the 1972 season the coastal Dungeness crab fleet in Washington lost over half a million dollars. However, from the distribution by vessel shown in Table III-4 it is estimated that about the top one-third of the vessels still made some profits. In the 1973 season

TABLE III-7

ESTIMATES OF COSTS, COST OF EXCESS EFFORT AND FLEET PROFITS FOR THE 1972 AND 1973 WASHINGTON COASTAL DUNGENESS CRAB FISHERY

	1972 Season	1973 Season
Average total cost per pot	$80-$88, say $85/pot ($55-$60 in 1958 $)	$85-$93, say $90/pot ($55-$60 in 1958 $)
Estimated excess effort	45,595 - 7,370 = 38,225 pots	42,161 - 3,780 = 38,381 pots
Estimated cost of excess effort	$3,249,125 or nearly $3-1/4 million	$3,454,290 or nearly $3-1/2 million
Total fleet revenues	$3,313,518.69 or $72.67/pot	$2,429,067.47 or $64.19/pot
Estimated total fleet costs	$3,875,575 or $85/pot	$3,694,490 or $90/pot
Estimated total fleet profits	-$562,186.35 or -$12.33/pot	-$1,365,422.53 or -$25.81/pot

the fleet as a whole lost over $1.3 million and it seems likely from Table III-4 that only the top 10 percent or so of vessels did not share in these losses.

An estimated breakdown of costs is presented in Table III-8. The purpose of this is twofold: (1) to provide a rough check on the reasonableness of the average total cost figures estimated above, and (2) to provide a rough estimate of the opportunity cost of labor employed in the fishery as a residual. In 1973 the total cost of acquiring a crab pot and the associated lines and buoys was about $50. A survey of fishermen conducted by the coastal laboratory of the Washington Department of Fisheries in the same year indicated that these pots lasted about five years before they were fully depreciated either through deterioration from use or from being lost, although there was considerable variation of opinion among fishermen on this point. Depreciation is treated as a variable cost here because it is a function of use and not the passage of time. From these bits of information the variable costs associated with use of a crab pot were estimated to be $10 per pot per year in 1973 and correspondingly less in 1972 dollars.

Most items in this cost breakdown were estimated from work done by Oregon State University under the Sea Grant Program. They interviewed fishermen to get a consensus as to what an above average vessel of a certain

TABLE III-8

ESTIMATED COST BREAKDOWN AND OPPORTUNITY COST OF LABOR FOR THE 1972 AND 1973 WASHINGTON COASTAL CRAB SEASONS

	1972 Season	1973 Season
Average total costs per vessel (250 pots)	$21,250	$22,500
Vessel share:		
Variable costs:		
Pots	$2,360 or $9.45/pot/year	$2,500 or $10/pot/year
Bait	$990 ($3.97/pot)	$1,050 ($4.20/pot)
Fuel and miscellaneous (e.g. galley)	$1,950	$2,075
Vessel and equipment maintenance	$1,810	$1,920
	$7,110 → $28.44/pot	$7,545 → $30.18/pot
Fixed costs:	$60,000 replacement cost and $40,000 operating capital at a rate of 10%/ year for a 4 month season:	$65,000 replacement cost and $45,000 operating capital at a rate of 10%/ year for a 4 month season:
Interest on	$3,333	$3,667

Table III-8 --Continued

	1972 Season	1973 Season
Vessel and equipment depreciation	at a rate of 5% on $48,000 for a 4 month season: $800	at a rate of 5% on $52,500 for a 4 month season: $875
Miscellaneous (e.g., insurance, moorage)	at a rate of 5% of investment plus operating capital, i.e., $100,000 for a 4 month season: $1,667	at a rate of 5% of investment plus operating capital, i.e., $110,000 for a 4 month season: $1,833
Opportunity cost of labor as a residual:		
Captain's share: (40% of remainder)	$3,336	$3,432
Equivalent full-time wage	$5.00/hour or $10,000/year	$5.15/hour or $10,320/year
Crew share: Equivalent full-time wage/man for 3 man-crew	$2.50/hour or $5,000/year	$2.58/hour or $5,160/year

type, e.g., a 52 foot Westport troll and crab vessel, would cost to operate. These estimates were prepared in 1969 to show fishermen how their operations compared to a good fishing firm in the same business or what might be expected in such a business if one were good at it. The estimates vary considerably from one port to another suggesting that the individuals interviewed strongly influence the estimates obtained, although some real differences among ports may also exist. While less confidence may be placed in any of these estimates than in the average total cost figures derived above, an average of these estimates for given boat types and ports on the Washington and Oregon coasts does show that the figures obtained here are in the same ballpark with the earlier work done in this area.

The opportunity cost of labor employed in this fishery is estimated as a residual after other estimated components of cost are deducted from the average total cost figure obtained above and expressed in Table III-8 for an average vessel fishing 250 pots and employing three crewmen. An average captain's time is estimated to be worth about $5.00 per hour or $10,000 per year, on a full-time basis in 1972 and an average crewman's time has an opportunity cost of only half this. The low opportunity costs should be regarded as preliminary estimates which invite more thorough study of the question.

Often it is the return to capital which is estimated as a residual and turns out to be very low in fisheries. Following such a procedure one must be prepared to argue why capital is so immobile over time as to sustain such low returns and why it is valid to use the wage bill as the opportunity cost of labor. It seems easier first to argue for labor immobility. The low opportunity cost of labor reflects (1) relatively poor alternatives for employment, especially for only a few months out of the year during the winter due to lack of skills, or lack of information about alternatives outside the areas near the fishing ports, and (2) fishermen generally prefer their work to alternatives if other things are even vaguely equal. For most fishermen the crab season lasts about four months before nearly all the available crab are caught. Most crabbers are employed in other fishing activities--mostly trolling for salmon or tuna and some gill net salmon fishing--during the remainder of the year; these other fishing activities are not generally available during the busiest months of the crab season. Mobility is limited unless one decides to leave the fishing areas to look for a job elsewhere. Most fishermen would not do this because in spite of the hours which are irregular and very long at the peak of a season and the strenuous nature of the work, they like the fishing life. Most crewmen aspire to captain their

own vessel one day, but would not invest the same time and money in many other business ventures which may have higher expected monetary returns. In that sense capital may be considered immobile too and shares in the low rate of return, but the capital is immobile largely because the labor is immobile.

There is a limited sort of maximizing involved here: people want to make as much money as they can fishing, but most would reject the opportunity to make more in some other business. There is also a tendency to remember the good times while complaining about the bad. Fishing is more risky than farming in the sense that one can never go to see how the crop is doing without harvesting some of it and each fishing trip is a sampling from an imperfectly understood population. There is certainly skill involved, but there is also a good deal of luck. Most fishermen probably have some preference for risk.

Fishermen's preference for the fishing life, lack of good alternatives and preference for the chance to make a lot of money quickly all contribute to their demonstrated willingness to accept low average wages and return to capital. These factors necessarily diminish the potential savings from management policies restricting effort. It is another strength of the method of cost estimation employed here that these factors are taken into account.

Few fishermen could or would put a dollar value on these things if asked in a survey.

Having had reasonably good success applying this method of estimating costs and the value of excess effort for the Washington coast, an attempt was made to explore the applicability of the method to the Oregon and California Dungeness crab fisheries. Only limited success resulted for Oregon and frankly a disaster for California. The results for Oregon are shown in Table III-9 where we see that cost estimates of $32 to $55 per pot (in 1957-59 dollars) were obtained. Except for the $55 estimate of the 1960's these are lower than should be expected unless the opportunity cost of capital were zero. Thus in Oregon more than in Washington all fixed costs of fishing must be viewed as being incurred to allow involvement of the vessel in other fisheries such as trolling for salmon or tuna or gill net salmon fishing during other months of the year. Variable costs except labor are estimated to be about $19.50/pot/year in 1958 dollars. (See Table III-8.) If the opportunity cost of labor time is assumed to be the same in Oregon as in Washington, this would bring the total variable costs of crab fishing including labor to about $28.50/pot/year in 1957-59 dollars. Thus in Oregon revenues cover variable costs of being in the crab fishery, but have not usually covered the share of fixed costs of

TABLE III-9

ENTRY BEHAVIOR AND COST ESTIMATES FOR
THE OREGON DUNGENESS CRAB FISHERY

% Rate of Entry	Constant	Previous Yr.'s Revenues/Pot in Oregon (in 1958 $)	Revenues Per Pot in WN 2 Years Before (in 1958 $)	R^2 (DW)	Implied Cost Estimate	Time Period	Number of Observations
ENTRYOR	-0.20281		0.0036888 (7.6783)	0.908 (1.97)	$54.98	1961-69	8
	-0.25635	0.0080193 (2.8203)		0.249 (1.93)	$31.97	1936-45 1950-69	26
	-0.44879	0.012752 (3.5995)		0.463 (2.08)	$35.19	1952-69	17
	0.41681	-0.010356 (-1.9658)		0.216 (1.86)	$40.25	1935-52	16

fishing which would be allocated to crab fishing on the basis of volume of activity in each fishery. Returns to investment, depreciation on the vessel and any equipment also used in other fisheries, moorage and insurance must be borne largely by these other fishing operations.

Both these cost estimates and the extent of the variation in entry behavior which is explained in Oregon are less than those obtained in Washington except for the 1960's experience. One would not expect large differences in costs to persist between adjacent states. Therefore, more reliance is placed in the $55 per pot estimate of the 1960's than would otherwise be the case. No usable results were obtained for California.

