To the Graduate Council:

I am submitting herewith a dissertation written by Hadley T. Mitchell entitled "The Development of the Economics of Fisheries: A Common-Property Renewable Resource." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

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THE DEVELOPMENT OF THE ECONOMICS OF FISHERIES
A COMMON-PROPERTY RENEWABLE RESOURCE

A Dissertation
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Doctor of Philosophy
Degree
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Hadley T. Mitchell
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ABSTRACT

This dissertation examines the development of the economics of marine fisheries, starting with Scott Gordon, and continuing to the present. Three major phases of development are noted. First, a static model was developed by Gordon and amended by the biologist Milnear Schaefer. Second, Anthony Scott, who was interested in applying capital theory to natural resources, devised a dynamic model of the economics of the fisheries. While this model was superior to the static model, mathematical limitations prevented its use. Finally, with the rise of optimal control theory within mathematics and its introduction into economic theory through the work of Kenneth Arrow, a useful dynamic model was made available to the economics of the fisheries. The first contribution using this approach was made by James Quirk and Vernon Smith. It was subsequently developed by others to be the main theory for determining the optimal harvest rate of marine fisheries, considering both the biological and economic dimensions of the problem. The history of this develoment is traced from the earliest contributions to the present.

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INTRODUCTION

There is a certain sense in which the understanding of a discipline is incomplete without the knowledge of how that discipline has developed and how it has responded to particular issues facing it at various junctures within its development. That development reflects the response that earlier practitioners had devised to problems of their own day.

This dissertation will examine the development of the application of economic theory to the problem of conservation or optimal utilization of marine fisheries, which is an example of common-property renewable resources.

Early in the twentieth century, various marine biologists became interested in the effects of human predation upon fish populations. Throughout the nineteenth century, most experts considered marine fisheries to be inexhaustible. But, starting with the Russian marine biologist, Feodor I. Baranov,[1] the Danish biologist C. G.

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[1]Feodor I. Baranov, "On the Question of the Biological Basis of Fisheries," Reports from the Division of Fish Management and Scientific Study of the Fishing Industry (Moscow) 1 (1918): 81-128, trans. William E. Ricker (Bloomington: University of Indiana (mimeo), 1945), and "On the Question of the Dynamics of the Fishing Industry," Bulletin of the Fisheries Administration (Moscow) 8 (August

Jon. Petersen,[2] the British zoologist and Chief Naturalist at the Marine Biological Association, Walter Garstang,[3] and later with the British researcher, Michael Graham[4] and

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1925): 7-11, trans. William E. Ricker (Bloomington: University of Indiana, (mimeo) 1945). These two articles were very important in the development of the understanding of fisheries from the biological perspective. They were foundational in the subsequent development of the Schaefer model which was used by Scott Gordon. Michael Graham noted that Baranov "should have priority for much that has innocently been included as original in later papers on overfishing." Michael Graham, "Rates of Fishing and Natural Mortality from the Data of Marking Experiments," Journal du Conseil (International Council for the Exploration of the Sea) 13 (April 1938): 77.

[2]Petersen was among the first to be concerned with the reduction of fish catches in the North Sea. C. G. Jon. Petersen, "On the Decrease of Flat-Fish Fisheries," Beretning, Dansk Biologisk Station 4 (1893): 48-85. He was among the first to be concerned with the concept of "overfishing." "What is Overfishing?" Journal of the Marine Biological Association (UK), n.s. 6 (1903): 587-94.

[3]Walter Garstang, "The Impoverishment of the Sea," Journal of the Marine Biological Association, n.s. 6 (1900): 1-69.

[4]Michael Graham was a prolific writer with regards to the conservation of marine fisheries. He was also the Director of Fishery Research, Lowestoft, a British marine studies laboratory. Some of his works include "Overfishing and Optimal Fishing," Rapports et Proces-Verbaux des Reunions (International Council for the Exploration of the Sea) 132 (1952): 72-78, and "The Sigmoid Curve and the Overfishing Problem," Rapports et Process-Verbaux des Reunions (International Council for the Exploration of the Sea) 110 (1939): 15-20.

the American William Ricker,[5] there was a growing concern with the effects of fishing on the population levels of heavily fished species.

With the exception of the Danish economist, Jens Warming,[6] very little was written by economists on the problem of optimal utilization of the fisheries. Certainly, a few wrote insignificant books or articles.[7] But most of the important economic contributions prior to Scott Gordon's 1954 article, "The Economic Theory of a Common Property Resource: The Fishery,"[8] were the result of works by biologists largely untrained in economics who recognized that economic factors such as cost, market

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[5]William E. Ricker, "Relations of 'Catch per Unit Effort' to Abundance and Rate of Exploitation," Journal of the Fisheries Research Board of Canada 5 (1940): 43-70.

[6]Peder Andersen, "On Rent of Fishing Grounds: A Translation of Jens Warming's 1911 Article, with an Introduction," History of Political Economy 15 (Fall 1983): 391-96.

[7]Economists other than Warming who wrote on the economics of the fisheries prior to Scott Gordon's 1954 article would include Homer E. Gregory and Kathleen Barnes, North Pacific Fisheries, with Special Reference to Alaska Salmon (New York: American Council of the Institute of Pacific Relations, 1939), Edward A. Ackerman, New England's Fishing Industry (Chicago: University of Chicago Press, 1941), and G. M. Gerhardsen, "Production Economics in Fisheries," Revista de Economia (Lisbon) 5 (March 1952): 1-12.

[8]Gordon, H. Scott, "The Economic Theory of a Common Property Resource: The Fishery," Journal of Political Economy 62 (April 1954): 124-42.

price, or efficiency needed to be addressed before an adequate management of the fishery would be possible. Indeed, with the exception of the largely unknown[9] work by Warming, the biologists, working intuitively rather than theoretically, contributed more to the economics of marine fisheries than had trained economists.[10]

Gradually, it became evident to marine biologists and those given the responsibility of regulating the various fisheries that input by economists was indispensable for an efficiently managed fishery.[11] Some economists were employed by governmental regulatory bodies, and thus influenced the management of fisheries. Gerhardsen,[12]

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[9]The first reference to Warming's article was in Anthony Scott, "Development of Economic Theory on Fishery Regulation," Journal of the Fisheries Research Board of Canada 36 (July 1979): 725.

[10]Scott remarked that prior to Gordon, the study of fishery economics had been "the occasional subject of academic and policy papers." "Development of Economic Theory on Fisheries Regulation," Journal of the Fisheries Research Board of Canada 36 (July 1979): 725.

[11]James Crutchfield and Arnold Zellner observed that "[a] majority of biologists concerned with fishery management are, however, acutely aware of the influence of economic factors in shaping the development of the commercial fisheries and of the economic effects of regulation." James A. Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," Fishery Industrial Research vol 1, #1 (Washington: US Department of the Interior): 22.

[12]His article, which appeared in an obscure Portuguese journal, did not get much past a discussion of efficiency.

the only economist cited in Gordon's 1954 paper, was an example. He had been Chief of the Economics and Statistics Branch, Fisheries Division, Food and Agricultural Organization of the United Nations.

So before economists developed an interest in the problem, various biologists became interested in valuation of resources as food, with responsiveness to the forces of supply and demand, and price-guided human action. Michael Graham[13] had written on the concern for economy of effort expended in harvesting. Robert Nesbit, of the US

He encouraged the role of economists in fishery management. "[T]he main purpose of fisheries management would be to regulate the average yield per unit of effort and keep it at the highest sustainable level. While sustained yield per unit of effort is not possible any longer and there is no change in natural conditions, 'overfishing' has taken place." G. M. Gerhardsen, "Production Economics in Fisheries," Revista de Economia 5 (March 1952): 3.

[13]He wrote: "an economy of effort is desirable in the North Sea, that is, that a certain proportion of the time and money of the fishermen is at present devoted to reducing their catch, or is at least wasted. It also follows that in unrestricted fishing, proceeding as it usually does at ever increasing intensity, as grounds and habits become better and better known and gear more and more improved, there must come a time when new inventions are harmful. Nevertheless, once the new invention has done its harm in reducing the productivity of the stock, its use must be continued, because the old gear will not pay expenses on the less productive stock. So the fishermen are left with the expense of the invention, with no compensating increase in yield." Graham, "Modern Theory of Exploiting a Fishery, an Application to North Sea Trawling," Journal du Conseil (International Council for the Exploration of the Sea) 10 (December 1935): 264f.

Fish and Wildlife Service, was concerned with matters of efficiency in fishing.[14] The British researchers R. J. H. Beverton[15] and E. S. Russell[16] each had raised issues

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[14]Nesbit recognized that "[e]fficiency is desirable, not for its own sake, but because it is capable of promoting human welfare, and only to the extent that it actually does so. In a purely economic sense, efficiency can be measured . . . in terms of what an operating unit will produce in a year compared with its productive capacity." Robert A. Nesbit, "Biological and Economic Problems of Fishery Management," US Fish and Wildlife Service (Special Scientific Report # 18) (Washington: Government Printing Office, 1943), 40.

[15]Beverton favored "eumetric fishing," which is regulating mesh size in nets to allow smaller fish to reach a more profitable size. Beverton recognized that ordinarily the profit maximizing point is the optimal level of intensity to pursue unless some social or political issue made a higher level of intensity desirable. This he called the optimum fishing intensity. Beverton noted that the problem of selecting the proper mesh size "is essentially an economic one, to be reckoned in terms of the value of the yield and the cost of obtaining it. Clearly, it is not desirable to attempt to obtain the greatest possible yield, since owing to the shape of the eumetric yield curve this can be achieved only with an extremely high fishing intensity, and hence at a prohibitive cost. On the other hand, if too low a fishing intensity is used, even though the fishing is eumetric, the yield will be unnecessarily small, and a relatively small increase would enable a greater yield to be obtained without as large an increase in the cost of fishing." R. J. H. Beverton, "Some Observations on the Principles of Fishery," Journal du Conseil (International Council for the Exploration of the Sea) 19 (May 1953): 65.

[16]Russell stated that "[t]he adjustment of fishing power in such a way as to obtain the maximum yield without waste of effort, thus avoiding overfishing, is an urgent task which must be undertaken, by international action, as soon as possible after the cessation of hostilities [of WW II]." Edward S. Russell, The Overfishing Problem (London: Cambridge University Press, 1942): viii. Russell

with the cost of fishing as having an effect on the level of fishing activity.

William F. Thompson,[17] Director of the Fisheries Research Institute at the University of Washington, also was concerned with cost issues in fisheries. Thompson was the first to describe the stock of fish as being one of accumulated capital.[18] But, in the writings of these

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recognized that a greater fishing activity prematurely thins the stock of fish, thus lowering the yield of harvest. But he did not discuss the economic incentives for individual fishermen to leave fish behind under a commonly-owned resource base. There was no discussion of market failure, nor of the government's role in remedying the situation.

[17]"From the economic standpoint the decrease [in yield per unit] has been the only limit on the intensification of the fishery, the yield per unit being forced as low as would permit the fishery to exist, and the catch being produced from each bank at the greatest possible cost. The abundance on each bank therefore has sought an economic, not a biological, level, although the intensity of the fishery and the resultant mortality rate did have important biological consequences.... Regulation of the intensity of the fishery should therefore have the important initial advantage of tending to correct a wasteful economic process--production of the catch at the highest possible cost and greatest effort." William F. Thompson, "Conservation of the Pacific Halibut," Annual Report Smithsonian Institution (June 1935): 374.

[18]He writes: "The varying size of the abundance of fish accumulation ... is a direct result of the law of accumulated capital.... [I]t shows the size of the stock on the banks may vary with the amount of fishing, but that the so-called permanent yield does not, unless the accumulation in an indirect way affects the income." "Theory of the Effects of Fishing on the Stock of Halibut." Report of the International Fisheries Commission 8 (1934): 12. Here Thompson is thinking of the stock of the fish representing capital. Under an adequately managed fishery, this stock could be maintained at a relatively constant

biologists, there was no compounding or understanding of time value of money, only the acquisition of new stock. There was no market value placed upon the fish, hence no way to measure the desirability of trade-offs regarding fishing levels in different periods of time.

The work of these biologists was atheoretical in that they did not use the tools of economics to discuss an economic issue--how the value that we impute to various species of fish affects the extent to which men would harvest those fish.

The Initial Work by Economists

Aside from the then unknown work of Warming, economists had not begun to apply the tools of economics to the fisheries until the 1950's. The first economist to work on the economics of fisheries was H. Scott Gordon. In the early 1950's, the Canadian government had asked him to ascertain why fishermen tended to have persistently low incomes.[19] From this work prompted by the Canadian

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this stock could be maintained at a relatively constant level, and the increase in mass would be offset by the level of fishing activity. There is no discussion of the effects of the changes in market value of fish, nor of the effects of supply and demand on the fishery.

[19]"In the late 1950's a Canadian economist, H. S. Gordon, was asked by federal fisheries authorities to provide an economic analysis of the persistent problem of low income among Canada's maritime fishermen. Gordon's

government emerged his 1954 article, "The Economic Theory of a Common Property Resource: The Fishery," which is generally regarded as the first real contribution to the economics of marine fisheries.

The rate of harvest of fish has an effect on the population size, and in some instances, possibly an effect on the very survivability of the species. But this rate of harvest is affected both by institutional factors, primarily that fish are not privately owned, and also by factors which are considered within the neoclassical model of economics, such as market price, cost, and amount of effort applied to the harvest of fish.