III-E. Entry/Exit Behavior

While good cost estimates were obtained for Washington, much of the variance in entry behavior for early years in Washington and Oregon and for all years in California was not explained by revenues per pot. Accordingly considerable work was done trying to get a better explanation of entry behavior especially for the entire Washington experience since the 1930's. The more significant OLS results for Washington are reported in Table III-10. Landings in all three coastal states fluctuate as noted in Chapter I. However, total revenues in Washington are somewhat trended in addition. It was

TABLE III-10

OLS ANALYSIS OF ENTRY BEHAVIOR IN WASHINGTON'S COASTAL DUNGENESS CRAB FISHERY

% Rate of Entry	Constant	Previous Yr. Revenue/Pot (in 1958 $)	Previous Yr. Fleet Catch (Pounds)	Previous Yr. Fleet Revenues (in 1958 $)	Current Yr. Revenue/Pot (in 1958 $)	Case No. (Time)	R^2 (DW)	Time Period
ENTRYWN	-1.7135	0.033523 (7.7128)	0.2018(-6) (2.3741)	-0.26512(-5) (-4.8429)	-0.015132 (-3.6564)	0.08127 (4.5112)	0.786 (1.27)	1935-70
	0.060715	0.00464 (2.0389)	0.236(-6) (3.0629)	-0.201(-5) (-2.908)	-0.00379 (-3.0386)		0.850 (3.14)	1935-44
	-1.3191	0.05864 (21.026)		-0.164(-5) -9.5286)	-0.0061 (-2.1997)		0.971 (1.39)	1952-70

	Constant	Previous Yr. Revenue/Pot (in 1958 $)	% Rate of Change in Fleet Revenues	Real Personal Income in Washington (in 1958 $)	R^2 (DW)	Time Period
ENTRYWN	-1.3724	0.01956 (4.1613)	1.5965 (5.3591)		0.688 (1.78)	1935-70
	-2.0267	0.019351 (4.2324)	1.5168 (5.1653)	0.11957 (1.6527)	0.715 (1.98)	1935-70

thought that the level of catch and revenues for the fleet in the previous year might attract entry. While landings were found to have a positive effect, the coefficient of revenues was negative. Although it was not immediately obvious, this was due to the fact that the level of revenues is negatively related to its direction and rate of change since revenues are both trended and cyclical. The rate of entry is positively related to the rate of change of fleet revenues which is in turn negatively related to the magnitude of fleet revenues.

The higher the revenues per pot in the previous year and the faster the total fleet revenues are increasing, the stronger the entry reaction. Fishermen enter when they see individuals in the business doing well or expand their own operations when they have been doing well themselves, and also when the size of the industry in terms of total revenues is growing rapidly. These two effects are independent. In addition to having profits from the previous season to invest, the level of real personal income in the state has some effect as an indicator of the financial climate for borrowing and the strength of demand. As we shall soon see it also has a negative impact as an indicator of alternative employment possibilities.

Real revenues per pot in the current year are negatively related to entry, because entry reduces revenues

per unit of effort with given revenues. The rate of change of real revenues depends on the current and previous year levels of real revenues. The rate of change of revenues per pot influences entry, but in turn it depends on the current and previous year levels of real revenues per pot. All of these inter-relationships point to the need to have a simultaneous equations estimation procedure if one is to explain more than the 72 percent of entry behavior which is explained by real revenues per pot in the previous year, the rate of change of total real revenues for the fleet and real personal income for Washington.

Two models using two stage least squares (2SLS) are presented in Table III-11. In this procedure the included endogenous variable(s) is (are) first estimated as a function of the included and excluded exogenous variables. The dependent variable is then estimated as a function of the resulting estimate(s) of the included endogenous variable(s), and the included exogenous variables. In both cases presented here the dependent variable is the percentage rate of entry of effort into the fishery. In each case a variable is included which is not significantly related to entry behavior, but is necessary for the structure of the model; its elimination leads to over-identification. In the better of these two models 85 percent of the entry behavior since

TABLE III-11

TWO-STAGE LEAST SQUARES MODELS OF ENTRY BEHAVIOR IN WASHINGTON'S COASTAL DUNGENESS CRAB FISHERY

% Rate of Entry	Constant	Previous Yr. Revenues/Pot (in 1958 $)	Real Personal Income in Washington	% Rate of Change in Fleet Revenues	% Rate of Change in Revenue/ Pot	Current Yr. Revenues/Pot (in 1958 $)	R^2 (DW)	Time Period
Dependent variable: % rate of entry.								
Included endogenous variables: previous year's real revenues per pot; real personal income for Washington.								
Included exogenous variables: % rate of change of fleet revenues; % rate of change of real revenues per pot; real revenues per pot in current year.								
Excluded exogenous variables: real fleet revenues in current year; real fleet revenues in previous year.								
	0.022485	0.083387 (SE=0.0299)	-0.050775 (SE=0.0907)	0.9525 (SE=0.3773)	5.2490 (SE=1.742)	-0.085137 (SE=0.0233)	0.833 (2.18)	1935-70

Table III-11 -Continued

% Rate of Entry	Constant	Previous Yr. Revenues/Pot (in 1958 $)	% Rate of Change in Real Fleet Revenues	% Rate of Change in Real Revenue/ Pot	Current Yr. Revenues/ Pot (in 1958 $)	Current Yr. Fleet Revenues (in 1958 $)	R^2 (DW)	Time Period
Dependent variable: % rate of entry.								
Included endogenous variables: previous year's real revenues per pot.								
Included exogenous variables: % rate of change of fleet revenues; % rate of change of real revenues per pot; real revenues per pot in current year; real fleet revenues in current year.								
Excluded exogenous variable: previous year real fleet revenues.								
	-0.17938	0.078765 (SE=0.0211)	1.0367 (SE=0.4022)	4.8267 (SE=1.7594)	-0.079487 (SE=0.0235)	-0.14666(-6) (SE=0.244(-6))	0.853 (2.19)	1935-70

the mid-1930's is explained for Washington. The rate of entry is 1.04 percent greater for every 1 percent increase in fleet revenues and 4.8 percent greater for every 1 percent increase in real revenues per pot. Each $1 increase in the previous year's revenues per pot increases the entry rate by 0.079 percent while this same rate of entry is associated with a $1 decrease in the current year's real revenues per pot.

Results of the study of entry behavior in other areas are shown in Table III-12. Only in Alaska does the state's personal income remain a significant influence, and there it has a negative coefficient. This may reflect that the general level of alternative employment opportunities in Alaska is more important than the availability of investment capital there since capital and supplies used in Alaska have historically come from the Pacific coast states. But also note that in the first of the 2SLS models for Washington presented in Table III-11 the coefficient on real personal income is negative.

Another item of note in Table III-12 is that when the rate of change of revenues per pot is significantly related to entry behavior as in Puget Sound, Oregon, and the King crab fishery in Alaska, the sign of the coefficient is negative. This indicates that the depressing effect that entry has on revenues per pot dominates the attractive impact that revenues per pot have on entry

TABLE III-12

ENTRY BEHAVIOR FOR PUGET SOUND, OREGON, CALIFORNIA, AND ALASKA

% Rate of Entry	Constant	% Rate of Change of Fleet Revenues for Area	Revenue/Pot in Previous Year in Same Area (in 1958 $)	% Rate of Change of Revenue/Pot in Same Area	Real Personal Income in State (in 1958 $)	Current Year Real Fleet Revenues in Area (in 1958 $)	R^2 (DW)	Time Period
ENTRYPS (Puget Sound)	-0.28770	0.15624 (3.1473)	0.012167 (4.6798)				0.46 (2.07)	1935-69
ENTRYPS	0.026268	0.68773 (10.777)		-0.72532 (-10.499)			0.80 (1.81)	1935-69
ENTRYOR (Oregon)	-0.30089	0.39720 (4.1889)	0.0084842 (2.6854)				0.378 (1.53)	1935-69

Two Stage Least Squares:

Dependent variable: % rate of entry; included endogenous variable: % rate of change of fleet revenues; included exogenous variables: % rate of change of revenues per pot, current year real fleet revenues; excluded exogenous variable: previous year real fleet revenues.

ENTRYOR	-0.47343	0.89374 (SE=0.475)		-0.90639 (SE=0.05126)		0.60605(-7) (SE=0.211(-7))	0.951 (1.99)	1935-69

Table III-12.--Continued

% Rate	Constant	% Rate of Change of Fleet Revenues for Area	Revenue/Pot in Previous Year in Same Area (in 1958 $)	% Rate of Change of Revenue/Pot in Same Area	Real Personal Income in State (in 1958 $)	Current Year Real Fleet Revenues in Area (in 1958 $)	R^2 (DW)	Time Period
ENTRYCA (Calif.)	0.052918	0.40160 (3.2220)					0.264 (2.07)	1935-69
ENTRYAL (Alaska)	1.0191	0.41078 (3.7375)	0.013974 (3.8335)		-2.7070 (-3.2748)		0.70 (1.67)	1950-69
ENTRYKC (King Crab in Alaska)	1.1015		0.0021946 (2.1786)		-2.2646 (-2.7260)		0.517 (1.94)	1959-69

Two-Stage Least Squares:

Dependent variable: % rate of entry; included endogenous variable: real revenues per pot in previous year; included exogenous variables: % rate of change in fleet revenues, % rate of change in real revenues per pot, real fleet revenues in current year; excluded exogenous variable: real fleet revenues in previous year.

ENTRYKC	0.56044	0.87599 (SE=0.1028)	-0.0018255 (SE=0.00118)	-1.5405 (SE=0.26245)		0.27429(-7) (SE=0.14188(-7))	0.981 (1.64)	1959-69

behavior. This view is strengthened by noting that in Puget Sound and Oregon previous year's revenues per pot have a significant positive effect on entry when the rate of change of revenues per pot is not included. When revenues per pot are high, they will be declining because of the entry that is attracted.

Entry behavior in California remains the least understood. Only the rate of change of total fleet revenues was found to be significantly related to entry behavior in the Dungeness crab fishery there. Thus little better than one-quarter of the variation in the rate of entry is explained in California compared to a total of 80 to 95 percent eventually explained for the Oregon and Washington coasts and Puget Sound. One is left wondering what sort of economic rationale, if any, governs most of the entry and exit behavior in the California fishery. It is not what has been found to govern behavior in the other areas of the Dungeness crab fishery. I leave it to others to discern what it is. It is possible that other employment opportunities at the same time of year as the crab fishery dominate more in the California area. It is also possible that the historical pot estimates are not as accurate there.

Footnotes

[1]Ralph Turvey, "Optimization and Suboptimization in Fishery Regulation," American Economic Review (March 1964), 64-76.

[2]Fred C. Cleaver, "Preliminary Results of the Coastal Crab (Cancer Magister) Investigations," Biological Report No. 49A (Seattle: Washington State Department of Fisheries, April 1949), 47-82.

[3]Ibid.

[4]See Frederick W. Bell, Ernest W. Carlson, and Frederick V. Waugh, "Production from the Sea," in Adam A. Sokoloski (ed.) Ocean Fishery Management: Discussions and Research, NOAA Technical Report NMFS CIRC-371 (Seattle, April 1973), pp. 72-91, where an attempt is made for some other fisheries, however.

[5]Robert G. Kuller and Ronald G. Cummings, "An Economic Model of Production and Investment for Petroleum Reservoirs," American Economic Review (March 1974), 66-79.

[6]Lee E. Erickson, "Summary of Preliminary Work and Proposal for Further Economic Study of the Dungeness Crab Fishery in Washington" (Olympia: Washington Department of Fisheries, July 1973).

[7]Salvatore Comitini and Davis S. Huang, "A Study of Production and Factor Shares in the Halibut Fishing Industry," Journal of Political Economy (August 1967), 292-300.

CHAPTER IV

PRICE ANALYSIS

Price variations have an important impact on fishermen's incomes:

> "Large processing and marketing margins mean that relatively small changes in demand for, and prices of, fish at the retail level are magnified at the level of the primary producer, since most of the intervening costs are unaffected by changes in the demand for fish. As a result fishermen's incomes fluctuate widely, not only because of variations in the availability of fish and in weather conditions that determine their ability to get out on the grounds, but also because of wide fluctuations in market prices."[1]

This undeniably important impact of changes in the ex-vessel price of Dungeness crabs is not the primary reason for studying these prices here, however. Rather it is the implications of the determinants of price changes for the validity of the theory which has been developed over the years, is reviewed in Chapter II, and is applied here, especially in Chapter III. It is a standard assumption of fisheries economics theory that the fishery being analyzed is small enough that the size of the landings there will not affect the price of the fish. This is analogous to the assumption of perfect competition in standard price theory, and may actually hold about as frequently. Surely there is always some size of fishing area for which

this assumption holds. The question is whether it is a valid assumption for the fishery studied here or, indeed, for any of the major fisheries of the world. It may be that the size of fishing area which is necessary for the assumption of no impact of the landings in that area on price to hold is too small an area for effective management of the fishery. If so, some modifications of the fisheries economics theory are necessary to make it fully applicable to the most important fisheries management problems.

There are two data sets available for analyzing the determinants of price changes in the Dungeness crab fishery. There are time series data comparable to those used for analysis of entry behavior in Chapter III. These include average annual prices and annual landings by state to which other socio-economic variables, which are also available on an annual basis, have been added. There are also two years of more detailed information on monthly prices and landings by vessel, dealer and port for the 1972 and 1972-73 coastal crab seasons in Washington.

IV-A. Time Series Price Analysis

We turn first to the time series data. Table IV-1 shows the time series of prices by area. The most significant OLS findings on the determinants of the Washington coastal crab price are presented in Table IV-2. Here

TABLE IV-1

TIME SERIES OF DUNGENESS CRAB PRICES BY AREA
(CENTS/POUND IN CURRENT DOLLARS)

Year	Washington Coast	Puget Sound	Oregon	California	Alaska	Alaskan King Crab
1934			4.1	8.3	8.3	
1935	7.3	5.1	6.4	10.2	8.5	
1936	7.7	5.5	9.4	11.0	8.8	
1937	8.0	5.1	5.0	11.0	9.8	
1938	4.8	2.9	5.7	6.4	9.1	
1939	4.5	2.1	4.2	6.3	7.9	
1940	4.9	2.2	4.4	5.8	7.0	
1941	7.2	6.3	4.8	7.2	2.1	
1942	7.9	8.7	7.1	11.7	3.3	
1943	8.4	8.5	8.0	15.2	3.6	
1944	7.3	8.0	7.6	14.6	4.2	
1945	7.3	8.0	7.4	12.0	3.2	
1946	13.3	14.6	12.6	13.7	5.4	
1947	8.7	11.3	8.7	12.2	5.0	4.2
1948	10.5	11.4	10.4	10.6	5.2	4.5
1949	9.9	12.0	8.9	11.6	5.7	6.0
1950	11.3	14.0	11.3	12.1	6.7	6.0
1951	12.4	14.0	12.7	14.0	8.7	11.4
1952	13.3	12.3	12.1	14.6	8.9	14.0
1953	13.2	13.5	12.7	17.2	9.0	11.9
1954	13.3	12.5	11.7	14.6	9.0	9.9
1955	13.0	11.2	12.4	15.9	8.5	9.9
1956	11.4	9.0	11.3	12.7	8.7	9.8
1957	8.1	8.1	8.0	8.6	5.1	8.1
1958	10.0	10.4	9.5	11.9	7.5	8.0
1959	13.8	13.5	13.4	14.9	8.2	7.8
1960	15.1	14.0	14.6	16.9	8.0	8.0
1961	15.6	13.6	15.9	16.9	9.6	9.0
1962	19.9	18.2	19.6	27.1	11.1	10.0
1963	22.4	15.4	20.9	35.2	11.2	9.7
1964	23.1	16.6	24.3	34.0	11.5	9.4
1965	18.5	14.4	16.8	22.2	11.2	9.7
1966	11.4	14.1	13.3	15.2	12.0	9.8
1967	16.4	15.4	16.2	17.4	13.0	11.7
1968	18.2	18.3	19.5	22.1	13.4	26.7
1969	23.7	19.6	27.1	28.9	14.3	27.1
1970	20.1	19.6				
1971	20.9					
1972	44.5					

TABLE IV-2

SOME ORDINARY LEAST SQUARES RESULTS ON THE TIME SERIES BEHAVIOR OF THE PRICE OF DUNGENESS CRAB ON THE WASHINGTON COAST

Price	Constant	Price in Oregon ($/lb.)	Price in California ($/lb.)	Landings in Washington (pounds)	Landings in Alaska (pounds)	R^2 (DW)
PRICEWN	0.011006	0.52404 (3.3267)	0.29060 (2.333)			0.859 (1.80)
PRICEWN	-0.011810	0.81167 (4.8043)	0.37814 (3.3002)		-.60067(-8) (-3.056)	0.892 (2.30)
PRICEWN	-0.010072	0.88470 (4.3153)	0.34496 (2.7227)	-.65773(-9) (-0.64212)	-.62921(-8) (3.0940)	0.893 (2.36)

we see that the price on the Washington coast is related to the price in Oregon and California, as one might expect. Landings in Alaska have a significant negative influence, probably because of their impact on inventories in Washington, which have a negative impact on price in Washington as we shall see from the cross-sectional data. Most of Alaskan fish products are shipped through Seattle to the rest of the country and Dungeness crab is no exception. Landings in Washington have the expected negative impact on price but not a significant one because of the positive influence of price on the size of landings. This points to the need for a simultaneous equations model as is usually the case for analyses of price behavior for an industry. Here there is not only the motivation of separating quantity influences on price from price influences on quantity; there is also the problem that prices in the different areas are determined by many of the same forces.

Table IV-3 shows the results of OLS time series analysis of price in Oregon and California. For Oregon the OLS results suggest that prices in Washington and California are important as well as some measure of purchasing power in California or the United States as a whole. Landings in Oregon do not seem to be important to the determination of price there, at least from the OLS analysis.

TABLE IV-3

OLS ANALYSIS OF THE
TIME SERIES BEHAVIOR OF THE PRICE OF DUNGENESS
CRAB IN OREGON AND CALIFORNIA

Price	Constant	Price in Washington ($/lb.)	Price in Oregon ($/lb.)	Price in California ($/lb.)	U.S. Disposable Personal Income (in 1958 $)	Real Personal Income in California (in 1958 $)	Landings in California (Pounds)	R^2 (DW)
PRICEOR	-0.020731	0.40184 (3.7443)		0.25035 (3.0023)	0.00018843 (5.5439)			0.941 (2.10)
PRICEOR	-0.0035719	0.40998 (3.7426)		0.23471 (2.7151)		0.0012166 (5.2983)		0.938 (2.03)
PRICECA	0.036365	0.49575 (3.0770)	0.49775 (2.2982)			0.0010917 (2.3276)	-0.423(-8) (-5.8464)	0.937 (1.61)

By reputation prices are first determined in California, the prime market area, and then prices in other areas largely derive from this through transportation and storage costs. The OLS analysis suggests that landings in California do have a more important impact on prices there than is the case in any of the other areas. Prices in Washington and Oregon are also important as is a measure of purchasing power.

On the basis of this OLS information a two-stage least squares model of price determination was first constructed for California. The results of this are shown in Table IV-4. (It is recognized that there is a problem both here and in the 2SLS results for Washington later in this chapter with using prices in other states as exogenous variables. Not enough truly exogenous variables could be found to determine the system of Dungeness crab prices more correctly or precisely. Therefore the results must be considered only suggestive and not conclusive evidence.) Landings were confirmed to have a significant impact on price; all other things equal an increase in landings in California by one million pounds causes the price there to drop by 0.34¢ in that year. The price of crab in California is more closely related to the price of crab in Oregon than to the price of crab on the more distant Washington coast. The price in California is higher by 0.87¢ for every 1¢ increase in

TABLE IV-4

TWO-STAGE LEAST SQUARES ANALYSIS OF
THE BEHAVIOR OF THE PRICE
OF DUNGENESS CRAB IN CALIFORNIA

	Constant	Price in Washington ($/lb.)	Price in Oregon ($/lb.)	Landings in California (Pounds)	R^2 (DW)
Dependent variable: price in California; Included endogenous variable: landings in California; Included exogenous variables: price in Oregon, price in Washington; Excluded exogenous variables: landings in Oregon, landings in Washington, real personal income in California.					
PRICECA	0.03335	0.37657 (SE=0.1649)	0.87251 (SE=0.1571)	-0.34105(-8) (SE=0.9307(-9))	0.926 (1.65)
Significance level of test of over-identification: 0.0325					

the price in Oregon. A 1¢ price change on the Washington coast is related to only a 0.38¢ price change in California.

In Alaska OLS analysis suggests that landings in Alaska are induced by higher prices in Oregon, California, and in Alaska itself much more than landings act to reduce prices. (See Table IV-5.) This corroborates the popular impression that landings in Alaska are higher when landings elsewhere are lower and prices are forced up. Thus as noted in Chapter I, Alaskan landings do not reflect the available population of Dungeness crabs there at least until recently. The proportion of the population caught in Alaska is much less stable than in other states and has been increasing with the rising prices in these other areas. It is also true, however, that the landings in Alaska have an important negative impact on the price in Washington which swamps any positive impact of price in Washington on Alaskan landings.