The focus of Gordon's approach was to take the biological model of the fisheries as a given. He used a variant of the sigmoid curve[20] as discussed by Graham and

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theory of the 'common property' fishery (Gordon 1954), which has since become a classic, not only explained the low income of fishermen, but also clarified in economic terms the so-called overfishing problem (Graham 1952). It explained how economic overfishing would be expected to occur in any unregulated fishery, while biological overfishing would occur whenever price/cost ratios were sufficiently high." Colin W. Clark, Bioeconomic Modelling and Fisheries Management (New York: John Wiley & Sons, 1985): 1. By 'economic overfishing,' Clark refers to the using of labor and capital to the point of exhausting economic rent. By 'biological overfishing,' Clark means the harvesting in excess of the maximum sustained yield. Economic over-fishing generally occurs at a lower population level than does biological overfishing.

[20]The sigmoid curve is an s-shaped curve that shows the rate of growth of the population of a species over

added the economic dimension of cost factors and the impact of the lack of property rights. Gordon assumed that the optimal level of fishing, that of the maximum sustained yield, would continue to be appropriate over time.

In the following year, another Canadian, Anthony D. Scott, who had studied for his doctorate at the London School of Economics,[21] applied capital theory to marine fisheries.[22] His perspective was significantly different than Gordon's, because it allowed one to consider the optimal level of harvest over time as changing rather than being static, as was the case for Gordon. Scott modified the Gordon model to consider the stream of future net returns from fisheries discounted back to the present.

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time. It assumes that when the species is first introduced to an environment, the number of specimens will increase rapidly. Then, as the population reaches the carrying capacity of that environment, the rate of growth will level out so that the population will be at some maximum level from then on.

[21]His dissertation, later published as Natural Resources: The Economics of Conservation (Toronto: University of Toronto Press, 1955), was concerned with viewing natural resources as a form of capital. So existing capital theory could be applied to the rate of resource consumption. His work in fisheries economics, then, was to apply these results to renewable capital rather than nonrenewable capital.

[22]Anthony Scott, "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy 63 (April 1955): 116-24.

While conceptually, Scott's approach was superior to that of Gordon, his policy recommendations did not significantly differ from those of Gordon. The problem was that mathematically, he could not optimize from within his model. So this conceptual improvement was not applied until after the development of optimal control theory by the Russian mathematician L. S. Pontryagin, and Kenneth Arrow's subsequent application of optimal control theory to economic theory,[23] particularly the theory of capital. James Quirk and Vernon Smith[24] were the first to apply optimal control theory to the fishery.

So there are three phases in the development of the economics of the fisheries. The first phase, starting with the work of Scott Gordon, combined economic insights into the biological model of the fisheries. He was the first to address the significance of fisheries being common property. This work proved to be very fruitful for subsequent research. Milnear Schaefer[25] was the first

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[23]Kenneth J. Arrow, Application of Control Theory to Economic Growth (Stanford University: Institute for Mathematical Studies in the Social Sciences, July 14, 1967).

[24]Quirk, James P. and Vernon L. Smith, "Dynamic Economic Models of Fishing," in Economics of Fisheries Management: A Symposium, ed. Anthony D. Scott (Vancouver: University of British Columbia, Institute of Animal Resource Ecology, 1970): 3-32.

[25]Two of his works that were especially important in

biologist to recognize the importance of Gordon's work, and so extended it into his biological model. This combination became known as the Gordon-Schaefer model.

The second phase, beginning with Anthony Scott, applied the theory of capital to marine fisheries. Scott expanded the Gordon model. James Crutchfield and Arnold Zellner expanded this work. But the then-existing mathematics limited the application of the model.

The third phase began with the application of optimal control theory to the economics of marine fisheries. Colin Clark did much to bring the theory to its present form.[26]

Organization

The dissertation will use this threefold division. The first chapter will explore the background and development of the Gordon-Schaefer model. It will show what changes in the neoclassical theory were necessary to

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this regard are Milnear B. Schaefer, "Some Considerations of Population Dynamics and Economics in Relation to the Management of the Commercial Marine Fisheries," Bulletin of Fisheries Research Board of Canada 14 (September 1957): 669-81, and "Biological and Economic Aspects of the Management of Marine Fisheries," Transactions of the American Fisheries Society 88 (April 1959): 100-04.

[26]Colin W. Clark Mathematical Bioeconomics: The Optimal Management of Renewable Resources, 2d ed. (New York: Wiley-Interscience, 1990) is fairly representative of the present state of the theory of the economics of fisheries.

develop the economics of marine fisheries, and what insights inspired these changes. The Gordon-Schaefer model successfully combined neoclassical economics with the biological model of fish populations that had been developing from the turn of the century.

The second chapter will trace the development of the application of capital theory to natural resources, starting with Harold Hotelling's important work. The application of capital theory to the fishery was a significant improvement to the Gordon-Schaefer model, and it stimulated much further research.

The third chapter will consider the application of optimal control theory to marine fisheries. Since the subsequent work has been embellishment of this work, we will be able to trace the development to the present.

A final chapter will summarize the work and present conclusions.

CHAPTER I

H. SCOTT GORDON AND THE STATIC GORDON-SCHAEFER MODEL OF THE ECONOMICS OF MARINE FISHERIES

Fishery Economists Prior to Gordon

The discussion by English-speaking economists of the economics of marine fisheries began with the publication of two books, written in 1939 and 1941 respectively. Both were descriptive rather than prescriptive. That is, each discussed some of the economic factors, such as market structure or labor organizations, of the marine fisheries. Neither of these books provided an analysis of a problem, nor were any recommendations for changes made.

In the first, North Pacific Fisheries,[1] Homer Gregory and Kathleen Barnes discussed some of the economic issues affecting Pacific fisheries, particularly the Alaskan salmon fishery. In the book, they quantified the importance of the fishing industry to Canada and the United States, particularly the Territory of Alaska and the State of Washington. They discussed the size of the

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[1]Homer E. Gregory and Kathleen Barnes, North Pacific Fisheries, with Special Reference to Alaska Salmon (New York: American Council of the Institute of Pacific Relations, 1939). Homer Gregory was Professor of Management and Accounting, College of Economics and Business, University of Washington, while Kathleen Barnes was on the Research Staff of the American Council of the Institute of Pacific Relations.

work force, the magnitude of capital investments, and the structure of the industry in a descriptive manner. Unlike later studies, Gregory and Barnes held that the main component of analysis was the way that the canning industry was organized, rather than the fishermen. Starting with Scott Gordon, analysis would focus on the free entry of fishermen into a common-property resource. But Gregory and Barnes held, particularly in the case of the Alaskan salmon fishery, that it was important to analyze how the canneries operated.

> In the salmon industry . . . elements of monopoly are to be found in the possession of favored trap sites, in preferred access to credit facilities, in the exercise of "price leadership," in the creation of specialized markets through the advertising of branded products, etc. On the other hand, it is equally clear that the industry is strongly competitive in many aspects, not only by virtue of the presence of numerous small operators but also with reference to relations among larger concerns as well. 2

Gregory and Barnes showed that several factors unique to the fishing industry caused the salmon fishery to be essentially competitive.[3] Although they noted the lack of individual property rights in the fishery, this played

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[2]Ibid., 80.

[3]Ibid., 82ff. These factors include an elaborate set of government regulations, the wide geographical dispersion of resources, the lack of individual property rights to the salmon reserve, and the relatively simple and noncapitalistic nature of fishing operations.

no role in their analysis. The partial exception to this lack of property rights in the Alaskan salmon fishery was the ability to place fish traps at specified locations, which then accounted for over half of the catch. The sites of these traps were licensed by the Territorial Government on an annual basis, but usually licenses were renewed. Licenses were subject to certain restrictions.[4] The possession of favored trap sites thus created an element of monopolistic control.

As an historical note of interest, one factor that prompted this study in 1939 was the effect of foreign nations who then were newly able to enter the salmon and halibut fisheries in the North Pacific. The American and Canadian governments had, by treaty, begun to manage these fisheries, with the result of restored harvests. With the introduction of canning ships, other nations, especially the Japanese, were entering these fisheries. Two concerns were apparent. First, the fish were for Americans and Canadians, not the Japanese. Second, outside nations, who were not bound by treaty, could undo the results of the management of the halibut and salmon fisheries which had been successfully undertaken by the Canadian and American governments.

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[4]Ibid., 83.

The second of the aforementioned two books, New England's Fishing Industry,[5] was an analysis of the market structure, labor arrangements, and cost components of the fishing industry off the coast of New England. Likewise, reference was made to the lack of private property in fisheries, but this did not enter significantly into the analysis.

> Without the establishment of private property on near-shore bottoms the New England oyster industry would amount to little, without legal restrictions the lobster industry would be senile instead of experiencing a rejuvenation; and the banks fishing depends in part for its existence on the laws which keep its market more or less exclusive. 6

Edward Ackerman noted that where private ownership was possible, the fishery was better managed.

> The common encouragement of artificial reproduction of the sessile or near-sessile forms ... is by the protection of private fish farming. Oysters, scallops, clams, quahaugs, and mussels can be planted and maintained in one place, so that ownership can readily be established. Leases or grants are made for certain sections of bottom in the vicinity of the shore for private shellfish production. Within the confines of the leases, which are plainly marked by stakes and bouys, an individual or company has the exclusive right of fishing. Presumably, therefore, the lessee will fish and care for his plot in such a way that it will produce the maximum amount possible, and he will not compete with others in

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[5]Ackerman, Edward A., New England's Fishing Industry (Chicago: University of Chicago Press, 1941).

[6]Ibid., 146.

> seeing how much he can get out of it in a short time. 7

Ackerman further noted that property rights could not be extended practically to other fisheries. "[T]he protection of 'farming' for other sea fishes is at present impractical because of the difficulty of establishing ownership or of keeping those fishes within given bounds."[8] So Ackerman appreciated the problems arising from the lack of private ownership of natural resources. But he did not recommend a method of implementing it, which he held to be impossible. Nor did he discuss alternative approaches to protecting the fishery in the absence of private property controls.

H. Scott Gordon

By all accounts, H. Scott Gordon was the originator of the economic analysis of overfishing and of the conservation of marine fisheries. His 1954 article, "The Economic Theory of a Common Property Resource: The Fishery," is normally cited as the initial contribution to the current model of the economics of marine fisheries.[9]

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[7]Ibid., 136.

[8]Ibid.

[9]Gordon cited G. M. Gerhardsen as the "single exception" to a lack of theoretical economic research in fisheries that had preceded his own work. H. Scott Gordon,

While other articles had been written earlier by economists,[10] this is the article that first analyzed the problems of the fisheries considering the cost components and used the common property nature of fisheries to explain the lack of economic rent. True, Alfred Marshall had discussed the application of the Law of Diminishing Returns to the fisheries.[11] But he did not make any use of it.[12]

"The Economic Theory of a Common Property Resource: The Fishery," Journal of Political Economy 62 (April 1954): 124n. Although reflecting upon the then current development in the biological aspects of marine fisheries, Gerhardsen's work stayed within the neoclassical research programme of his day. He dealt with such subjects as substitutability of capital for labor, and the economic optimal quantity of the catch. He saw the problem of the number of fish caught as being biological, while the cost of catching them as economic; there was no interaction between these two aspects. He was generally appreciative of the work that the International Fishing Commission for the Pacific Halibut had been doing. G. M. Gerhardsen, "Production Economics in Fisheries," Revista de Economia (Lisbon) 5 (March 1952): 1-12. Gerhardsen was then chief of the Economics and Statistics Board, Fishing Division of the Food and Agriculture Organization of the United Nations.

[10]Like most persons unacquainted with the Danish tongue, Gordon was not aware of the work of Jens Warming. Warming had written "On Rent of Fishing Grounds" forty some years earlier. In this article, Warming anticipated much of the work on marine fisheries that was to appear later. For a discussion of his work, together with a translation, see Peder Andersen, "'On Rent of Fishing Grounds:' A Translation of Jens Warming's 1911 Article, with an Introduction," History of Political Economy 15 (3) (1983): 391-96.

[11]Alfred Marshall, Principles of Economics (London: Macmillan and Co., 9th (Variorum) ed., 1961), 166f, 369.

[12]John Butlin observed that "[a]lthough Marshall (pp

Indeed, Gordon claimed that Marshall was in error with his application of this law to marine fisheries.[13]

The impetus for Gordon's interest came from the Canadian government. Gordon, then an economics professor at Carleton College in Ottawa, was asked by the Canadian government to provide an economic analysis of why maritime fishermen characteristically had a low income.[14] At

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166-7 and 369-72) addressed himself to the problems of diminishing returns to inputs into fishing, the first article that directed its attention explicitly to the economic basis of the overfishing problem (the observed tendency, paradoxically, for fishing fleets to exploit a commercially viable stock to the point at which the existence of the stock, and thus its commercial viability, are threatened) was by Scott Gordon in 1953." John Butlin, "Optimal Depletion of a Replenishible Resource: An Evaluation of Recent Contributions to Fisheries Economics," in The Economics of Natural Resource Depletion, ed. D. W. Pearce and J. Rose (New York: John Wiley and Sons, 1975), 86.