With these results in mind attempts were made to build a two-stage least squares model of price for the Washington coast. Two of the better results of these efforts are shown in Table IV-6. Prices in Oregon and California continue to be significant with a price change in Oregon having about twice the impact that a price change in California does. The result that about 0.38¢ of a 1¢ price change in California finds its way to

TABLE IV-5

OLS ANALYSIS OF TIME SERIES BEHAVIOR OF LANDINGS OF DUNGENESS CRAB IN ALASKA

Landings	Constant	Price in Alaska ($/lb.)	Price in Washington ($/lb.)	Price in Oregon ($/lb.)	Price in California ($/lb.)	Real Personal Income in California (in 1958 $)	R^2 (DW)
LBSAL	-5165900.0	38934000.0 (3.4514)		25884000.0 (2.1370)	19941000.0 (2.2929)		0.881 (1.47)
LBSAL	-4670500.0	29288000.0 (2.6892)	-25445000.0 (-2.1425)	29923000.0 (1.7547)	28471000.0 (3.3483)	47324.0 (1.6853)	0.911 (1.72)
LBSAL	-4585600.0	30980000.0 (2.7729)	-30969000.0 (-2.6335)	47272000.0 (3.3753)	27535000.0 (3.1500)		0.903 (1.84)

TABLE IV-6

TWO-STAGE LEAST SQUARES MODELS OF THE TIME SERIES BEHAVIOR OF THE PRICE OF DUNGENESS CRAB ON THE WASHINGTON COAST

Price	Constant	Price in Oregon ($1/lb.)	Price in California ($/lb.)	Landings in Washington (Pounds)	Landings in Alaska (Pounds)	Real Personal Income in Washington (in 1958 $)	Consumer Price Index for Food (100 for 1957-59)	R^2 (DW)
Dependent variable: price on the Washington Coast; Included endogenous variable: real personal income Washington; Included exogenous variables: price in Oregon, price in California, landings in Washington, landings in Alaska; Excluded exogenous variable: landings in California.								
PRICEWN	-0.028695	0.78166 (SE=0.274)	0.36605 (SE=0.1598)	-0.28271(-8) (SE=0.242(-8))	-0.95633(-8) (SE=0.401(-8))	0.10129 (SE=0.00958)		0.840 (1.59)
Dependent variable: price on the Washington coast; Included endogenous variable: consumer price index for food; Included exogenous variables: price in Oregon, price in California, landings in Washington, landings in Alaska; Excluded exogenous variable: landings in California.								
PRICEWN	-0.25287	0.73046 (SE=0.239)	0.38934 (SE=0.133)	-0.16667(-8) (SE=0.129(-8))	-0.69397(-8) (SE=0.212(-8)		0.043162 (SE=0.033)	0.894 (2.21)

Washington compares closely with the earlier result that a 1¢ price change on the Washington coast is related to a 0.38¢ price change in California. Landings in Alaska continue to have a more significant depressing influence on price on the Washington coast than landings on the Washington coast itself. An increase of landings on the Washington coast by one million pounds causes about 0.2¢ drop in price there whereas the same increase in landings in Alaska causes about four times this drop in price. Nevertheless, the impact of Washington landings on prices there is now too clear to be ignored. The standard assumption of constant price with respect to landings in the same area does not hold at least for Washington and California.

Although either real personal income for Washington or the consumer price index for food work acceptably as an included endogenous variable, the latter is somewhat better. The standard error is a smaller fraction of the coefficient and a somewhat larger proportion of the variation in price behavior (89 percent) is explained. A significant difficulty in building a simultaneous equations model of price behavior for the Dungeness crab fishery in Washington was that nearly all variables which were related to this price were also found to be part of the system and not truly independent. The number of included endogenous variables which could be

found to be independent of one another restricted the number of excluded exogenous variables which could be used without encountering over-identification problems. The use of prices in other states as included exogenous variables is recognized as leading to results that must be considered only suggestive and not conclusive. Not enough truly exogenous variables could be found to more correctly determine the system of prices.

IV-B. Cross-Sectional Price Analysis

We turn now to the monthly data for the 1972 and 1972-73 Dungeness crab seasons on the Washington coast. Table IV-7 gives the average (mean) prices for each month of these two seasons. Notice that the price rises during the season from 32.2¢/pound to 46.8¢/pound in 1972 and from 52.4¢/pound to about 63¢/pound during the 1972-73 season. The sample size in Table IV-7 refers to the number of different combinations of vessels, dealers and ports that occur during a given month; all transactions between a given vessel and a given dealer in a given port and for a given month are grouped into a single observation. Note that the number of observations per month declines during the season. This is mostly due to vessels dropping out of the fishery although it is also due to some dealers ceasing to buy. Both occur as landings per month decline during the season and revenues

TABLE IV-7

MONTHLY AVERAGE PRICES FOR THE 1972 AND 1972-73
WASHINGTON COASTAL DUNGENESS CRAB SEASONS

Month	1972 Season		1973 Season	
	Mean Price	Sample Size	Mean Price	Sample Size
December			52.4¢	200
January	32.2¢	187	54.5¢	180
February	36.0¢	181	54.3¢	158
March	39.9¢	162	59.6¢	95
April	41.0¢	151	61.3¢	65
May	41.5¢	136	63.9¢	50
June	43.0¢	60	64.3¢	44
July	43.4¢	47	62.6¢	34
August	44.0¢	39	64.1¢	29
September	46.8¢	24	62.9¢	22

Source: Unpublished data from Washington Department of Fisheries.

no longer cover costs of operating indivisible units of equipment both in fishing and in processing.

Average prices for the five most important Dungeness crab ports on the Washington coast are given in Table IV-8 for these two seasons. Recall that from the time-series data we saw that the popular impression that price is determined largely in California and other prices are tied to this is consistent with the statistical results. If the reason for this is that a prime market for the product is in California, then one would expect prices to be generally lower as one looks north because additional transportation costs must be absorbed to have a competitive price in the California market. To assess this we will first remove the influence of other factors to get an "adjusted mean price." This "adjusted mean price" is the value which would be predicted based on the equation used to estimate it in each port.

The "adjusted mean prices" in Table IV-8 were derived by OLS analyses of prices by port which are summarized in Tables IV-9 through IV-12. Because there are so few dealers in some ports, more of the detailed analyses of price by port which lie behind the derivation of "adjusted mean prices" are presented only for Westport, Bay Center, and Ilwaco. Important variables on which data were available are the percentage of the total Washington coastal catch for the season which has been

TABLE IV-8

AVERAGE SEASONAL PRICES FOR MAJOR DUNGENESS CRAB PORTS ON THE WASHINGTON COAST

Port (North to South)	1972 Season		1972-73 Season	
	Mean Price	Adjusted Mean Price	Mean Price	Adjusted Mean Price
Westport	38.7¢	38.3¢	57.3¢	56.7¢
Tokeland	34.9¢	32.8¢	54.5¢	51.5¢
Bay Center	39.3¢	40.0¢	56.7¢	58.2¢
Ilwaco	39.4¢	41.3¢	56.0¢	58.4¢
Chinook	40.2¢	40.6¢	59.0¢	59.3¢

Source: Unpublished data from Washington Department of Fisheries.

TABLE IV-9

DETERMINATION OF PRICE BY PORT FOR THE WASHINGTON COAST: WEIGHTED AVERAGE OVER ALL PORTS

Price	Landings in That Port in That Month (lbs.)	Landings in WN Coast in That Month (lbs.)	% of WN Coastal Season Landings Prior to Current Month	WN Dungeness Crab Inventory (Pounds)	Vessel Length (Feet)	Approx. Average R^2
PRICE 1972		0.84200(-7) (8.5931)	0.47002 (11.900)	-0.20390 (-2.6225)	0.27968(-3) (3.4708)	0.75
PRICE 1973	0.43875(-7) (3.6290)	0.81335(-7) (10.605)	0.32339 (20.458)	-0.66884(-7) (-9.3559)		0.60

TABLE IV-10

ORDINARY LEAST SQUARES DETERMINATION OF PRICE IN WESTPORT IN THE 1972 AND 1972-73 WASHINGTON COASTAL CRAB SEASONS

Price	Constant	Landings in That Port in That Month (Pounds)	Landings on WN Coast in That Month (Pounds)	% of WN Coastal Season Landings Prior to Current Month	WN Dungeness Crab Inventory (Pounds)	Vessel Length (Feet)	R^2
PRICE 1972	-0.52708	0.72596(-7) (3.2960)	0.16655(-6) (15.366)	0.97629 (13.561)	-0.20770(-7) (-2.4511)	0.17666(-3) (2.3180)	0.781
PRICE 1973	0.33277	0.61933(-6) (4.1811)	-0.17800(-6) (-2.6494)	0.35455 (15.100)	-0.64150(-7) (-6.2849)		0.457

TABLE IV-11

ORDINARY LEAST SQUARES DETERMINATION OF PRICE IN BAY CENTER IN THE 1972 AND 1972-73 WASHINGTON COASTAL CRAB SEASONS

Price	Constant	Landings in That Port in That Month (Pounds)	% of WN Coastal Season Landings Prior to Current Month	WN Dungeness Crab Inventory (Pounds)	R^2
PRICE 1972	0.24616	0.21709(-6) (1.8070)	0.24037 (5.2591)	-0.96011(-7) (-3.5894)	0.721
PRICE 1973	0.11493	0.19170(-5) (8.4222)	0.70102 (10.446)	-0.64526(-7) (-3.7950)	0.842

TABLE IV-12

ORDINARY LEAST SQUARES DETERMINATION OF PRICE IN ILWACO IN THE 1972 AND 1972-73 WASHINGTON COASTAL CRAB SEASONS

Price	Constant	Landings in That Port in That Month (Pounds)	Landings on Coast in That Month (Pounds)	% of WN Season Landings Prior to Current Month	WN Dungeness Inventory (Pounds)	R^2
PRICE 1972	-0.45461	-0.41150(-6) (4.5559)	0.26843(-6) (4.5337)	0.98383 (5.1964)	-0.25156(-6) (-5.4612)	0.779
PRICE 1973	0.24060		0.16258(-6) (10.785)	0.51281 (12.628)	-0.56169(-7) (-3.4951)	0.774

caught prior to the current month, landings on the Washington coast in the current month, landings in the port in question in the current month, inventories of Dungeness crab in Washington, and size of the vessel making the landings.

These OLS analyses show that prices rise as the end of the season approaches and as inventories fall. Both of these results are as expected, although the magnitude of their impact is not stable. As dealers begin to see that all of the available crab for the season will soon be landed, there is more competition to buy the remaining landings. This is the main reason for the price rising during the season. In most years the price then falls between seasons and begins the next season at about the same level as the previous season. This did not occur between the two seasons for which data were available here partly because of inflation in the general price level, but mostly because of low landings and inventories in all areas. Prices rise as inventory levels fall because demand is depleting inventories faster than production is building them back.

Landings for the whole Washington coast and in the same port in the current month have an important effect, but the sign is usually positive. This indicates that the price exerts a strong effect on where a vessel lands its catch and probably where it fishes also. Higher

prices attract additional landings both to an individual port and to the area. Following the price through the season this attractive effect of price generally outweighs the negative impact of larger total landings on price which we observed in the time series data. Both effects are important.

The size of the vessel making the landings is important in 1972; larger vessels got a somewhat higher price. This is probably because larger vessels are more mobile and able to go elsewhere if they do not get a higher price. In equilibrium all vessels may get the same price, but some get the higher price sooner as the price rises during the season. This result is due largely to the Westport data as can be seen from Tables IV-9 through IV-12, and is not confirmed for the 1972-73 season. Westport dominates the overall results because over half of the observations in both seasons came from that port.

After removing the effects explained by these variables from the prices in each port, the remaining variation in "adjusted mean prices" among ports is probably due to distance from California markets and the extent of monoposony power exercised by individual dealers. To distinguish these two effects would violate the confidentiality of the data.

The variation of mean price among dealers is shown in Table IV-13. The "adjusted mean prices" shown here

TABLE IV-13

AVERAGE SEASONAL PRICES FOR MAJOR DUNGENESS CRAB DEALERS ON THE WASHINGTON COAST

Dealer Rank By Season's Dungeness Crab Purchases		1972 Season		1972-73 Season	
1972	(1973)	Mean Price	Adjusted Mean Price	Mean Price	Adjusted Mean Price
1	(1)	38.2¢	38.8¢	57.4¢	57.2¢
2	(3)	39.9¢	39.7¢	58.4¢	57.3¢
3	(2)	34.9¢	32.6¢	54.6¢	51.6¢
4	(4)	37.0¢	38.2¢	54.3¢	57.8¢
5	(6)	40.6¢	40.5¢	57.3¢	57.7¢
6	(7)	39.9¢	40.7¢	57.7¢	58.4¢
7	(5)	40.2¢	40.0¢	59.4¢	58.6¢
8		34.8¢	37.7¢		
	(8)			57.1¢	54.9¢

were derived by OLS analyses similar to those done for ports above. These OLS results are summarized in Table IV-14. Much of the remaining price variation is due to the location of the dealers along the coast, and hence their distance from California markets. However, it would be almost like naming the dealers to give both their rank and port location, because most dealers buy primarily in one location. This also makes it difficult to separate price variations due to location from those due to market power, even if the distinction could be reported.

The industrial structure of the Dungeness crab fishery is much like other fisheries. At the dealer/processor level the organization is fairly concentrated with the top four dealers handling about two-thirds of the catch in each of the 1968-73 seasons on the Washington coast. Three of these top four dealers were the same in each year. Note from Table IV-13 that the top seven dealers were the same in both the 1972 and 1972-73 seasons, although their individual ranks and market shares differed. The top eight firms bought 85 to 90 percent of the catch in both of these seasons. Recall that this is in spite of the catch in the 1972-73 season being less than half that in the more normal 1972 season.

At the vessel level the industrial structure is much more competitive. Table IV-15 shows the number and

TABLE IV-14

DETERMINATION OF PRICE BY DEALER FOR THE WASHINGTON COAST: WEIGHTED AVERAGE OVER ALL DEALERS

Price	Landings in That Port in That Month (lbs.)	Landings on WN Coast in That Month (lbs.)	% of WN Coastal Season Landings Prior to Current Month	WN D. Crab Inventory (lbs.)	Vessel Length (Feet)	Approx. Average R^2
PRICE 1972	-0.12494(-7) (-5.6514)	0.83414(-7) (8.3997)	0.44184 (11.022)	-0.19159(-7) (-2.4094)	0.36641(-3) (4.6351)	0.80
PRICE 1973	0.22452(-7) (2.2481)	0.89950(-7) (11.465)	0.32825 (19.277)	-0.70917(-7) (-9.2414)		0.70

TABLE IV-15

CONCENTRATION OF LANDINGS BY VESSELS IN THE 1968-73 CRAB SEASONS ON THE WASHINGTON COAST

Year	Catch per Vessel (pounds)	% of Vessels	No. of Vessels	% of Catch
1968	over 200,000	23	17	49
1969	over 200,000	31	36	73
1970	over 200,000	16	23	42
1972	over 100,000	16	27	48
1973	over 50,000	11	20	45

percentage of the total vessels landing corresponding proportions of the total catch in the 1968-73 seasons. In 1968 17 vessels or 23 percent of the total landed 49 percent of the catch while in 1973 the total number of vessels had increased so that 11 percent of the vessels represented 20 vessels landing 45 percent of the catch. Thus about two dozen vessels have been generally landing about half of the catch in spite of large changes in both total catch and total number of vessels which have made the concentration of landings look greater. Furthermore, less than half of these vessels were the same in all years. While the landings are not evenly distributed among the vessels, the total number of vessels involved seems large enough to promote competition.

It is unlikely that this monopsonistic structure will be changed much by effort management policies which reduce the number of pots, vessels, and fishermen. The top vessels will remain in the fishery and bargaining power between fishermen and processors is not likely to change much. Any change which did occur would favor the bargaining power of fishermen over processors and would hence make a more competitive behaving industry.

Theoretically a monopsonist would impose a rational solution on a fishery. He would capture the rent accruing to ownership of fishing rights by offering the

fishermen a price that would permit only the most efficient exploitation of the fish resource to occur. Thus the misallocation of resources which usually results from the common property, free entry nature of the resource would be avoided. In practice these results are not observed in spite of monopsonistic tendencies in most fisheries. The Pacific salmon and halibut fisheries are cited in the literature.[2] This is also the case in the Dungeness crab fishery.

The results of the ordinary least squares analyses of price for the 1972 and 1972-73 seasons are summarized in Table IV-16. It is clear from the positive coefficient on monthly landings on the Washington coast in both seasons that a simultaneous equation model is needed. Attempts to build such a model for both seasons are presented in Table IV-17. For the 1973 season the signs of the coefficients are confirmed and the proportion of the variation explained is increased somewhat to nearly one-half. Each 10 percent increase in the proportion of the available population which has been caught boosts price by about 3.3¢. It takes about a 9.4¢ rise in price to attract a million pounds of crab to Washington coastal ports, but only about 1.8¢ is needed to shift the same amount between ports on the Washington coast. A million pounds increase in inventories of Dungeness crab in

TABLE IV-16

ORDINARY LEAST SQUARES DETERMINATION OF PRICE IN THE 1972 AND 1972-73 WASHINGTON COASTAL CRAB SEASON

Price	Constant	Landings in That Port in That Month (Pounds)	Landings on WN Coast in That Month (Pounds)	% of WN Coastal Season Landings Prior to Current Month	WN Dungeness Inventory (Pounds)	Vessel Length (Feet)	R^2
PRICE 1972	0.086019	-0.12241(-7) (-5.9013)	0.59353(-7) (5.1842)	0.33996 (7.4122)		0.35037(-3) (3.8684)	0.584
PRICE 1973	0.40309	0.20896(-7) (2.3124)	0.75290(-7) (9.2250)	0.28242 (16.238)	-0.72439(-7) (-8.9717)		0.429

TABLE IV-17

TWO-STAGE LEAST SQUARES MODELS OF PRICE DETERMINATION FOR THE 1972 AND 1972-73 WASHINGTON COASTAL CRAB SEASONS

Price	Constant	% of WN Coastal Season Landings Prior to Current Month	Landings in That Port in That Month (Pounds)	Landings on WN Coast in That Month (Pounds)	WN Dungeness Inventory (Pounds)	R^2
For Both Seasons: Dependent variable: price on the Washington Coast; Included endogenous variable: % of total Washington coastal season's landings occurring prior to the current month; Included exogenous variables: landings in the port in question in the current month, landings on the Washington coast in the current month; Inventories of Dungeness crab in Washington (mostly in Seattle); Excluded exogenous variable: size of vessel making the landings.						
PRICE 1972	3.4176	-3.0561 (SE=2.2302)	-0.11113(-7) (SE=0.524(-8))	-0.78373(-6) (SE=0.553(-6))	0.36145(-7) (SE=0.358(-7))	0.051
PRICE 1973	0.37147	0.32536 (SE=0.15718)	0.18382(-7) (SE=0.876(-8))	0.93801(-7) (SE=0.658(-7))	-0.77448(-7) (SE=0.779(-8))	0.484

Washington depresses prices on the Washington coast by about 7.7¢, although most inventories are held in Seattle.

For the 1972 season this same model does not yield comparable results. Not only is the proportion of the total price variation explained negligible, but also all the signs of the coefficients are reversed. The problem seems to be finding an adequate excluded exogenous variable on which comparable data are available. In the 1972 season the vessel size should not be an excluded variable, because we already have some indication that it influences price. However, an acceptable substitute is not available in this data set.