[13]Gordon noted that "the operation of the Law of Diminishing Returns is regarded as equivalent to a reduction in the input of the 'natural' factor of production, an interpretation that Marshall persistently denied when referring to agriculture. The reason for this misinterpretation is that Marshall did not fully realize that the fishing industry possesses some important differences from agriculture. The natural resource of the industry has a character which places it somewhere between Marshall's two basic categories: mining ... and agriculture." H. Scott Gordon, "On a Misinterpretation of the Law of Diminishing Returns in Marshall's Principles" Canadian Journal of Economics and Political Science 18 (February 1952): 97.

[14]Colin Clark noted that Gordon "not only explained the low income of fishermen, but also clarified in economic terms the so-called overfishing problem [referred to in Graham, 1952]. It explained how economic overfishing would be expected to occur in any unregulated fishery, while biological overfishing would occur whenever price/

first, Gordon operated within the neoclassical model as well as considering work done within marine biology on the overfishing problem. Gordon became aware that the neoclassical model had some important omissions if an adequate explanation of the persistently low income of marine fishermen were to be made. He was the first to discuss the economic analysis of the common property nature of fisheries. Later, marine fisheries came to be the first place where the notion of market failure[15] would be

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cost ratios were sufficiently high." Colin W. Clark, Bioeconomic Modelling and Fisheries Management (New York: John Wiley and Sons, 1985), 1.

[15]Market failure is the situation in the private market where certain goods are either not provided at all, or in improper quantities. Market failure arises either because of non-excludability or of non-rival consumption of a good. In marine fisheries, the lack of property rights in the fish stock means that if one fisherman leaves behind some of the catch for later, or to allow it to reproduce, other fishermen may harvest it for themselves. So, there is no incentive to leave part of the stock uncaught. In the absence of property rights, the discount rate for future harvests becomes infinite. Here, the inability to exclude other fishermen from a specific stock leads to overfishing, both in the biological sense, where too many fish are harvested relative to what would produce the maximum rate of increase in the biomass, and in the economic sense, where the economic rent fails to be maximized. Biomass refers to the total weight of a given fishery, and so includes both the number of fish and the weight of each fish. As we shall see, while Gordon recognized the significance of the lack of property rights to the marine fishery, his approach was to find a substitute for property rights rather than to invite governmental regulation. Most subsequent contributors took the market failure approach, with the policy recommendation for regulation of the fisheries. While marine biologists had advocated regulation,

applied. Gordon did not discuss market failure; he was concerned rather with finding ways to implement property rights.

Gordon's 1953 Article

Gordon's first attempt to apply economics to fisheries was his 1953 article, "An Economic Approach to the Optimum Utilization of Fishery Resources," which presented some of the themes that were to emerge in his subsequent, classical article. He raised the challenge of using economic theory to "clarify the objectives of conservation and contribute to a better evaluation of control measures."[16] Although Gordon cited some who recognized the economic and political dimensions to the problem of the fisheries, he was unaware of any economist who had dealt with these issues.[17]

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they did so to treat overfishing as a problem per se, rather than a symptom of market failure.

[16]H. Scott Gordon, "An Economic Approach to the Optimum Utilization of Fishery Resources," Journal of the Fisheries Research Board of Canada 10 (September 1953): 442f.

[17]Gordon quoted O. E. Sette as saying "the method of conserving a commercial fishery involves social, economic, and political considerations and lies in the field of political economy." O. E. Sette, Studies on the Pacific Pilchard or Sardine, U. S. Fishery and Wildlife Service, Special Scientific Report #19, (1943): 4. Gordon also made reference to E. S. Russell, The Overfishing Problem (London: Cambridge University Press, 1942). Russell had

In this first paper, Gordon anticipated that "some of the standard devices of economic theory can help to clarify the object of conservatism and contribute to a better evaluation of control measures."[18] The 1953 paper was very much within the neoclassical research programme of his day.

Gordon observed that the main aspect of the analysis of the fisheries theretofore not treated was that of cost.[19] Unlike the assumption that the maximum sustained yield[20] was to be the objective of regulated fisheries,

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recognized the economic dimensions of the problem. But neither of these men were trained in economics, and so did not contribute to an economic theory of the fisheries. Nor did they solicit contributions from economists. Gordon quoted favorably the British biologist R. J. H. Beverton, who had observed that "the economic optimum is not necessarily the human optimum." Beverton was then at the Fisheries Laboratories at Lowestoft in Britain. R. J. H. Beverton, "Some Observations on the Principles and Methods of Fishery Regulation," mimeographed paper presented to the General Meeting of the International Council for the Exploration of the Sea in Copenhagen in 1952.

[18]Gordon, "An Economic Approach," 442f.

[19]Gordon cited R. A. Nesbit, Fishery Management, U. S. Fishery and Wildlife Service, Special Report # 18 (1943) and R. J. H. Beverton as some who were aware of the need for this analysis. Beverton was quoted as saying that "no satisfactory analysis of that side of the question and its relationship to the production side yet exists." Ibid., 443.

[20]This was the objective of fisheries as proposed by the leading British marine biologist, Michael Graham, and recommended to the International Fisheries Commission which regulated the Pacific halibut fishery. See, for example, Michael Graham, "Modern Theory of Exploiting a Fishery, and

Gordon showed that the economic objective of a commercial fishery should be the maximum economic yield, or the level of fishing where net revenues exceed net costs by the greatest amount. He argued that "the economic optimum is at a level of fishing intensity somewhat less than that which would produce the maximum physical landing."[21]

Following the lead of some of the biologists he cited, Gordon argued that both catch and cost are related to effort.[22] Thus, effort was used as the independent

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Applications to North Sea Trawling," Journal du Conseil International pour l' Exploration de la Mer 10 (December 1935): 164, or "The Sigmoid Curve and the Overfishing Problem," Conseil International pour l' Exploration de la Mer, Rapport et Process-Verbaux 110 (1939): 20.

[21]Gordon, "An Economic Approach," 447.

[22]For example, Michael Graham considered both the actual costs and the revenues received by fishermen in his model of the level of fishing activity. So he concluded that "[i]t will pay to reduce the fishing rate sufficiently for the product of the new reduced fishing rate multiplied by the new augmented stock to be no less than the product of the old higher rate and the old smaller stock." Graham, "Modern Theory," 274. Note that the notion of an efficient fishery as developed here is from the perspective of a biologist rather than that of an economist. Graham was concerned with maximizing the sustained yield (later what would be called the maximum sustained yield) of the fishery, ignoring any opportunity cost which might be incurred in the process. Elsewhere, Graham had noted that "an economy of effort is desirable in the North Sea, that is, that a certain proportion of the time and money of the fishermen is at present devoted to reducing their catch, or is at least wasted. It also follows that in unrestricted fishing, proceeding as it usually does at ever increasing intensity, as grounds and habits become better and better known and gear more and more improved, there must come a

variable. The sigmoid curve was used as the standard production function providing a region where increased effort gave landings at an increased rate, then an area for which decreasing returns applied. He asserted that all fishing occurs in areas of diminishing returns.[23]

In his 1953 work, Gordon also introduced the consid-

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time when new inventions are harmful. Nevertheless, once the new invention has done its harm in reducing the productivity of the stock, its use must be continued, because the old gear will not pay expenses on the less productive stock. So the fishermen are left with the expense of the invention, with no compensating increase in yield." Ibid., 264f. Likewise, other biologists advocated limiting catch to provide for a sustained yield. E. S. Russell observed that during World War I, fish stocks recovered while harvest efforts were reduced. But during 1919-1920, unrestricted fishing wiped out the gains in the fish stock which occurred during the war. He proposed avoiding such overfishing at the end of World War II. E. S. Russell, The Overfishing Problem (London: Cambridge University Press, 1941): viif. Likewise, Thompson and Bell commended the Pacific halibut fishery as one that was well regulated, which resulted in substantial improvement not only of the fish population, but in sustained levels of subsequent harvests. William F. Thompson and F. Heward Bell, "Biological Statistics of the Pacific Halibut Fishery, (2) Effect of Changes in Intensity upon Total Yield and Yield per Unit of Gear," Report of the International Fisheries Commission 8 (1934): 64-76. These biologists also opted for government regulation, since overfishing was inevitable without government-imposed limits on fishing effort. But their guidelines invariably were defined with respect to maximizing the sustainable fish harvest rather than considering the costs of extracting such a harvest. Indeed the 1924 treaties underlying the International Fishing Commission, which regulated the Pacific halibut fishery, used the biological criterion of maximizing the physical yield of halibut over time.

[23]Gordon, "An Economic Approach," 444.

eration of fisheries being a common property resource. This explained, in part, the overexploitation of fishing grounds.[24] But he did not seriously analyze the common property nature of the fishery until his 1954 article. He did, however assert that

> [t]he form of competition which exists in fisheries for open resources not only dissipates any net yield that might have been attained, but goes farther and reduces the straight labour income of fishermen below that of other occupations. The immobility of fishermen, their attachment to their local communities and to their occupations, prevents an equilibrium of labour income from being established with that of other industries, and the result is that even in fisheries where the resource is rich, the fishermen are poor. 25

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[24]Ibid., 449f.

[25]Ibid., 453f. Note that this discussion anticipated another source of market failure, namely the inability of persons in one occupation to have sufficient occupational or geographical mobility to earn the market wage. Certainly, Adam Smith's assumption of sufficient occupational mobility such that workers' wages would be equalized within the community, taking into consideration different advantages and disadvantages of diverse occupations is challenged by Gordon. Smith had held that "[t]he whole of the advantages and disadvantages of the different employments of labour and stock must, in the same neighbourhood, be either perfectly equal or continually tending to equality. If in the same neighbourhood, there was any employment evidently either more or less advantageous than the rest, so many people would crowd into it in the one case, and so many would desert it in the other, that its advantages would soon return to the level of other employments." Adam Smith, <u>The Wealth of Nations</u>, ed. by Edwin Canaan (New York: Random House, 1937), 99. But Gordon argued that the fishermen's ties to their occupation were such that this equilibrium factor did not operate. However, note that Warming, unlike Gordon, stayed with the classical assumption that adequate occupational mobility

Gordon also criticized the regulation of the Pacific halibut fishery in that while the total catch was limited, individual fishermen did not have a catch limit. Thus there was an inducement to use more costly methods of fishing so as to get as large a portion of the limited amount of the catch as possible.[26] Gordon agreed with Graham that the tendency to add gear would continue until any economic rent from the fishery would be dissipated.

In this 1953 article, Gordon gave the conditions under which the optimal level of fishing effort would occur.

> [A]n approximation to the optimum level of fishing effort can be achieved only under four kinds of conditions. (1) the resource may be divided

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exists. He asserted that as there was a limit to the number of workers in a given fishing ground, the rest "had to seek employment elsewhere, but the increased purchasing power of the state (or of the taxpayer) is exactly enough to take over the increased product both in fisheries and in other industries." Andersen, 394.

[26]Ibid., 455. Recall that Graham recognized the tendency to use the most advanced techniques. Graham was aware that fishermen failing to use such could not compete. But Graham, lacking an economic analysis, did not suggest a remedy. Here, Gordon saw that if the individual fisherman's bag limit were established, he would have the incentive to get that limit as cheaply as possible. Unfortunately, most of the then current attempts to regulate fisheries ignored individual costs. Most of those methods were established by biologists who were concerned with the optimal size catch from the perspective of maintaining the maximum species population and size, not from the perspective of minimizing the cost of the catch, nor indeed, if opportunity costs were to be considered, whether the maximum sustainable yield criterion was indeed appropriate. Subsequent researchers, working within the Gordon model, criticized such approaches advocated by the biologists.

> into private property rights, as in oyster culture,... (2) Where this is not possible, the resource can be given the status of group private property and exploited by the unified and co-ordinated action of its owners, (3) If neither of these is possible, the resource can be declared to be public property, and its exploitation governed, in specific detail, by public authority. (4) A taxation system could be devised that would reduce fishing effort on particular grounds to the optimum point. 27

Many of the themes that he would develop in his classic 1954 paper were presented in this first article.[28] But they were not adequately developed into a coherent theory. Rather, Gordon's analysis focused more on the fact that firms will equate marginal costs to the market value of the average landings rather than marginal landings. Here he assumed that landings would increase as the rate of effort applied expanded. He recognized that such an increase in fishing would reduce the population.[29] There was a danger of overexploitation (and here he was using the term in the biologist's sense),

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[27]Ibid., 457. Warming had made a similar recommendation: the government should assess rent based on the differences in the quality of the fishing grounds. Andersen, 393.

[28]For example, he stated that "[t]he fundamental cause of this overexploitation is the fact that fishing grounds are, in most cases, the common property of all who might wish to use them." Gordon, "An Economic Analysis," 450f.

[29]Ibid., 448.

because of the tendency for fishermen to maximize their average product.[30] But he expected the fecundity of the fisheries to forestall extinction.

Gordon used a geometric argument to show that the law of diminishing returns applied to fisheries. Unlike the biologists who had written on the economics of the fishery, Gordon showed that changes in the price of fish would affect the optimum fishing effort directly. He also considered the effect of the price of fishing gear on the optimum effort.[31]

Gordon's conclusions were the same as Warming's:[32]

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[30]Ibid., 449. Gordon contended that since "the costs of fishing supplies, etc. are assumed to be unaffected by the amount of fishing effort, marginal cost and average cost are identical and constant." Gordon, "The Economic Theory of a Common Property Resource," 130 Thus, in the case of a common-property resource, the profit maximizing firm would achieve greater total yield by maximizing average productivity rather than marginal productivity.