Table IV-18 presents the results of two-stage least squares analysis of price for Westport. The inability to get an acceptable model for 1972 for this port is reflected in the similarly poor results for the Washington coast as a whole for that season. In 1973 we see a somewhat larger impact of the stage of the season and a somewhat smaller impact of inventory levels than is true for the whole coast of Washington as presented in Table IV-17. It takes a much larger increase in price to induce additional landings into Westport than for the average port, because Westport is the most northerly of the major ports and therefore has a lower average price than more southerly ports. An increase in total landings

TABLE IV-18

TWO-STAGE LEAST SQUARES MODEL OF PRICE DETERMINATION FOR WESTPORT IN THE 1972-73 WASHINGTON COASTAL CRAB SEASON

Price	Constant	% of WN Coastal Season Landings Prior to Current Month	Landings in Westport in Current Month (Pounds)	Landings on WN Coast in Current Month (Pounds)	WN Dungeness Crab Inventory (Pounds)	R^2
Dependent variable: price; Included endogenous variable: % of total Washington coastal season's landings occurring prior to the current month; Included exogenous variables: Landings in Westport in the current month, landings on the Washington coast in the current month, inventories of Dungeness crab in Washington; Excluded exogenous variable: size of vessel making the landings.						
PRICE 1973	0.29375	0.40581 (SE=0.10674)	0.65107(-6) (SE=0.269(-6))	-0.17115(-6) (SE=0.900(-7))	-0.71863(-7) (SE=0.104(-7))	0.532

on the Washington coast in a given month depresses the price in Westport for similar reasons. Westport already has a low price since it is further north from California. Therefore the price in Westport does little to attract landings to the State, so the depressing effect of landings on price is felt more strongly there on balance.

Ilwaco is the second largest crab port in the Washington coast and is very nearly the most southerly. The results of two-stage least squares analysis of price for Ilwaco are presented in Table IV-19. The extent of the price variation explained is much greater than for Westport or for the Washington coast as a whole. This is the only port for which an acceptable model of price in the 1972 season was obtained. Note that the price rose extremely rapidly as the season progressed and was about twice as fast as the average for the coast in the 1973 season. This is at least partly because more of the season's catch was taken earlier in this more southerly port. This is especially true in the 1972 season when the Oregon season opened in December 1971. In both seasons the landings in Ilwaco in the current month depressed prices on balance, but higher prices attracted landings to the Washington coast as a whole on balance. Both the attractive effect of prices and the depressing effect of landings are present for both variables, but

TABLE IV-19

TWO-STAGE LEAST SQUARES MODELS OF PRICE DETERMINATION FOR ILWACO IN THE 1972 AND 1972-73 WASHINGTON COASTAL CRAB SEASONS

Price	Constant	% of WN Coastal Season Landings Prior to Current Month	Landings in Ilwaco in Current Month (Pounds)	Landings on WN Coast in Current Month (Pounds)	WN Dungeness Crab Inventory (Pounds)	Landings Per Vessel Per Dealer in Current Month (Pounds)	R^2
Dependent variable: price; Included endogenous variable: % of total Washington Coastal Season's Landings occurring prior to the current month; Included exogenous variables: Landings in Ilwaco in the current month, landings on the Washington coast in the current month, inventories of Dungeness crab in Washington, landings per vessel per dealer in current month, i.e., landings per observation; Excluded exogenous variable: size of vessel making the landings.							
PRICE 1972	-3.2978	3.9783 (SE=3.4377)	-0.16526(-6) (SE=0.145(-5))	0.11970(-5) (SE=0.107(-5))	-0.85038(-6) (SE=0.696(-6))	-0.58325(-6) (SE=0.413(-6))	0.580
Dependent variable: price; Included endogenous variable: % of total Washington Coastal Season's Landings occurring prior to the current month; Included exogenous variables: Landings in Ilwaco in the current month, landings on the Washington coast in the current month, inventories of Dungeness crab in Washington; Excluded exogenous variable: size of vessel making the landings.							
PRICE 1973	0.061269	0.73266 (SE=0.13531)	-0.29462(-6) (SE=0.164(-6))	0.31585(-6) (SE=0.725(-7))	-0.46855(-7) (SE=0.271(-7))		0.761

one is stronger in each case. In spite of the fact that most Dungeness crab inventories in Washington are held in Seattle, this variable is an important one for Ilwaco. Higher inventories depress prices there in both seasons, although the impact is greater in the 1972 season. In the 1972 season the size of the individual vessel's total landings with a given dealer in a given month in Ilwaco also depress the price received. This is probably due to the strain of large landings during the peak of the season on processing capacity. This was not observed in the 1972-73 season because total landings were much less.

The biggest difficulty in building a simultaneous model of price determination for these two seasons was that there were no data available on many variables which should have been included. As we saw from the time series data, the price on the Washington coast is determined as part of a coast-wide simultaneous system. However, comparable monthly data for the other states were not available. One must therefore be content with an admittedly partial explanation of the cross section determination of price.

A few conclusions can be added to the time series results, however. While the size of the coefficients may vary, certain variables are consistently important: (1) The proportion of the available crab population

which has already been caught has a positive impact on price. As the end of the season draws near, there is increased competition to get the remaining landings. This is the primary reason for prices rising during the season. (2) Although most of the inventories of Dungeness crab are kept in Seattle, the size of these inventories has an important negative impact on price. This is largely the effect of Alaska landings on price in Washington that we observed in the time series data. (3) Prices are generally lower further north along the coast. This reflects distance from California markets where delivered prices are higher. Transportation costs must be absorbed by firms further north if their delivered prices in California are to be competitive with dealers shipping from ports located further south. (4) Thus most ports have fairly competitive pricing in spite of few buyers facing many fishermen. Very few examples of what is probably monopsonistic power on the part of a dealer were observed, and these cannot be detailed because of the confidentiality of the individual data. (5) There is significant competition between ports and states for the available landings. This effect often swamps the depressing effect of larger total season's landings on price which we observed in the time series data. However, the evidence available from both time series and cross sectional data suggests that the

validity of the standard assumption of fisheries economics theory that price and landings are independent for the geographic scale of the fishery being studied should be viewed with some doubt for the Dungeness crab fishery on the state or even port level. Further study of this assumption for this and other fisheries is therefore recommended. At the same time revisions in the theory to allow relaxation of this assumption are also suggested.

Footnotes

[1]James A. Crutchfield, "Economic Objectives of Fishery Management," in James A. Crutchfield (ed.) The Fisheries: Problems in Resource Management (Seattle: University of Washington Press, 1965), p. 44.

[2]James A. Crutchfield and Giulio Pontecorvo, The Pacific Salmon Fisheries: A Study of Irrational Conservation (Baltimore: Published for Resources for the Future by Johns Hopkins University Press, 1969), p. 36.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

V-A. Policy Alternatives and Recommendations[1]

Before summarizing the conclusions of this paper and recommending further research directions, a look at the policy alternatives available and their appropriateness for this fishery is in order. There are a variety of ways of protecting fisheries from over-fishing. As we have seen in the Dungeness crab fishery a minimum size limit, prohibition of harvest of females and season closure during the months of greatest vulnerability to other predators due to soft-shelled condition after molting have been used. These measures protect the species from extinction which might otherwise result from over-fishing, but they do not prevent fishing effort in excess of the socially optimal levels.

In addition to sex or condition limits, size or weight limits and season closures, there are other measures commonly used in other fisheries. These include closure of certain nursery or spawning areas and various gear limitations. Frequently, the most efficient type of gear is simply outlawed altogether rather than limiting the number of units of the gear; salmon traps are a

good example. In other cases the size or selectivity of the gear is specified. Other methods of restricting the efficiency of the fishing operations have also been employed including size limits on vessels. It seems that there are always new ways of restricting fleet efficiency being discovered somewhere in the Western world to provide protection of the fish while maintaining the option for anyone to exploit the common property resource.

A catch quota is a good example of a policy which protects the species but causes inefficient fishing operations. A limit on the total catch allowed each season is employed in the Pacific halibut fishery, for example. Such a limit encourages intensive fishing early in the season as each fisherman tries to claim a larger share of the total allowable catch. The costs of quotas thus include the waste caused by this rush to catch the fish, the extra processing and storage costs of handling the landings in a shorter time, and the resulting reduction in fresh fish products available at other times of year.[2] Thus while such a policy protects the species, it does not solve the problems of excess effort associated with the common property nature of the fishery.

All of the restrictions noted thus far cause overly intense use of the possibilities left open to fishermen so that still more effort is absorbed in an industry which would have excess effort anyway. Indeed it is

just the over-fishing caused by excess effort which these efficiency limiting regulations should be trying to reduce.

Of course, there are ways of limiting fishing effort which do not limit fishing efficiency. These techniques have been discussed much more than they have been used. The solutions resulting from the theory discussed in Chapter II call for a tax on capital investments in the fishery in question (boats and gear) and a tax per pound of fish landed which are equated to the marginal congestion costs of additional boats and gear and the marginal cost of fishing a reduced stock of fish in the future, respectively. This approach, while it is the most theoretically correct and simple one, has not been applied for two major reasons: First, data which would allow calculation of these taxes is commonly lacking as is true in the instant case of the Dungeness crab fishery. Second, it is thought to be political suicide to try to levy more taxes on fishermen while many of them are doing poorly anyway. A tax solution would be much easier to implement as a deterrent to over-fishing than as a cure for it.

The second major category of effort limitation techniques that do not limit fishing efficiency is licensing. Both taxes and licenses restrict fishing mortality while

permitting use of the most efficient techniques and encouraging cost reducing research and innovations. The easiest licensing method to institute is a "grandfather system" where those who are fishing at a given time are issued licenses to continue fishing, but new entry is restricted. These licenses would not be transferable. As fishermen die or leave the industry the number of fishing enterprises declines until the optimum number is reached. At this point licenses could be made transferable so that the number ceases to decrease, but this might be judged to be unfair to many who retired before the rules changed and provide windfalls to those almost ready to retire. Retirement behavior would be different if people knew when and if the rules would change.

A modification of the "grandfather system" would be to allow licenses to be transferable from the beginning, but to impose a yearly license fee which would be manipulated to encourage sale of some of the licenses to the government. This "buying-in" process would continue until the appropriate number of outstanding licenses is achieved. This system would keep the rents accruing to fishing rights for those initially in the fishery just like the "grandfather system" and would thus be relatively easy to implement politically. A form of this

"buying-in" system is being used in the British Columbia and Alaska salmon fisheries.