[31]Ibid. Recall that Graham had considered the effect of using new gear on fishing. But Graham had not considered the effect of the supply of the additional fish on the market price, which, by lowering the income of fishermen even more, would reduce fishing effort.

[32]Jens Warming had shown that the inability to assess rent on fishing grounds led to overfishing. He assumed that there were two different fishing grounds of diverse fertility. So, under perfect competition, the allocation of labor between the two grounds would be such that the rates of return from the two fisheries would converge. This results in one ground being exploited too heavily while the other insufficiently. His solution was for the government to assess a tax on the fishermen to garner

"When a fishery is carried out on grounds of different productivity, the richer (or nearer) grounds will be overfished."[33] The reason for this coincidence of analysis

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such rent. "What is then suggested is in reality only a transfer to fishing of the same system as has always been in agriculture. If access to good land were not more expensive than to land of poor quality, everyone would cultivate the good land; but the rent on land, which depends on the quality of the land, regulates conditions so that it will be equally advantageous to cultivate the different lands." Andersen 394. He recognized that while a tax would be appropriate for offsetting the differential in value of fishing grounds, and so under perfect competition, allocate the right number of fishermen to each fishery, in practice, it would be difficult to evaluate each fishing ground adequately. Ibid., 396. Again, Warming's work remained unknown until after Gordon's work, since he had written in Danish. It is true that several of the marine biologists who were concerned with overfishing were Danish, for example C. G. Joh. Petersen, or at least Scandinavian, such as Johan Hjort, Gunnar Jahn, and Per Ottestad, who were Norwegian. So the fact that Warming had written in Danish was not the critical barrier to their understanding his work. Rather, they were biologists, treating the problem within the framework of biology. So the biological research programme that had developed was sufficiently coherent as to exclude Warming's early economic contributions. The significance of his work was realized only after the economic research programme had developed.

[33]Gordon, "An Economic Analysis," 452. Warming had made nearly the same analysis, and suggested that the state should assess a rent on the good grounds as a remedy to the problem. Andersen, 393. There was a remarkable coincidence in the analysis of these two men at this point. Both contrasted fisheries to farmland. Both recognized that, unlike farmland, there is nothing to prevent the net economic rent from being dissipated. This dissipation accounts for the low income of fishermen. The conclusion holds because the high net yield is possible only with increased capital to the extent that any additional income is negligible. The similarity here must be attributed to the fact that both, while working independently, were operating within the neoclassical research programme.

and conclusion is not necessarily due to Gordon's cribbing from Warming. Indeed, Warming's work was still untranslated from the Danish at the time of Gordon's writing. Rather, they both were operating from the same neoclassical research programme. The 1952 note that Gordon had written regarding Marshall's application of diminishing returns to the fisheries evidences Gordon's study of Marshall and the neoclassical tradition at the outset of his own analysis. Warming was working from the same tradition, and so the similarity of their analysis and conclusions is not surprising. The 1953 paper was, like the work of Warming, very much within the neoclassical research programme.

Gordon's 1954 Paper

In his 1954 paper, Gordon made the common property nature of the fisheries central to his analysis of the problem. He shifted from using a strictly neoclassical model.

> [M]ost of the problems associated with the words 'conservation' or 'depletion' or 'overexploitation' in the fishery are, in reality, manifestations of the fact that the natural resources of the sea yield no economic rent.... Although the theory ... is worked out in terms of the fishing industry, it is, I believe, applicable generally to all cases where natural resources are owned in common and exploited under conditions of individ-

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fact that both, while working independently, were operating within the neoclassical research programme.

ualistic competition. 34

This a contrast to the 1953 paper. There Gordon used "o- verexploitation" in the sense that the biologists had. He had essentially endorsed their analysis. But apparently, subsequent to the writing of the earlier paper, there was sufficient challenge to the neoclassical research programme within Gordon's own understanding for him to modify his analysis to see overexploitation being an economic problem.

Gordon showed that several biologists were aware of a need for an economic analysis of the fisheries, and in some instances, had attempted to provide this in their analysis. He asserted that "biologists have been forced to extend the scope of their own thought in the economic sphere and in some cases have penetrated quite deeply, despite the lack of analytical tools of the economic theory."[35] But they lacked an adequate understanding of economics.[36]

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[34]Gordon, "Economic Theory," 124.

[35]Ibid., 124. Here Gordon was referring to Nesbit (1943), Taylor (1951), and Beverton (1953).

[36]Gordon cited the American Martin Burkenroad (1951), the Russian marine biology theorist T. I. Baranov (1918, 1925), A. G. Huntsman (1944), who was with the Canadian Fisheries Research Board, and Michael Graham (1952), the eminent Director of Fishery Research at Lowestoft Laboratory. Later, Gordon observed that "[f]ocusing attention on the maximization of the catch neglects entirely the inputs of other factors of production which are used up in fishing and must be accounted for as costs. There are many refer-

Gordon developed the theory of the fishery within the neoclassical theory of the firm, assuming constant average, and hence, constant marginal costs, but with decreasing average product, hence decreasing marginal product.[37] Thus he was extending the standard neoclassical research programme to solve a new problem. He assumed that as the effort of fishing increased, the catch would decrease per unit of fishing effort because of the effect of the catch on the fish population. So, as fishing intensity increased, the total catch would increase at a decreasing rate. Thus the pure law of diminishing returns does not hold.[38]

Gordon was aware that while economists had ignored the problem of overfishing, marine biologists were quite con-

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ences to such ultimate economic considerations in the biological literature but no analytical integration of the economic factors. In fact, the very conception of a net economic yield has scarcely made any appearance at all." Gordon, "Economic Theory," 128.

[37]Gordon, "The Economic Theory," 130. Here Gordon was defining marginal and average costs in terms of units of fishing effort, rather than units of production, as usually is done. Hence he could have constant cost functions while the average product and hence marginal product per unit of fishing effort were declining. The reason for this decline was due to biological and economic overfishing.

[38]Ibid., 129.

cerned both with the biological causes and consequences of overfishing and also with the economic reasons for overfishing. While they had little to no formal training in economics, they were making reference in their writings to some of the economic issues involved. Several of the marine biologists that Gordon cited in his 1954 paper had made comments about the need to study the problem of overfishing from an economic perspective.[39]

So Gordon's 1954 work integrated the results from the biological model that was most developed, the sigmoid curve that Hjort, et al.[40] and Michael Graham had

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[39]Gordon traced the development of the analysis by biologists of overfishing in marine fisheries from the turn of the century, starting with the Russian researcher F. I. Baranov and continuing to the then most current works. The history that Gordon traced was one that by the turn of the century had rejected the notion of the inexhaustible nature of marine fisheries as there was an increasing recognition of the depletion of the fish population due to increased fishing effort. There were several theories advanced by biologists to support their proposals for a fishing policy. Baranov first developed the model of thinking of the fish population as being affected by the catch effort, which led to the notion of the optimal catch. Gordon critiqued this as neglecting "entirely the inputs of other factors of production which are used up in fishing and must be accounted for as costs." Gordon, "Economic Theory," 128. Gordon promoted the idea of the net economic yield as the appropriate criterion for fishing policy. Many of those cited by Gordon referred to the economic dimension of the problem of overfishing.

[40]J. Hjort, G. Jahn, and Per Ottestad, "The Optimum Catch," Hvalradets Skrifter (Oslo) 7 (1933): 92-127.

introduced.[41]

But while many of these biologists were aware that an economic analysis of the problem was necessary, none of them had a sufficient understanding of the neoclassical (or any other) model to discuss the problem theoretically. Specifically, none of them were aware that the common property nature of marine fisheries was intrinsic to the economic aspect of overfishing.[42] Nor did the biologists take economic factors into consideration in designing their policy recommendations, even though they recognized that economic issues were important to the overfishing problem. "[P]ractically all control measures have, in the past, been designed by biologists, with the sole attention paid to the productive side of the problem and none to the cost

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[41]Michael Graham, "The Sigmoid Curve and the Overfishing Problem," Rapports et Process-Verbaux des Reunions (International Council for the Exploration of the Sea) 110 (1939): 15-20.

[42]It was in the 1954 paper that Gordon discussed the "competition among fishermen which culminates in the dissipation of the rent of the intramarginal grounds." Gordon "Economic Theory," 131. He continued to use the analysis from the 1953 paper that average production rather than marginal production is relevant for decision making for the fishermen because average production determines the total yield. But the 1954 paper recognized the lack of economic rent on intramarginal grounds leads to the possibility that "some ground will be exploited at a level of negative marginal product." Ibid., 132. For a discussion of rent as it pertains to the fisheries, refer to the appendix.

side."[43] He cited the problem with excessive capital being deployed in the Pacific halibut fishery. Thus the average cost was rising with no corresponding increase in the catch. The effect of regulation ignored the cost of fishing while protecting the fish population.

In Section III, Gordon discussed the sigmoid curve that Hjort, et al. and Graham had introduced to show the relationship between catch effort and revenues. But in Section IV, where he developed his mathematical model, he used a linear relationship between landings and population as the basic biological tool in his model with which he wanted to discuss the "bionomic equilibrium" in fisheries. His economic tools were the cost function and the equilibrium condition of comparing costs and revenues.[44] He treated both the biological dimension and

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[43]Ibid., 132.

[44]Gordon's model was:

$$P = P(L) \quad (1)$$
$$L = L(P,E) \quad (2)$$
$$C = C(E) \quad (3)$$
$$C = L \quad (4)$$

where P is the population of a particular species of fish, L is the quantity of those fish landed by man, measured in units of value, C is the cost of such an effort. The fourth equation is the equilibrium condition of an unregulated fishery. Gordon, "Economic Theory," 136. Later, he used as the explicit function for fish population $P = a + bL$. Ibid., 141. This explicit function was not consistent with the population dynamics that the biologists to the economic. His model examined the interactions among populations, which are affected by the amount of landings; landings, which are a function of both fish population and human effort; costs, which are a function of landings; and the condition that costs must equal revenues. His revenue function was based strictly on the number of landings times a fixed price. It did not take into consideration other factors affecting fish population. Gordon showed that only one combination of effort, landings, and fish population was consistent.[45]

So, while he recognized the existence of the sigmoid curve, which is intrinsically dynamic,[46] his analysis assumed that at equilibrium the solution would be at a specific point on the sigmoid curve. He did not show how changes in one of his variables might affect the other variables. Thus, although he accepted the sigmoid curve from the fishery biologists, he did not use it dynamical-

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whom he referred had developed.

[45]Ibid., 141.

[46]The sigmoid curve, as used by Hjort, et al., graphs the population against the time rate of growth of population. That is, $dP/dt = f(P)$ where P is the population of a given species. Hence the curve is intrinsically dynamic. Gordon, by considering only a specific point of intersection with this curve, was able to keep his model static even though he was using a dynamic curve for part of the model.

ly. He showed how a change either in the natural population of fish or the depletion coefficient would affect optimal effort levels. But there was no feedback mechanism from effort back to population, which would be necessary to make the system dynamic. Such an analysis waited for Kenneth Arrow's contributions to control theory.

Since fishing regions are unowned, Gordon held that average productivity, not marginal productivity, was relevant for the profit maximizer; i.e. the competitive firm would equate AP to MC. He contended that, in the absence of property rights, the incentive to the boat owner was to catch as much fish as possible. Any fish left behind might not remain for future fishing trips, since other boats could catch them. That is, the only way to establish ownership rights over marine fish is by catching them. Since Gordon defined the marginal and average costs in terms of units of fishing effort rather than units of fish caught, average, and hence marginal, costs would be constant over the relevant range. But productivity was defined in terms of fish caught per unit effort. And, in most fisheries, the boat owners, captain, and crew are paid in terms of shares of the fish caught rather than specific dollar wages. So the objective is to have these shares as large as possible for each. Hence average productivity rather than marginal productivity is relevant. While each fisherman may not understand the economic concept of marginal and average productivity, intuitively they want to earn as much as possible. Thus they do not carry too large a crew.

But this would lead to some fishing grounds being exploited to the level of negative marginal productivity.[47] Thus the "rent which the intramarginal grounds are capable of yielding is dissipated through misallocation of fishing effort."[48] Consequently, with the lack of property rights in fishing grounds, and with the average revenue rather than the marginal revenue being relevant to determine the level of production, then the potential rent is dissipated. Competition among fishermen to establish ownership over the fish by catching them results in this dissipation of rent. Fishermen are not wealthy despite the abundance of fishery resources.[49]

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[47]This insight was already made by Jens Warming. Warming had argued that the nearer or richer grounds would be overexploited, not only reducing the income of the fishermen, but excessively depleting the ground, making it inferior. In his numerical example, he showed that under conditions of perfect competition, "both grounds now yield somewhat less than a maximum, one because it is exploited too heavily, the other contrarily." Andersen, 393.

[48]Gordon, "Economic Theory," 131f.

[49]Ibid., 132. See the Appendix for a further discussion of rent.

Gordon discussed two reasons why fishermen continue to have lower income levels than would be required to keep persons interested in fishing relative to switching to another job, given the risk, skill levels, and hazards of their occupation. The first reason he gave was occupational and geographical immobility. This he attributed to isolation of fishing communities and lack of knowledge of conditions or opportunities elsewhere. This also is a reason that the perfectly competitive model does not apply to the fishing industry. The second factor he attributed to the fishermen staying with the industry in spite of their prevailing low incomes was a hope of a "lucky catch." This gambling instinct, which he asserted fishermen to have, caused them to settle for less than the prevailing wage.[50]

Gordon recognized that since the perfectly competitive model did not apply, market forces by themselves would be insufficient to prevent the dissipation of rent and thus to assure fishermen an adequate income. Gordon urged government controls as a solution to this dissipation.