Although it might be politically more difficult to implement than other licensing schemes, the fishing rights could be assumed to rest initially with the State rather than the fishermen. Licenses could then be sold each year by the government with the number being reduced to the optimal level either immediately or gradually. License fees could be set at a fixed rate or by competitive bidding. Auctioning the licenses would have the advantages of allowing the market to confirm the value of the licenses and insuring that the better fishermen would be licensed. Since it is generally easier to determine the appropriate amount of effort than to calculate the tax necessary to achieve this, it is administratively easier to auction licenses than to tax capital at rates equivalent to such license fees, although the two methods are theoretically equivalent. Over-confident fishermen might bid too much for the licenses until they become familiar with the system, but licenses would be transferable so that the proper value of licenses would be achieved after an adjustment period. Under this type of licensing, fees approaching the total rents accruing to ownership of the fishery resource would be collected by the State. This money could then

be used for retraining those fishermen who became excluded from the fishery or for any other purpose society deems desirable.

Such licensing can achieve the appropriate amount of capital as well as a tax on capital can; it is also easier to implement politically and administratively. Licensing alone, however, will encourage overuse of the units licensed. (While this point now seems obvious, no note of it has been found in the literature, probably due to the great emphasis on tax rather than license schemes.) Further restriction of licenses to prevent the over-fishing which would result from overuse of license privileges would lead to the strange situation of too little of the licensed capital being used in the fishery in comparison to nonlicensed inputs. Licensing plus a tax per pound on fish landed can be optimal, however. This tax should be equated to the marginal cost imposed on all fishermen who must in the future fish a stock of fish which is less than would exist without harvest of the taxed fish. Where the effect of harvest on the stock of fish in the future is not well known, this tax cannot be calculated. Even if the necessary biological knowledge is available, this tax would be difficult to determine: The tax should either increase throughout the season, which would cause the same inefficient clamoring by each fisherman to land his catch first as

exists currently, or the tax would have to be determined before the season on the basis of the expected catch by the licensed units under varying levels of the tax.

In the British Columbia salmon fishery vessels are licensed while in the Alaska salmon fishery it is the fishermen who are licensed. As discussed in Chapter III the most appropriate single measure of fishing effort for this fishery is the crab pot. This unit of gear is fairly standardized for the Dungeness crab fishery, while vessel characteristics and fishermen's skills are far from uniform. Furthermore, it seems that the least deviations from efficient fishing operations would result from restrictions on pots as opposed to the alternatives of vessels and fishermen commonly suggested in other fisheries. If the number of vessels were limited then the number of crab pots and crewmen per vessel would be increased in an attempt to maintain a high level of fishing pressure on the stocks. If the number of fishermen were limited then each fisherman would be encouraged to use more gear. Fishing intensity is more basically determined by the number of crab pots and extent of their use than by the number of vessels and fishermen. Accordingly, direct regulation of the number of crab pots seems the logical place to begin. To the extent that emptying these pots more (or less) often or changing the size of the pots can increase the catch per

pot, these things will be tried by ingenious fishermen. The latter can be controlled by speaking in terms of a volume equivalent to standard crab pots; for example, if the volume of the pot is doubled this would be treated as the equivalent effort of two standard pots.

Given a prediction of crab availability for the coming season and an estimate of the average catch per pot which is possible, the optimal number of crab pots can be determined. However, existing biological knowledge does not seem to permit accurate estimation of crab availability more than a few months in advance. Therefore, this will be a key link in predicting the appropriate number of licenses each season, and in determining when natural exit will have occurred to the point where restrictive licensing will be easiest to implement in terms of excluding the fewest fishermen. It has been suggested that each vessel be limited to the same number of crab pots to achieve the reduction in effort which would be necessary. However, this restricts fleet efficiency by restricting more efficient fishermen to the same scale of operations as less efficient ones. The best method of avoiding this is to auction the rights to fish crab pots to the highest bidders until the total optimal number of licenses has been sold. In this way the most efficient fishermen are able to fish as many pots as they are willing to buy a license to fish while

the least efficient fishermen will be forced to exit the fishery because they cannot bid as much for the license based on their lower profit expectations. This method of allocating fishing rights leaves the rents accruing to initial ownership of those rights with the State to be used to compensate those who exit the fishery or to do whatever else seems appropriate.

In addition to the restrictive licensing, a tax per pound of crab landed (or its equivalent) would have to be set at the start of each season on the basis of estimates of how many crab the licensed pots would catch during the season and how this level of catch would affect the availability of crab in future years. The minimum size limit can be used in lieu of this tax on catch to regulate the effect of the crab catch in each year on future levels of crab availability. Currently this size limit seems to be set at about the right level, as shown in Chapter I. However, additional information on crab growth rates and natural mortality beyond the current legal size may lead to adjustment of this size restriction once and for all or periodically, in lieu of a tax, to even out the natural fluctuations in availability. While licensing plus size regulations may not be as elegant a solution as some tax schemes that have been devised, the inability often to calculate these tax rates

in practice or to implement them politically reduces their appeal.

It should be noted that because crab availability fluctuates for largely biological reasons as noted in Chapter I, the optimal effort calculated on the assumption of no lag in the achievement of alternative employment for the resources freed when this optimum declines will also fluctuate. Given the lag in the shift of resources into or out of this fishery that exists in practice, however, this would mean that the optimum as calculated in Chapter III will probably be changing faster than the allocation of resources can be adjusted in response to it. Therefore, optimum effort must actually fluctuate less than initially calculated and effort will seldom be optimal in the sense used in Chapter III and in all the theory summarized in Chapter II in order to obtain an optimal time path of effort. These fluctuations could be reduced and overall efficiency of the fleet in terms of average catch per unit of effort over time could be increased by reducing the fluctuations in the crab catch. If fluctuations in crab availability cannot be controlled biologically, then this could be achieved only by varying the proportion of the current legal sized crab taken in each year. The advisability of postponing the capture of some legal sized crab in good years depends on the growth and natural mortality which

they will experience. In any case it is clear that forecasts of the available crab population each season are a key element of any management strategy whether it be taxes or licenses or individual transferable quotas for fishermen.

In summary, it is recommended that all pots currently in use be licensed initially. The number of pots should then be reduced through a voluntary buying-in program financed by license fees. Once the number of pots is reduced to the number which would be optimal in the highest catch year, then the licenses should be made transferable to allow movement of other resources in and out of the industry and to encourage the most efficient crab fishermen to be in that business. Ultimately, it is suggested that restrictive licensing of pots with the appropriate number of licenses being auctioned each year prior to the opening of the season will be optimal for the State when combined with appropriate size restrictions. This can be equivalent to schemes which place a tax on capital invested in the fishery and a tax on fish landings both in terms of providing optimal resource allocation and in terms of returning rents accruing to ownership of the resource and the rights to fish it to the State, although this is not noted in the literature.

V-B. Summary and Conclusions

In Chapter I a general description of the Dungeness crab fishery and its problems was given. A relationship between width and weight of male Dungeness crabs was estimated. Weight was found to be approximately a function of the cube of width as is typical of such biological relationships. This relationship was combined with biological studies of the growth of Dungeness crabs in shell width up to the current legal size to give a relationship between growth in weight and size. This relationship was then used to assess the appropriateness of the current minimum size limit. During the last molt which brings male Dungeness crabs above the minimum legal size, they are growing at a rate of about 33 percent per year in weight. While this is above the rate of return on capital invested elsewhere, this rate is also declining very rapidly. Waiting for another molt may bring this rate far below that on alternative investments since molting may not occur for more than another year and natural mortality is probably increasing. While more evidence on the growth of these crabs above the current legal size is too sketchy for a definitive evaluation, it was concluded that the size limit is about right.

Fluctuations in the size of the commercial crab catch from year to year have been great. Some people have suggested that these fluctuations follow a regular or cyclical pattern. Work was done to test this hypothesis. A ten year cosine cycle was found to explain more of the variation in landings over time in Washington, Oregon, and California than any other regular sine or cosine cycle. This ten year cycle plus a time trend explained over half of the variation in landings in Washington and slightly less in Oregon and California. Biologists have long felt that the causes of these fluctuations in catch were biologically caused fluctuations in the available crab population. Recent evidence shows that environmental conditions, especially rainfall which affects ocean surface salinity, during the critical larval period explain about two-thirds of the variability in crab landings four years later when these male crabs enter the fishery. It may be that what tends to have a ten year cycle is rainfall levels along the Pacific Coast.

In Chapter II the relationship between common property problems and other "market failures," where governmental intervention is necessary to make the economy work as well as the standard model says it can, were discussed. All of these problems lead to a divergence between price and social marginal costs at the market

equilibrium, but the causes of the divergence vary and distinguish the problems.

Economies of scale which are significant compared to the size of the market cause monopoly or oligopoly problems. Firms see downward sloping demand curves and price exceeds private and social marginal costs. In extreme cases where long run average costs decline up to industry output, such "natural monopolies" are either regulated or owned by the government. The problem then becomes how to charge a price which is equal to marginal costs and still covers all fixed costs.

When some unpriced part of one entity's production or consumption enters directly into the production or consumption function of some other entity, such external effects cause a divergence between private and social marginal costs. When the good being produced or consumed is the same as the externality which is jointly generated, this good is a pure public good (or public bad to people with different tastes). A public good costs nothing to produce for another person once it is produced for someone else; indeed, no one can be excluded from its consumption once it is produced. The pure public good is a limiting case which is useful for expositional purposes but is seldom, if ever, observed in practice.

The less extreme cases of external effects are divided into congestion and pollution types. From these titles it is clear that these are usually considered to be negative rather than positive externalities. Congestion or crowding exists when externalities generated by persons engaging in an activity affect other persons' enjoyment or productivity of engaging in the same activity. Pollution exists when these externalities affect other persons' enjoyment or productivity of engaging in other activities. The distinction here is between competing users and competing uses of scarce resources.

In common property, open access resources such as fisheries another problem prevents the equation of price and social marginal costs at the competitive equilibrium. This is an intertemporal externality caused by the existence of positive rents at the socially optimal level of output which cannot be capitalized into the cost of this resource to its users. In a normal competitive market equilibrium where all inputs are owned by their users, price will equal average costs including capitalized rents to scarce factors (and also marginal costs excluding such rents). In the common property case these rents are not capitalized into the average costs to which price becomes equal at equilibrium. Instead these rents induce additional entry of other resources into the industry, because a greater share of these rents can only

be obtained by producing a greater share of the output. This entry stops where price equals average costs excluding these rents to ownership of fishing rights and these rents have been dissipated through higher costs.