> A factor of production that is valued at nothing in the business calculations of its users will yield nothing in income. Common-property natural resources are free goods for the individual and scarce goods for society. Under unregulated

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[50]Ibid.

> private exploitation, they can yield no rent, that can be accomplished only by methods which make them private property or public (government) property, in either case, subject to a unified directing power. 51

Yet the governmental controls which he urged were to find a substitute for private property rights. Gordon did not advocate, unlike many subsequent economists dealing with marine fisheries, taxation such that the economic rent would be shifted to the governmental sector.[52] However, Gordon did not use the then relatively new analysis of externalities to justify government regulations.

Rather, Anthony Scott saw Gordon siding with Frank

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[51]Ibid., 135. Note that Warming had already made a similar recommendation. Warming doubted that the optimal solution would occur under conditions of perfect competition. He showed that "perfect competition makes the best ground into the inferior one." Andersen, 393. He had asserted that rather than to use gear restrictions, closed seasons, and the like, to prevent the overfishing of the superior grounds, the state should collect rents from the good grounds equal to the excess income a fisherman receives there as compared to working at some alternative job. This rent would be assessed through the issuing of licenses to fish specific grounds. The number of licenses bought would give the right number of persons at each fishing ground because of the normal wages that could be earned elsewhere. Ibid. He recognized that "a tax on fishing would be more difficult to manage, because a valuation of the fishing grounds would be necessary." Ibid., 396. There also was the practical problem of control of fishing and handling international fishing grounds.

[52]Even Warming held that the government should collect the rent through taxation or licensing fees rather than it being received by the private sector. Andersen, 393.

Knight[53] in the earlier debate between Knight and A. C. Pigou[54] over the nature of common property.

> S. Gordon touched off a wave of theorizing. Carefully applying Knight's two-road example to two fishing grounds, he demonstrated that on any fishing ground the unrestricted entry of units of effort would lead to an unusual bionomic equilibrium in which the resource would yield less fish than its capacity, and labor and capital would be overapplied so that their marginal product in fishing would be below opportunity cost. 55

Scott saw Gordon as taking the property rights position of Knight, modifying it as necessary in the case of the common property fishery. And others who had begun to write in the area of the economics of fisheries[56] accepted Gordon's explanation of poverty among fishermen.

Scott explained the immediate reception of Gordon's approach by the economic community in terms of his

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[53]Frank H. Knight, "Some Fallacies in the Interpretation of Social Cost," Quarterly Journal of Economics 38 (August 1924): 582-606.

[54]A. C. Pigou, The Economics of Welfare (London: Macmillan, 1918).

[55]Anthony Scott, "Development of Economic Theory on Fisheries Regulation," Journal of the Fisheries Research Board of Canada 36 (July 1979): 726.

[56]Here Scott was referring to, among others, participants in the round table organized by the International Economic Association and held in Rome in September 1956, sponsored by the Food and Agriculture Organization of the United Nations, Ralph Turvey and Jack Wiseman, ed. The Economics of Fisheries (Rome: FAO, 1957).

extension of Knight's work.[57]

> These great men knew little or nothing about the new field for applied economics. But they did know about Knight's theoretical work on external economies and property and they usefully prevented a tendency among new enthusiasts to blame every unusual feature of the fishing industry, anywhere, on the ubiquitous common-property characteristic. 58

Scott further pointed out that Gordon developed the field of fisheries economics in the property-rights tradition of Knight, while many who accepted his model continued in their Pigovian perspective.

> The evils of common property having been identified, what should economists recommend? This was

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[57]Knight had shown that, in the case of two roads of different conditions, the superior road would be chosen to the point of congestion. But both the opportunity cost associated with the congestion and a higher toll which could be assessed by the owner of the better road would lead to a redistribution of usage of the roads until the costs associated with each were equal. "The owner of a superior opportunity for investment can set the charge for its use at any amount not greater than the excess of the product of the first unit of investment above what that unit could produce on the free opportunity. Under this change investment will flow into the superior road up to the point where congestion and diminishing returns set in." Knight, 587. Curiously, although Warming used essentially this argument to distribute fishing between grounds of different abundance, he concluded that the market would not operate in the manner that Knight had asserted. "[T]he state has a very natural instrument to handle it all by collecting rents for the good grounds. If the state takes the difference between the yield per man at maximum catch and the usual wages (plus costs) then the exact number of fishermen necessary to obtain maximum production will go to each ground." Andersen, 393f.

[58]Scott, "Development of Economic Theory," 726.

> the second theme that got its start in the 1950s. Those who followed Gordon and Knight naturally tended to favor the invention and application of new property rights, similar to those that had brought to an end common land-use. Those who had been brought up on Pigovian welfare economics favored taxes or subsidies to bridge the gap between private and social net marginal products. 59

Subsequent to Gordon's work, most of the theoreticians in the economics of the fisheries sided with the Pigovian welfare economics approach. Scott observed that the debate between these two camps gave way to discussing policy issues: whether to use taxes or to create some "feasible form of property rights."[60]

But there also was the growing recognition that in the creation of property rights, the "for whom" issue was relevant. This also strengthened the Pigovian perspective in fisheries economics over time.

Gordon's Other Works

Although Gordon gets credit for the static model, he also was aware of the need for a dynamic model. He was

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[59]Ibid. Recall that Warming had advocated the use of taxes on fishing grounds as a way to assess the differential rent of various grounds, analogous to the Ricardian theory of rent for land. But he held that this rent should go to the government. Thus, although writing independently of the debate between Knight and Pigou, he had come down on the Pigovian side.

[60]Ibid.

in agreement with Ciracy-Wantrup and Anthony Scott that conservation is essentially an application of the neo-classical theory of capital.[61] That is, resources are to provide a stream of services over time. Hence, the optimal rate of harvest is that which would give the greatest present discounted value of future revenues from the anticipated harvests. Gordon had asserted that

> [t]he conservation problem is essentially one which requires a dynamic formulation. To conserve means to postpone the use of a resource. The economic justification of conservation is the same as that of any capital investment--by postponing utilization we hope to increase the quantity available for use at a future date. 62

Gordon asserted that "the optimal degree of exploitation must be treated as a time function of some sort."[63] But he recognized that the interaction among the biological dynamics of the fish population, the economic time preference of the community and the rate of the catch would be quite a complicated problem to calculate. The then extant applied mathematics made such a calculation

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[61]H. Scott Gordon, "Economics and the Conservation Question," Journal of Law and Economics 1 (October 1958): 119.

[62]H. Scott Gordon, "Obstacles to Agreement on Control in the Fishing Industry," in The Economics of Fisheries, ed. Ralph Turvey and Jack Wiseman (Rome: FAO, 1957), 67.

[63]Ibid.

inconceivable. He left the dynamics of fish population as a problem for the biologist. He also recognized that a full treatment of the problem must allow for the location of the desired species within the food-chain; the dynamics of its prey and of species that feed upon it must be considered for a complete model.[64]

Schaefer's Extension of the Gordon Model

Milner Schaefer was the first marine biologist to incorporate the Gordon model into the problem of the optimal catch. Schaefer was a marine biologist with the Inter-American Tropical Tuna Commission, and, as such, was concerned with managing the tuna catch to get the maximum sustained yield.[65]

Schaefer welcomed the economic treatment of the problem, but he noted limits to Gordon's 1954 paper.

> [W]e are interested in the average annual harvest that will be sustained by the fish population in-definitely at different levels of fishing effort. This approach has been admirably and carefully applied by Gordon (1954), but some further considerations appear to be necessary, because (1) he has not made the necessary distinction between the self-regulating, density

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[64]Ibid.

[65]Milner B. Schaefer, "Some Aspects of the Dynamics of Populations Important to the Management of the Commercial Marine Fisheries," Bulletin of the Inter-American Tropical Tuna Commission 1 (1954): 28.

> dependent fish resources and other common-property resources of a different nature, (2) the mathematical model in Section IV of his paper is not consistent with the assumptions in Section III (and is not quite in accord with some dynamic properties of fish populations), and (3) he has (p 129) defined the optimum degree of utilization of any particular fish stock as that which maximizes the net economic yield ... on one hand, and total receipts ... on the other. 66

Schaefer combined Gordon's work with the biological model to form the bionomic model now referred to as the Gordon-Schaefer Model.[67] The biological model had to that point come to its complete form in the work of E. S. Russell.[68] Schaefer used Russell's approach to fishery dynamics: in the absence of fishing, losses of the mass of the stock due to predation and natural mortality will equal the increase due to growth of individual specimens and reproduction. With fishing, the removal of stock is greater, but so also is the rate of growth. Thus the loss

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[66]Milner B. Schaefer, "Some Considerations of Population Dynamics and Economics in Relation to the Management of Marine Fisheries," Journal of Fisheries Research Board of Canada 14 (September 1957): 670.

[67]Ibid., 674.

[68]See, for example, Edward S. Russell, "An Elementary Treatment of the Overfishing Problem," Rapport et Process-Verbaux des Reunions (International Council for the Exploration of the Sea) 110 (1939): 6-14; The Overfishing Problem (London: Cambridge University Press, 1942); or "Some Principles Involved in Regulation of Fisheries by Quotas," Canadian Fish Culturalist 22 (May 1958): 1-6.

of the biomass to fishing is partially offset due to the reduced competition for food and due to the fact that fishing has replaced some of the predation by other species. Thus the fishery operates at an equilibrium, but possibly at lower levels than would occur in the absence of fishing. Russell, following others, used the inverted parabola resulting from comparing the time rate of change in the fish population as a function of the population. This is a variant of the sigmoid curve that was introduced by Graham and by Hjort, et al. Schaefer asserted that

> [t]here seems to be reason to believe that the Verhulst-Pearl logistic adequately describes the growth of marine fish populations. This law ... is the same employed by Graham (1935) as a basis for this analysis of the North Sea demersal fish stocks. 69

The Verhulst-Pearl logistic to which Schaefer referred is the dynamic model of fish populations which relates the estimated annual catch as a function of the maximum size population, as determined by the carrying capacity of the ecosystem, the rate of growth in the population, and a constant term. It is related to the sigmoid curve.

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[69]Milnear B. Schaefer, "Fisheries Dynamics and the Concept of Maximum Equilibrium Catch," Proceedings of the Gulf and Caribbean Fisheries Institute, 6th Annual Session (1954): 60. Elsewhere, Schaefer noted that this equation would explain the annual equilibrium catch corresponding to the mean stock as verified by using tagging experiments. Schaefer, "Some Aspects of the Dynamics of Populations," 32f.

Schaefer incorporated the value of fish to man, as reflected in the market price, into Russell's model. He began his analysis using a hypothetical theretofore untapped fishing ground, hence one in which the equilibrium exists in the absence of fishing, and then considering the change in equilibria as fishing intensity increases.

> The sequence of events when a stock of fish is subjected to a fishery of increasing intensity is well-known. In the early period of the fishery, when the annual catch is small, the average catch per unit of effort is high, corresponding to a high abundance of the fish population. With increasing intensity the annual catch increases, though not in proportion to the decreases. Eventually, if the fish are sufficiently valuable to make fishing economically possible at quite low population levels, as the intensity is still further increased, the total catch falls off as well. Finally, when the abundance has fallen to a point, where the fishery is not attractive to more fishermen, the intensity ceases to increase, and may even decrease, so that the amount of fishing and the catch tend to remain at a more or less constant level. This level is determined, of course, not by the total catch but by the catch per unit of effort and the value of a unit of catch. 70

As the level of harvest increases up to a new stable point, the fish population reaches a new equilibrium. So the model considers the dynamic effects of changes in the intensity of fishing on fish populations.

Now, as the fishery becomes increasingly intense

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[70]Schaefer, "Fisheries Dynamics," 54.

> and continues to remove each year a catch in excess of the equilibrium catch, the population falls continuously. The natural rate of increase and the corresponding equilibrium catch, however, rise for a time as the population falls. There is eventually a population level at which the equilibrium catch is maximal. Further increase in fishing intensity drives the population down to levels where the natural rate of increase, and the corresponding equilibrium catch, is less than the maximum. This is the writer's concept of what is meant by 'overfishing.' 71

Schaefer recognized that fishermen act so as to maximize their profits. Hence, they would fish in areas having greater concentrations of fish.[72] So the population must fluctuate above or below the maximum equilibrium catch. The effort is also determined by the unit value of the catch. So two dimensions exist in Schaefer's model: 1) the dynamics of fish population as affected by a particular predator, a biological dimension; and 2) the effect of price on fishing activity, an economic dimension.

> This approach is from the laws of population growth -- to the estimation of equilibrium catch at different stock sizes, and of the maximum equilibrium catch, seems to be one of the more promising recent developments in the field of fishing dynamics. It offers a means of estimating the status of a fishery, and indicating the direction, if any, which management needs to

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[71]Ibid.

[72]Warming had already discussed this problem of the overcrowding of effort on the best fishing grounds. Andersen, 392f.