At this competitive equilibrium more effort is employed in a fishery than is required to take the catch and the catch is too large in the early years of the fishery. The intertemporal externality is felt in a smaller population of fish available to catch in subsequent years. In the remainder of Chapter II literature showing how a catch tax plus a license fee will correct this situation was summarized.

In the first part of this chapter it was argued that the minimum size limit could substitute for the catch tax in the Dungeness crab fishery. This is because of the effect of this regulation on the shape of the sustainable yield curve as discussed in the first part of Chapter III. Some decline in sustainable yield beyond the MSY point probably occurs, but it is very slight compared to what would be the case without this restriction.

Nevertheless, there is considerably more effort employed in this fishery than is required to take the available catch and therefore even more than would be socially optimal. The extent of this excess effort has been estimated in Chapter III by comparison of current catch per unit of effort with that observed in earlier

years. A new sustainable yield curve exists in each year due to the changing ecological environment of the crab population which causes this population to fluctuate. Therefore care was taken to choose a base year for this comparison for which the catch, and by implication from biological work the population, is at least as large as in the current year. This controls for the changes in productivity of the crab harvesting technique which result from changes in crab population and density. Given a base year with catch per unit of effort higher than in the current year, but other conditions the same or better, it was argued that the gear could be at least that productive in the current year. This gave an estimate in each year of the number of units of effort required to take the catch in that year. Less effort than this would mean some eligible crabs would not be caught and more effort would not land any more crabs. It was therefore argued that the estimated effort level was the MSY level. The estimate of the extent of excess effort was argued to be a minimum estimate for a number of reasons: there may be excess effort in the base year chosen, the technology may have improved if anything, and the MSY effort level always exceeds the socially optimal level.

The number of crab pots used each year was taken as the measure of effort. A composite effort index such as is assumed in the theory reviewed in Chapter II was not

available. The crab pot is the prime input that is used for no other purpose. Most vessels and fishermen are engaged in other fisheries at other times of year. These other fisheries are primarily salmon trolling and gill netting.

The proportion of effort employed which was determined to be actually needed to take the MSY catch level varied from 63 percent in 1957 to less than 9 percent in 1973 using the base years of 1941 and 1940, respectively. Cross sectional distributions of catch per pot by vessel indicated that about 40 percent of the vessels do better than the mean in an average year. This proportion is closer to half the less the extent of excess effort.

The value of this excess effort was estimated first by assuming a competitive equilibrium and therefore that total costs equaled total revenues. Then this assumption was relaxed and the opportunity costs of the resources employed in this fishery were estimated. This was done by first estimating the entry/exit responses to changes in real revenues per pot. The entry/exit rate was then set equal to zero to estimate the costs which revenues would have to be expected to equal to achieve economic equilibrium in the fishery.

Based on these cost estimates and the physical estimates of the extent of excess effort, the value of effort

which could be saved through a move to optimal effort management policies was estimated to be over $3 million in the 1972 and 1972-73 coastal Dungeness crab seasons on the Washington coast alone.

Comparing the estimated costs to the fleet revenues it was estimated that over half a million dollars in the 1972 season and nearly a million dollars in the 1972-73 season was lost by the Washington coastal crab fleet. From the study of distributions of catch per pot by vessel it was estimated that about one third of the vessels probably still turned a profit in the 1972 season and only about 10 percent did so in the 1972-73 season.

The opportunity cost of labor employed in this fishery was then estimated as the difference between these estimated total costs and what was known about the other costs of the fishing operations. The average captain's time was estimated to be worth about $5 per hour on a full time basis during the crab season in 1972 and the average crewman's time was estimated to have an opportunity cost of only about half this. Although these estimates could be refined, a useful, new procedure has been tested. It should prove to be much easier and cheaper to estimate the opportunity costs of labor employed in fisheries through this indirect procedure than to attempt it directly through surveys. The opportunity

costs of fishermen's time are as low as they are because of lack of good alternatives especially for the winter months of the crab season and a preference for the life of a fisherman and the chance to make a lot of money quickly. To estimate the opportunity costs of this labor through surveys would require identifying and evaluating employment alternatives and placing a monetary value on the preference for this particular job.

Further analysis of entry/exit behavior revealed that the rate of increase in total fleet revenues was another important influence in addition to the previous year's revenues per pot. Fishermen enter the industry when they see those in the business doing well or expand their own operations when they have been doing well themselves, but entry also occurs when the size of the industry in total revenues is growing rapidly. Attempts to apply the methods developed in Chapter III to the Dungeness crab fisheries in other states met with less success.

Chapter IV tested the standard assumption of fisheries economics theory that the price of the fish is independent of landings for the geographic scale of the fishery being studied. Not enough exogenous variables could be found in the time series data to build a truly satisfactory model of price determination. Prices in each area are influenced strongly by prices in the other

areas as one might expect. However, the evidence available suggests that landings in Washington and California do influence prices in this states, respectively.

Cross sectional analyses of crab prices on the Washington coast revealed that the stage of the season as measured by the proportion of total season landings on the Washington coast which have been taken prior to the current month is the most important determinant of price there. Prices rise as the season progresses. Other important determinants of price were the landings on the Washington coast in the current month, current inventories of Dungeness crab in Washington, and sometimes landings at the same port in the current month and size (length) of the vessel making the landings. In most cases it was found that higher prices attract more landings to the state and to a given port more than higher landings in an area depress prices there. More of a price rise is needed to attract landings to the Washington coast as a whole than to shift them between Washington ports. Thus we find that prices and landings may not be independent even on the port level. Higher inventory levels depress prices and larger, more mobile vessels have a tendency to get higher prices on average. When the influence of these other factors is removed, one can see that prices tend to be lower further north along

the coast. This reflects higher transportation and storage costs of reaching the prime California markets.

The industrial structure of this fishery was found to exhibit monopsonistic tendencies just like most fisheries; few dealers buy from many fishermen in each port. The top four dealers/processors handled about two-thirds of the catch consistently in the years for which data were available, and three of the top four dealers were the same in each year. During the same period the total number of vessels increased markedly but about two dozen vessels regularly landed about half of the catch. This reflects less concentration at the fisherman level than at the dealer level. Also less than half of these two dozen or so vessels were the same in all these years.

In spite of objective measures which indicate monopsonistic industrial structure tendencies, the fishery does not behave monopsonistically. Theoretically a monopsonist would capture all the rents accruing to ownership of fishing rights by paying a price for fish which would permit only the most efficient exploitation of the fish resource to occur. In such a case the misallocation of resources which usually results from the common property, free access nature of the resource would be avoided. However, these misallocations do exist in most fisheries and are significant in the Dungeness crab fishery, as we have seen.

The gains from instituting a policy to license crab pots in the coastal Dungeness crab fishery in Washington have been shown to be very substantial. It has been recommended that all pots currently in use be licensed and that the number be reduced gradually through a voluntary buying-in program financed by license fees. Ultimately, the appropriate number of licenses should be auctioned each year prior to the opening of the season.

APPENDIX:

CYCLICALITY OF LANDINGS IN WASHINGTON, OREGON AND CALIFORNIA

TABLE A-1

CYCLICALITY OF LANDINGS IN THE WASHINGTON COASTAL DUNGENESS CRAB FISHERY

Length of Cycle	Constant	Cosine	Sine	Case Number (Time)	R^2 (DW)
8 Years	2185900	975270 (1.2257)	-786170 (-0.99173)	233230 (4.3256)	0.399 (0.667)
9 Years	2404000	244900 (0.32251)	-1930100 (-2.5675)	217570 (4.1883)	0.464 (0.772)
10 Years	2026500	-2605600 (-3.7488)	-395830 (-0.58433)	226600 (4.8626)	0.554 (0.888)
11 Years	1860100	-616640 (-0.85922)	2380700 (3.5009)	236120 (4.9560)	0.540 (0.853)
12 Years	2375500	2167600 (3.0169)	1023500 (1.4244)	219030 (4.4004)	0.523 (0.860)
13 Years	263500	1751600 (2.3131)	-1314600 (-1.8054)	212560 (4.1667)	0.490 (0.819)

TABLE A-2

CYCLICALITY OF LANDINGS IN THE OREGON DUNGENESS CRAB FISHERY

Length of Cycle	Constant	Cosine	Sine	Case Number (Time)	R^2 (DW)
8 Years	476770	203140 (0.39374)	247630 (0.47823)	134150 (3.8231)	0.318 (0.906)
9 Years	5156000	-1487100 (-3.2637)	267040 (0.5952)	113750 (3.6592)	0.486 (1.107)
10 Years	4869600	-1442400 (3.2103)	-247160 (-0.54471)	126240 (4.1174)	0.483 (1.073)
11 Years	4621300	-139730 (-0.27987)	1013300 (2.1056)	139180 (4.1651)	0.395 (0.962)
12 Years	4903600	-73981 (-0.14951)	1132000 (2.3597)	127400 (3.7736)	0.413 (1.026)
13 Years	5134800	668780 (1.4461)	1340600 (-2.9639)	119960 (3.8187)	0.482 (1.167)

TABLE A-3

CYCLICALITY OF LANDINGS IN THE CALIFORNIA
DUNGENESS CRAB FISHERY

Length of Cycle	Constant	Cosine	Sine	Case Number (Time)	R^2 (DW)
8 Years	3851300	1067400 (0.99768)	1660200 (1.5461)	236190 (3.2495)	0.302 (0.548)
9 Years	4890100	1292300 (1.3999)	-340600 (-3.7231)	184450 (2.8836)	0.482 (0.564)
10 Years	4227400	-3602200 (-3.9731)	-1021200 (-1.1153)	214310 (3.4639)	0.499 (0.627)
11 Years	3308000	-1734400 (-1.7754)	2988900 (3.1742)	261920 (4.0059)	0.448 (0.667)
12 Years	3437100	1889600 (1.8704)	2132400 (2.0463)	262990 (3.6990)	0.379 (0.649)
13 Years	4006500	2326600 (2.1635)	-705550 (-0.67086)	242150 (3.3152)	0.333 (0.635)

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