> take to improve the sustainable catch. It makes possible such estimates without information on age composition, rates of growth, and rates of natural mortality, which are difficult to obtain in sufficient detail for many fisheries. [73]

Schaefer treated the effect of price on changes of the level of fishing intensity, thence of the fishing population. He showed that since the amount of investment is proportional to the expected return, the time rate of change of fishing intensity, F, may be given as

$$dF/dt = k_3 f(P - b)$$

where b is the critical level of the fish population, k_3 is a constant term determined empirically, and P is the population.[74]

Assuming his model to reflect correctly the dynamics of fish population, Schaefer drew two conclusions.

> 1) Large scale fluctuations in fish populations and catch can arise as a result of the interaction of the forces of growth of the fish population and growth of the intensity of fishing, with all other conditions constant.
> 2) During the development of a fishery, it is to be expected that in the course of reducing the stock of fish from its virgin condition, the catch will rise for a short time well above the level at which it will reach natural stable equilibrium, and also above the maximum equilibrium catch. [75]

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[73]Schaefer, "Fisheries Dynamics," 62f.

[74]Schaefer, "Some Aspects of the Dynamics of Population," 38.

[75]Ibid., 47.

Research Based on Gordon's 1954 Model

The success of the Gordon 1954 model was evident as it became the basis for subsequent research and analysis of existing fishery conservation programs. James Crutchfield, at the University of Washington, in Seattle, applied the Gordon model in his critique of existing management programs.

He criticized the International Fishing Commission which regulated the halibut fishery for causing excessive costs to the fishery. He recognized the substantial gains that were made in restoring the population levels of the Pacific halibut. But the criterion used for determining the catch was the maximum annual harvest possible that would allow the remaining fish population to grow at the optimal rate of increase, given the carrying capacity of their environment. The specified catch was not allocated to individual fishermen or boats, but was available on a first-come basis. The season would remain open until that year's permissible catch was harvested. This criterion encouraged each fisherman to get as large a portion of the catch as possible, leading to excessive amounts of capital being deployed, hence lowering the return to the fishermen.

There are some economic points we should consider. First, in obtaining an increased

> sustained physical yield, we reach the point where it costs more to catch additional fish than the value of those fish. Second, there is a difference between setting the right amount of catch and taking it efficiently with respect to the rest of society. Regulations which are based only on biological considerations may tie up labor and capital to no useful purpose and may also waste any improvements or advances in the technical phase or in marketing or processing. 76

Crutchfield pointed to the important distinction between maximizing physical yield and the economic value of that yield. For example, diverting the effort from the Pacific halibut fisheries into rockfish or dogfish would increase the physical yield, but would cause a significant decline in the economic yield.[77] He was also cognizant that to have economic efficiency in the fisheries, it is necessary to have regulations not only of the fishery, but also of the processing and marketing. Specifically, the effect of regulations by the International Fishing Commission is to squeeze the harvest into a very short period of time, increasing not only the capital required for harvesting the halibut, but requiring enormous capacity at the cannery for a short period of time. For most of the

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[76]James A. Crutchfield, Biological and Economic Aspects of Fisheries Management (Seattle: University of Washington Press, 1959), 31.

[77]Ibid.

year this capital would be idle.[78] So, he wrote: "The question of <u>when</u> fish ought to be taken is essentially an economic one involving a comparison of alternative costs and revenues at the different points in time when fishing is possible."[79]

Crutchfield employed other economic tools from within the neoclassical research programme. Implicitly, he was using profit maximizing levels of production from a competitive model in his discussion of the actions of the individual fishing crew.

Also, like Gordon, Crutchfield preferred a property-rights approach to restricting the harvest over the social welfare maximizing use of taxes. He observed that the use of taxes would leave the fishermen no better off than they had been in the absence of taxes. Also, the use of taxation presupposes that the administrators accurately known the appropriate levels of harvest.[80] Rather, Crutchfield advocated licensing fishermen, and gradually limiting the number of licenses available. He was sympathetic with Anthony Scott's concern that holders of the

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[78]James A. Crutchfield, "An Economic Evaluation of Alternative Methods of Fishery Regulation," Journal of Law and Economics 4 (October 1961): 131.

[79]Ibid., 135.

[80]Ibid., 141.

remaining licenses would realize a gain from having these property rights to fish, and so suggested periodically requiring these rights to be repurchased.[81] So Crutchfield was in agreement with Gordon regarding the use of property rights rather than taxation to limit the levels of harvest.

Several biologists, starting with Beverton, had suggested eumetric fishing, or the taking of the optimal harvest with respect to maintaining the largest possible fish population. Crutchfield rejected this approach.

> [T]he Holt-Beverton formulation is not analytically complete. Given the objective of economic efficiency, the optimal combination of fishing effort and selectivity cannot be specified solely in physical terms. It also requires consideration of time rates of change in value yields and costs resulting from changes in gear and effort, and of the rate of interest. An increase in physical yields resulting from a shift toward the eumetric function will occur only after a lapse of time; the short-run effect will be a decrease in the catch. Unless the discounted present value of the larger future yield exceeds that of the catch which must be foregone in the short run, it would not be worthwhile to make the shift. 82

Crutchfield considered other methods of limiting catch, such as taxes;[83] restricting entry,[84] which he

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[81]Ibid., 142.

[82]Ibid., 138.

[83]Ibid., 140f.

[84]James A. Crutchfield, "The Marine Fisheries: A

rejected; or ownership,[85] which must be limited to such fisheries as molluscan operations.

Conclusions

Gordon definitely deserves the credit for developing the initial model for the economics of the fisheries. John Butlin noted that

> [f]rom [1953] until the late 1960's, the work in fisheries economics either refined or qualified the work of Gordon (see, for example, Scott, Crutchfield and Turvey) or undertook empirical investigations into the particular commercial fisheries, developing the model from the basic theory as presented by Gordon's paper (see especially the work by Crutchfield and Zellner, and by Crutchfield and Pontecorvo.) 86

The conceptual improvements that Gordon made in his 1954 paper over what he had written in the 1953 paper are vast. The former paper operated mainly within the neo-classical research programme, with only infrequent reference to the analysis developed by the fishery biologists. He brought economic tools to bear on the problem of over-fishing by using essentially standard microeconomic theory.

Regarding these conceptual improvements that Gordon

Problem in International Cooperation," American Economic Review -- Proceedings 54 (May 1964): 211f.

[85]Ibid., 211.

[86]Butlin, 86.

had made, Anthony Scott noted that

> [f]ew economists ... had thought about the problem of coupling economic with biological equilibrium to produce a steady state in both sectors, until Scott Gordon, in an important article written in the 1950s, advanced the idea of a "bionomic equilibrium" of a commercial fishery and illustrated how economists may struggle with other steady states. In particular, he was concerned that economists think about the equilibrium of the whole economy in harmony with the natural environment. In fact, this may turn out to be the greatest contribution. 87

In the 1954 paper, Gordon rejected the law of diminishing returns in the pure sense as being "inoperative in the fishing industry."[88] And he paid much more attention to market failures, largely in his discussion of common property, but also in explaining geographic and occupational immobility. But his response to these market failures was to seek to create a new form of property rights through regulation rather than by taxation.

Colin Clark asserted that "many of the remedies originally proposed on the basis of Gordon's model were far too simplistic to successfully overcome the 'tragedy of the commons' (Harden 1968) in fisheries."[89]

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[87]Anthony D. Scott, ed., Economics of Fisheries Management: A Symposium (Vancouver: Institute of Animal Resource Ecology, University of British Columbia, 1970), v.

[88]Ibid., 129.

[89]Clark, 1.

Butlin also recognized that while the foundations of fisheries economics was laid by Gordon in his 1954 article, he had left quite an incomplete model.

> [T]he [Gordon (1954)] model was deficient in several ways. a) It was not explicitly dynamic. The adjustments of the fish stock to a greater or lesser level of fishing effort, and the feedback from this to the rate of increase in stock biomass was not allowed for....
> b) Whilst, implicitly, the failure of the unregulated fishery to allocate factors efficiently is an example of Bator's 'ownership externality' or 'failure by enforcement' the more general problem of the ways in which certain external efforts hamper efficient factor allocation are not dealt with thoroughly.
> c) The model, as developed, did not allow for the uncertainty inherent in fishing....
> d) [I]t was of limited use as a tool on which to base policy decisions relating to any particular fishery. 90

The biologist Milner Schaefer was the first to incorporate Gordon's 1954 paper into the biologist's research programme of maintaining a sustainable catch. While he made substantial criticism of Gordon's work, nevertheless, he combined Gordon's economic model together with the biologist's model, developing the Gordon-Schaefer model. Schaefer's modification went a considerable way towards making Gordon's approach dynamic.

Crutchfield had expanded on the Gordon model by considering ways that overfishing could be limited. While he

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[90]Butlin, 89.

advocated the property-rights approach that Gordon had proposed, not all economists who worked on the Gordon model were so inclined. Indeed, there was some discussion as to the optimal way to prevent overfishing. Scott noted that

> in the proceedings of the FAO Rome Conference of 1956, there is little discussion of methods of regulation by the assembled economists, and little in the 1958 Conference on costs and earnings of fishery enterprises. But in 1957 in Seattle, and again in 1959, a conference was held on the economics and biology of fisheries' management, and the proceedings of the latter, edited by Crutchfield, are a fruitful source of fact and opinion. 91

James Crutchfield and Giulio Pontecorvo also recognized limitations in the early Gordon model. They cited two main defects: 1) the nature of the production function was inadequate. Gordon assumed a simple yield-effort model that was not sufficiently general. 2) The biological production function and its effects on the market structure or performance was not adequately examined.[92]

> The theoretical work on the fisheries by professional economists falls into two phases. In the early period, roughly the 1950's, the chief

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[91]Anthony Scott, "The Economics of Regulating Fisheries," in Economic Effects of Fishery Regulation, ed. Robert Hamlisch (Rome: Food and Agriculture Organization of the United Nations, 1962), 27.

[92]James A. Crutchfield and Giulio Pontecorvo, The Pacific Salmon Fisheries: A Study of Irrational Conservation (Baltimore: The Johns Hopkins Press, 1969), 14.

> concern was over the initial articulation of the problem and the formulation of models that emphasized the dissipation of economic rent.... More recently, in the 1960's, several attempts have been made to reformulate the older models in order to integrate the efforts of the marine biologist and the economist. 93

Crutchfield and Pontecorvo saw part of the problem with the marine fisheries as being the institutional arrangements. They asserted that both classical and neoclassical economists have treated the case of exploitation of unowned resources on the basis of competitive withdrawal.[94]

> The key to the distinction between the open access resource and, for example, agriculture lies in the institutional arrangements relating to ownership of the resource. In the fisheries, Knight's "social function of ownership" is not performed. 95

Despite its limitations, however, the initial work by Gordon became the basis for the work in the static model of fisheries economics. His assumption of the common-property nature of the fishery being the basic cause of the lack of economic rent continued to be used by subsequent workers. His static analysis remained dominant in the economics of marine fisheries until the 1970's, when

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[93]Ibid.

[94]They cited Frank H. Knight, "Some Fallacies in the Interpretation of Social Cost."

[95]Crutchfield and Pontecorvo, 12.

Kenneth Arrow's work on control theory was applied to the fisheries economics by C. G. Plourde and others. But as the dynamic model began to emerge, it was recast from the static Gordon-Schaefer model by considering the optimal catch in each future period, and then discounting that back to the present at the social discount rate.

CHAPTER II

THE EARLY DYNAMIC MODEL OF FISHERIES

Shortly after the publication of the Gordon paper, Anthony D. Scott became interested in the economics of marine fisheries. Scott earlier had been interested in natural resource economics; he had already written on applying the theory of capital to natural resources.[1]

In this, he followed in the tradition of Harold Hotelling, who, in an ingenious paper, had demonstrated a relationship between the rate of increase in nonrenewable resource prices and the interest rate on high grade corporate bonds.[2] Siegfried von Ciriacy-Wantrup also had applied capital theory to natural resource economics.[3]

But most of their work was with non-renewable

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[1]See, for example, Anthony D. Scott, "Conservation Policy and Capital Theory," Canadian Journal of Economics and Political Science 20 (November, 1954): 504-13, or his Natural Resources: The Economics of Conservation (Toronto: University of Toronto Press, 1955).

[2]Harold Hotelling, "The Economics of Exhaustible Resources," Journal of Political Economy 39 (April 1931): 137-175. Hotelling recognized that the fishery might have been included in his paper, but that "[w]ildlife which may replenish itself if not too rapidly exploited presents questions of a different type" than he discussed. p. 139. Hotelling showed that a free market system would optimize the consumption of an exhaustible resource over time.

[3]Siegfried von Ciriacy-Wantrup, Resources Conservation--Economics and Politics (Berkeley: University of

resources. What Scott did was to apply capital theory to renewable resources. Specifically, he was the first to use present-value techniques to determine the optimal catch over future periods.

Scott built on the basic Gordon model. In Scott's "The Fishery," he had used the four fundamental equations from Gordon's 1954 paper, combining them into one diagram.[4] Then, in "Optimal Utilization," he modified the equation for landings as a function of population to make it consistent with the Schaefer model. By modifying this fourth equation, Scott was able to make the Gordon model dynamic, taking the discounted present value of the optimal catches over time.[5] Gordon, in commenting on Scott's change, said that "the curve drawn in the N.W. quadrant of Scott's diagrams . . . was much closer to the latest biological theory than were earlier ones,"[6] including the curve his own 1954 article.

Scott Gordon was concerned with sustaining the maximum

California Press, 1952.

[4]Anthony D. Scott, "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy 63 (April 1955): 118.

[5]Anthony D. Scott, "Optimal Utilization and the Control of Fisheries," in The Economics of the Fisheries, ed. Ralph Turvey and Jack Wiseman (Rome: FAO, 1957), 49.

[6]Ibid., 59.

yield of the fisheries over time. Scott, on the other hand, was interested in maximizing the present value of future yields. In this, Gordon was closer to the biologists who wanted to maximize the physical yield. Gordon's criterion would never open itself to the eradication of a species should interest rates increase sufficiently. Scott, however, was closer to the economic goal, viewing fisheries as a type of capital. The weakness of Scott's approach was that species extinction might be optimal if the interest rate were sufficiently high.[7] However, Scott opted for a high sustainable yield.

> The objective of the conservation of renewable resources, with social policy cut loose from the maximization of private profit, is a difficult thing to define. If the market won't invest enough, how much <u>should</u> be invested in forests, or soil, or fisheries? The answer obviously must stop short of devoting all of society's current factors to reproducing these resources. An answer, where given, has sometimes been stated by specialists to be a "high sustained yield," and this might be thought of for our purposes as a definition of conservation of renewable resources. 8

Scott, who was then at the University of British

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[7]Later, a discussion occurred regarding what conditions would be necessary for extinction to be the optimal choice. See Colin W. Clark, "Profit Maximization and the Extinction of Animal Species," <u>Journal of Political Economy</u> 81 (August 1973). Not only is the interest rate a factor, but so also is the fecundity of the species.

[8]Scott, <u>Natural Resources</u>, 16.

Columbia, saw the appropriate management objective as being to maximize the present value of the fishery. He concurred with Scott Gordon in that the competitive model, which characterized fisheries, would not allow for optimal depletion. He disagreed, however, that the common-property nature of fisheries was exclusively to blame for the low income levels of fishermen. He asserted that occupational and geographical immobility of fishermen also was there.[9]

> [T]he low incomes in fishing relative to those in farming arise from the fact that the typical farmer of the Western world receives a return that is a mixture of rent, interest, profit and wage; while the return of the fisherman (a) omits rent --indeed there is none to receive, (b) includes a wage--but this may be lower than the farmer's wage because of immobility (low opportunity cost) and (c) includes some profit and interest--but these too may be low both because the share system gives capital a low return and the immobility of capital may give it a low opportunity cost. 10

However, he developed his analysis based on Gordon's common-property assumption.

Scott disagreed with Gordon's assumption regarding the law of diminishing returns.

> [T]he fundamental assumption in Gordon's paper ... is that there are in fishing no diminishing returns and hence no increasing costs and no incentive to stop operations short of the

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[9]Scott, "Optimal Utilization," 43.

[10]Ibid. See the Appendix for discussion on rent.

> equality of total costs and landings. Surely this fundamental assumption is incorrect; surely in the short run (with population and equipment fixed) each fishing boat will experience increasing costs as it attempts to increase its landings. 11

This criticism of Gordon is valid. Gordon was ignoring the perspective of the individual boat operator. When the individual boat owner is considered, diminishing returns also applies to the fisheries, and hence, marginal cost analysis rather than average cost analysis becomes relevant.

> Gordon's analysis ... relies upon the depletion of the population to produce a species of "diminishing returns" effect that will explain, with price given, why the competitive fishery does not expand indefinitely. But this explanation applies only to the long run and cannot hold within a single season, when the fish population is one of the fixed inputs. In the short run, fishermen do not expand their catch indefinitely because they do experience increasing costs in attempting to increase their landings. 12

Governmental regulation was needed, according to Scott, because of the lack of property rights. The proper amount of production would occur in the case of a sole owner because of prevailing market rates. The government then must function as the sole owner to determine the profit maximizing level of production. He later showed

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[11]Scott, "The Fishery," 119f.

[12]Ibid., 120.

how production quotas should be allocated to individual fishing firms.

For Scott's model, cost is the driver of the system, so the way to regulate the fishery is by adjusting costs. Taxes can be an effective way to adjust costs, depending on how they are implemented. He discussed several approaches. But Scott felt that regulation should emulate sole ownership of fisheries by restricting access, or by licensing only certain fishermen. He recognized that such would entail policing costs as well as requiring monitoring of fish populations, market prices, and the like. He also discussed how the rent should be distributed.[13]

He related market interest rates to levels of resource production.

> Whether or not the natural resources are hoarded for future use depends upon business expectations and the going rate of interest. And whether or not renewable resources will be replaced depends upon expectations and the alternative available opportunities for investment, that is, again, upon the going rate of interest. 14

Implicit here, although Scott did not discuss this point, is the assumption that appropriate regulation of levels of production must allow for monetary policy-induced changes in the market rate of interest designed to affect the

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[13]Scott, "Optimal Utilization," 54.

[14]Ibid., 506.

macroeconomy.

Here Scott was making an important extension of Hotelling's work. Hotelling had implied that non-renewable resources and physical capital were substitutes; at high rates of interest, natural resources would be consumed instead of using as much capital. But Scott treated the expansion of renewable resource stocks as a form of investment. High interest rates make future stocks relatively less valuable, and hence present consumption increases at the expense of future. Conversely, low interest rates leads to deferring consumption of renewable resources.

Scott built his model on the assumption of there being a sole owner of the fisheries, recognizing that, under sole ownership, the issue of common property is irrelevant. Thus, the owner can determine the optimal level of catch based on long-run objectives.

> [I]f the catch today has an influence on the production and so on the catch tomorrow, the sole owner will wish not only to maximize current returns but also to arrange for the optimum series of landings through the ensuing future periods. He will, in fact, wish to maximize the present value of his property. This we will do by investigating the effect of his marginal current output on the present value ... and by fixing current output where marginal current net revenue is equal to marginal user cost. 15

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[15]Scott, "The Fishery," 122f.

This concern for inter-temporal usage of resources was at the heart of Scott's model. Gordon had assumed that when the maximum sustainable yield (MSY) had been achieved, this level of fishing would remain optimal into the future. But as later came to be recognized, fish population levels fluctuate due to natural factors other than fishing intensity.[16] Scott's model implicitly allowed him to model such fluctuations over time.

Scott assumed, however, that market prices fairly well reflect the social costs. Scott contended that by including user cost into the analysis, i.e. by equating marginal revenue and marginal user costs, we do not need to distinguish between a market and a social rate of interest.[17] He recognized the potential for market imperfection, but denied that such market imperfections would be significant enough to cloud the underlying analytical framework.[18]

Notice also Scott's reference to 'marginal user cost.' Since he was concerned with relative levels of fishing over time, the effect of one period's fishing on future

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[16]Colin W. Clark, Bioeconomic Modeling and Fisheries Management (New York: John Wiley & Sons, 1985), 6.

[17]Scott, Natural Resources, 6.

[18]Scott, "Conservation Policy," 507.

catches had to be calculated. This required the use of user cost. Gordon had finessed the problem by assuming that harvesting occurs at the MSY in each period. Scott's dynamic model allowed other levels to be fished each period, depending upon price, cost, or market demand.

Marshall had devised the concept of user cost in his Principles to refer to the 'wear and tear' that occurs to fixed capital resulting from its use.[19] In his General Theory, Keynes had modified Marshall's notion of user cost.[20] Keynes had defined 'user cost' as

> the reduction in the value of the equipment due to using it as compared with not using it, after allowing for the cost of the maintenance and improvements which it would be worth while to undertake and for purchases from other entrepreneurs. It must be arrived at, therefore, by calculating the discounted value of the additional prospective yield which would be obtained at

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[19]Marshall used 'supplementary cost' to include the 'wear and tear' on the plant. He also included in this concept the effect of a manufacturer using idle capacity as opposed to holding out for a higher future price. Alfred Marshall, Principles of Economics, 9th (Variorum) ed. (London: Macmillan & Co., Ltd., 1961), I: 360.

[20]Paul Davidson has argued that while Marshall's term was essentially used to describe the depreciation that a machine undergoes resulting from its use, Keynes defined user cost as "the reduction in value of the equipment due to using it as compared to not using it, after allowing for the cost of the maintenance and improvements." John Eatwell, Murray Milgate, and Peter Newman, eds. The New Palgrave: A Dictionary of Economics (New York: Stockton Press, 1987), s.v. "User Cost," by Paul Davidson.

some later date if it were not used now. [21]

User cost is a variety of opportunity cost. Opportunity cost usually is applied to deciding between two concurrent choices, while user cost refers to usage of an item in one period of time precluding its usage at another time.

Keynes had also extended the notion to raw materials. For example, he observed that

> [i]n the case of raw materials the necessity of allowing for user cost is obvious; if a ton of copper is used up to-day it cannot be used to-morrow, and the value which the copper would have for the purpose of to-morrow must clearly be reckoned as a part of the marginal cost. [22]

Keynes had applied the term 'user cost' to raw materials in an attempt to clarify his usage with respect to fixed capital.

> Let us take the prospective value of copper at various future dates, a series which will be governed by the rate at which redundance is being absorbed and gradually approaches the estimated normal cost. The present value or user cost of a ton of surplus copper will then be equal to the greatest of the values obtainable by subtracting from the estimated future value at any given date of a ton of copper the interest cost and the current supplementary cost on a ton of copper between that date and the present. [23]

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[21]John Maynard Keynes, _The General Theory of Employment, Interest, and Money_ (New York: Harcourt, Brace and World, 1936), 70.

[22]Ibid., 73.

[23]Ibid., 70f.

For Keynes, the main difference between user cost in the case of raw materials and in the case of fixed capital is that for fixed capital, user cost consists of a single term, whereas with fixed capital, it consists of a series of terms as the capital is used up.[24] In either case, since two different periods of time were considered, Keynes compared them by using the discounted present value approach. Here the market rate of interest was applied. Again, Keynes had implied that the rate of interest determines the rate of consumption of raw materials. But, he did not develop that idea; his purpose in the General Theory rather was to consider the usage of fixed capital.

Scott had already applied Keynes' notion of user cost to the rate of consumption of natural resources.[25] While the original article did not make explicit application to the rate of consumption of natural resources, he referred to this insight in his subsequent articles as being important to the problem.[26]

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[24]Ibid., 73. Keynes made the error of thinking that a unit of raw material would be used at one time, rather than thinking of depletion of a deposit occurring over time.

[25]Anthony D. Scott, "Notes on User Cost," Economic Journal 63 (June 1953).

[26]For example, he stated that "the planner ... will try to schedule his production from his natural resource so that the profit from the last unit of output from his

Scott saw natural resources as being a form of social capital, together with physical capital.

> The point of departure for this examination of the use of natural resources is that natural resources are a part, but only a part, of the social capital. They share with buildings, factories, transportation, and equipment the quality that they may be combined with labour and other current services in the production of final, consumable goods and services.... While there are certain aspects of the use of natural resources which do require special emphasis, these are merely matters of emphasis: differences in degree, not in kind. The analysis and the criteria for resource policy which follow will be based upon this theoretical similarity.27

As we saw, Scott used the notion of marginal user cost as a measure of the marginal social costs of production in fisheries. That is, the relevant costs are not just the private costs which are borne by the fishermen, but also the costs to society related to future reduction in consumption resulting from increased present consumption. With renewable resources, user cost includes future depleted populations resulting from excessive present fishing.

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resource in any period of time does not fall short of the profit (discounted at the going rate of interest) which that unit could earn in any other period." "Conservation Policy," 505.

[27]Scott, Natural Resources, 3. Later, Scott observed that "[t]he exploitation of resources is not necessarily destructive. It is the first step in a constructive process which produces goods and services for consumption and maintains the national capital in new and more efficient forms." Ibid., 15.

> If increased output tends to diminish the population and so to reduce the new revenues that could be earned in other periods had output been restrained today, the user-cost curve will slope upward, marginal user cost will equal marginal net revenue at less than the total net revenue, and sole ownership will result in a still greater reduction of desired output than would be the case of short-run considerations only were at stake.28.

Scott analyzed the effect on society of redeploying 'excess' fishermen to other occupations.

> [E]ven if political economists ... accept the point that there is misallocation of labour in the fisheries under common-property resource ownership, the economist must also demonstrate that society has much to gain by remedying the situation. As things develop in the above model, a fisheries tenure reform would benefit fishermen a good deal more than the rest of the world. 29

Scott considered the effect on the rest of society should fishermen leave to other occupations. He is concerned that should the price of fish rise too greatly, persons might long for the "days when they exploited the fishermen." But should fish prices rise, that would attract fishermen back into the industry. Scott's analysis of the welfare to society accruing from some of the excess fishermen's leaving the industry had some fallacies. He sees higher wages earned by former fishermen now working elsewhere as being a cost to society.

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[28]Scott, "The Fishery," 123.

[29]Scott, "Optimal Utilization," 45.

Such an analysis ignores that under perfect competition, the profit maximizing firm will hire to the point where MFC = MRP. So if the former fisherman is earning higher wages, that is due to his increased productivity elsewhere. Second, the extent to which fish prices increase after fishermen leave the industry is subject to several elasticities and the changes of marginal productivity of the remaining fishermen. Higher prices may attract persons back into the industry. Third, for a person who otherwise would be unemployed, the marginal cost to society of his becoming a fisherman is zero. Scott recognized this latter point.

Scott held that society's point of view should not be the criterion of whether there are too many fishermen. If some fishermen were hired away from the fisheries, the gains to society might be offset by three factors: 1) the higher incomes of remaining fishermen, 2) the higher incomes paid to former fishermen, and 3) the probable increase in the price of fish. He asserted that most of the gain would accrue to those remaining in the industry.

Scott saw that the common-property nature of the fisheries was the main reason for excess labor and capital being applied to that industry. He considered one of two approaches to resolving the excess factor usage, which was depleting economic rent in the long run.

In his article, "The Economics of Regulating Fisheries," Scott categorized the approaches theretofore used to regulate fisheries into three groupings: 1) where safety for the fisherman was a factor, 2) group rivalries, such as sovereignty issues, or conflicts between diverse ethnic groups, and 3) "Nautical Luddism," or the prohibition of certain types of gear.[30] He considered various approaches tc regulation, such as closed seasons, closed areas, gear regulations, various ways to limit the number of fishermen or vessels such as by licensing methods, or alternative approaches to taxation as means to regulate the size of the catch or the size of the industry. He examined the effects that alternative types of taxation, showing how each would affect the level of effort applied or the number of fish caught.

> A fishery with unlimited entry will be exploited, according to Gordon's hypothesis, by growing pressure of fishing (and number of vessels) until the average product of fishing is equal to the costs and opportunity income of the fishermen.... [But] the chief objective of limiting entry is to reduce the fleet until the marginal product of fishing just equals the costs and opportunity incomes of fishermen. The profit, surplus or rent that the fishery can yield at the given opportunity incomes and final prices then

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[30]Anthony D. Scott, "The Economics of Regulating Fisheries," in Economic Effects of Fishery Regulation, ed. Robert Hamlisch (Expert Meeting on the Economic Effects of Fishery Regulation) (Rome: Food and Agriculture Organization of the United Nations, 1962), 28f.

will be maximized. 31

Scott was concerned with the economic side of regulation. Most regulatory agencies had been concerned with the biological considerations: what is the optimal catch. Scott wanted to expand the regulatory objectives to provide for acquiring that desired level of catch in the least costly manner. Scott observed that "any method used for 'conservation' will have a social impact, and the beneficiaries may always expect to be the target of regulation made by the potential losers.[32]

Scott's conclusions were that sole ownership of the fisheries would tend to provide the greatest amount of conservation at the least cost to society. Four benefits would result from the sole ownership of fisheries as compared with the present structure or with any of the alternative means of regulation. 1) The relative bargaining power for fishing authorities and buyers would be altered. 2) The drive to use new technology would become the same as for any other monopoly; new technology would be brought to bear, but not excessively so. 3) The share system by which laborers were being paid no doubt would change. 4)

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[31]Ibid., 45f.

[32]Ibid., 31.

Congestion in fisheries no longer would occur.[33]

By 1957, Gordon also was aware of the need for a dynamic model for the fisheries. He was in agreement with Ciriacy-Wantrup and Anthony Scott that natural resource management is essentially an application of the theory of capital. Gordon had observed that

> [t]he conservation problem is essentially one which requires a dynamic formulation. To conserve means to postpone the use of a resource. The economic justification of conservation is the same as that of any capital investment--by postponing utilization we hope to increase the quantity available for use at a future date. 34

Gordon asserted that "the optimal degree of exploitation must be treated as a time function of some sort.[35] But he recognized that the interaction between the biological dynamics of the fish population, the economic time preference of the community and the rate of the catch would require quite a complicated model. He left the dynamics of fish population as a problem for the biologist. He also recognized that a full treatment of the problem must allow for the location of the desired species

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[33]Ibid., 57f.

[34]H. Scott Gordon, "Obstacles to Agreement on Control in the Fishing Industry, " in _The Economics of Fisheries_, ed. Ralph Turvey and Jack Wiseman (Rome: FAO, 1957), 67.

[35]Ibid.

within the foodchain; the dynamics of its prey and of species that feed upon it must be considered for a complete model.[36]

Although Gordon agreed that a dynamic model, one that optimized production over time, was preferable to what he had devised, he did not try to create a new model. Also, Scott, although his model was specifically dynamic, made a preference for sole ownership although he recognized that monopolies tend to conserve more than perfectly competitive industries. But he did not use his dynamic model to reach these conclusions.

James A. Crutchfield and Arnold Zellner, in their monumental study of the Pacific halibut fishery used the Scott model. As James Quirk and Vernon Smith observed, "Crutchfield and Zellner provided an explicit dynamic model of competitive harvesting and a calculus of variations approach to optimal fishing over time using the quadratic biological growth law."[37]

Their insights into fishery management transcended those of Scott. They saw fishery management as entailing

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[36]Ibid.

[37]James P. Quirk and Vernon L. Smith, "Dynamic Economic Models of Fishing," in Economics of Fisheries Management: A Symposium, ed. Anthony Scott (Vancouver: University of British Columbia, Institute of Animal Resource Ecology, 1970), 3.

three aspects: 1) a biological component, which determines the optimal weight of the catch; 2) the technological component, which determines the optimal catching gear; and 3) the economic component, which includes market price, and costs of production. These three issues are seen as needing to be held in balance.[38]

Like Scott, Crutchfield and Zellner opted for unified control over the fishery, where the objective was to maximize the present value of the stream of income over time.[39] Yet they acknowledged that the Pacific halibut fishery could not be reduced to sole ownership.

> If a fishery resource could be privately owned and managed, there would be an incentive to maximize the net economic yield from the resource, and overfishing would not occur except through inadequate knowledge. There is no practical way in which the deep-sea halibut fishery could be converted to private ownership. If the total catch is restricted by public action the economic rent from more rational exploitation will again be dissipated by excessive costs as new entrants are attracted to the fishery. 40.

However, they observe that optimal fishing must consider cost components, biological components and the

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[38]James A. Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," Fishery Industrial Research vol I, # 1 (Washington: US Department of the Interior, 1962), 10.

[39]Ibid., 18.

[40]Ibid., 20.

appropriate use of both capital and labor.

> Optimal fishing requires (1) that the right catch be taken with the minimum cost, (2) that the industry should be able to develop and adopt new and better techniques, and (3) that incomes to labor and capital should be equal to those that could be earned elsewhere and should be as stable as possible. 41

One reason that they gave for the excess capacity within the fishery is that the "squeezing-out" process does not work well in the fishing industry due to the long life of boats. When economic profits occur, new entrants are attracted. But once these new entrants are in the industry, the marginal costs of maintaining a boat are minimal. Under perfect competition, as long as MR = MC above the minimum average variable costs, exit is unlikely. So excess capacity tends to remain. Also, these boats are not easily converted to other uses.[42]

After considering alternative methods of limiting the number of fishermen permitted in the Pacific halibut fishery, Crutchfield and Zellner recommended a system of licensing, where, over time, the number of licenses would be reduced. The proceeds from licensing would be used to operate the Commission and to fund fisheries research.[43]

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[41]Ibid., 27.

[42]Ibid., 91.

[43]Ibid., 109.

Both confirming Crutchfield and Zellner's analysis and observing that their recommendations have not been adequately implemented, the 1991 Pacific halibut fishery catch had 6000 boats going after the catch. These boats landed 23.7 million pounds of fish, 4 million pounds of which rotted since they could not be frozen quickly enough. "So many fishermen compete for the valuable Pacific halibut that the entire year's quota--once harvested over a leisure six-month season--is now taken in two frantic 24-hour periods."[44]

This fishery is an example of a nonallocated total allowable catch quota (TAC) approach to limiting the harvest. Clark, using the 1987 figures, where the season lasted for three days, calculated the additional cost of having such an excessive fishery. He showed that under an individual, transferable catch quota (ITQ) system, there would be economic rent, which would benefit even those who chose to exit the fishery.[45]

The mathematical model that Crutchfield and Zellner devised maximized profits over time as being the sum of

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[44]Michael Satchell, "The Rape of the Oceans," U. S. News and World Report 22 June 1992, 75.

[45]Colin W. Clark, Mathematical Bioeconomics: The Optimal Management of Renewable Resources (New York: Wiley-Interscience, 1990): 261ff.

the discounted revenues in excess of the costs of fishing. This maximum was seen as being subject to three constraints: 1) a technological production function, 2) a cost function, and 3) biological constraints. They used the Schaefer model to determine the optimal population level. But they observed that two important variables were omitted from the model: changes in income and changes in technology.[46]

While the components of Crutchfield and Zellner's model went beyond Scott, they did not have adequate mathematics to develop a complete model. The mathematics necessary for optimal control theory had not yet been developed. So they were not able to give a sufficiently rigorous model to include all the components they recognized to be necessary.

The problem was not that a dynamic model is not superior to Gordon's model, or to the model as modified by Schaefer and Scott, but rather the mathematics were not adequately worked out. It was not until the development of optimal control theory,[47] which Kenneth Arrow

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[46]Crutchfield and Zellner, 114f.

[47]The Russian mathematicians Pontryagin, et al., devised this optimization process in the 1960's. Unlike the Lagrangian method, which is widely used in economic theory, this optimization method allows one to optimize systems involving differential equations, and so is initially applied to capital theory in the 1960s,[48] that a

truly dynamic approach could be devised which could be used by fishing managers. There was a substantial leap in the rigor of the mathematics being used within fisheries bioeconomics in the early 1970's as compared with the late 1950's and even during the 1960's.

As Clark, et al. summarized it,

> [A]though there were a few attempts to develop models of the fisheries in the early 1960s (e.g. Crutchfield and Zellner, 1962), the static analysis remained dominant throughout. The first truly successful attempts to develop a dynamic optimization approach to fisheries appeared in the early 1970s, with the pioneering work of Plourde (1970, 1971), Quirk and Smith (1970), and others. These models were characterized by the extensive application of optimal control theory.49

At the time in which Scott was initially writing, few economists who were interested in natural resource economics had an adequate mathematical background in order to develop the theory more completely. This lapse was

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appropriate where rates of growth are concerned. See L. S. Pontryagin, V. Boltyanskii, R. Gamkrelidze, and E. Mischenko, The Mathematical Theory of Optimization Processes (New York: Interscience, 1962).

[48]For example, see Kenneth J. Arrow, Application of Control Theory to Economic Growth (Stanford University: Institute for Mathematical Studies in the Social Sciences, July 14, 1967).

[49]Clark, Colin W., Gordon R. Monroe, and Anthony T. Charles, "Fisheries, Dynamics, and Uncertainty," in Progress in Natural Resource Economics, ed. Anthony Scott (New York: Oxford University Press, 1985): 101.

overcome by 1970.

Scott made two important contributions in treating the economics of the fishery as a form of capital theory. He was the first to apply user costs to renewable resources. He also was the first to consider the optimal production of fisheries over time as a dynamic process as opposed to searching for a maximum sustained yield (MSY) level.

CHAPTER III

OPTIMAL CONTROL THEORY APPLIED TO THE ECONOMICS OF MARINE FISHERIES

During the 1960's, a major development was occurring in capital theory. Kenneth Arrow had begun to apply to capital theory a then relatively new mathematical approach--optimal control theory.[1] By 1969, it had begun to be introduced into the economics of the fisheries.[2]

Optimal control theory, or the Pontryagin Maximization Principle as it is variously called, was just being introduced into capital theory. Arrow built on John Hicks's suggestion of treating capital theory as an

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[1]Optimal control theory was first applied to capital theory in Kenneth J. Arrow, "Optimal Capital Policy, the Cost of Capital, and Myopic Decision Rules," Annuals of the Institute of Statistical Mathematics 16 (1964): 21- 30. The first mathematical discussion in English of optimal control theory was that of L. S. Pontryagin, V. Boltyanskii, R. Gamrelidze, and E. Mischenko, The Mathematical Theory of Optimal Processes, trans. D. E. Brown (New York: Interscience, 1962).

[2]James P. Quirk and Vernon L. Smith, "Dynamic Economic Models of Fishing," in Economics of Fisheries Management: A Symposium, ed. Anthony D. Scott (Vancouver: University of British Columbia, Institute of Animal Resource Ecology, 1970): 3-32. This article first appeared as a research paper at the University of Kansas in 1969, a version of which was published June of 1969. The version cited above was presented at the H. R. Macmillan conference at the Cecil Green House at the University of British Columbia in March 1969. A. D. Scott edited and published the papers from that conference in April 1970.

optimization problem for the firm.[3] Arrow had just begun to make the use of this technique to optimize decisions in capital theory.

Arrow traced the origin of the Pontryagin technique.

> This recursive aspect of the production process simplifies analysis and computation, as was first recognized in the context of inventory theory in the magisterial work of Masse (1946).... Subsequently, the mathematician Bellman (1957) recognized the basic principle of recursive optimization common to inventory theory, sequential analysis of statistical data, and a host of other control processes in the technological and economic realms and developed the set of computational methods and principles known as dynamic programming. Finally, the Russian mathematician Pontryagin and his associates (1962) developed an elegant theory of control of recursive processes related to Bellman's work and to the classical calculus of variations. The Pontryagin principle ... has the great advantage of yielding economically interesting results very naturally. 4

This Pontryagin Maximum Principle method entails the creating of a Hamiltonian out of the objective function together with the constraint equations. Then this Hamiltonian is maximized by the selecting of the optimal value of the control variable.

The objective of maximizing the Hamiltonian, as Arrow employed it, is to determine the optimal sequencing of

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[3]Kenneth J. Arrow, "Optimal Capital Policy with Irreversible Investment," in Value, Capital, and Growth: Papers in Honour of Sir John Hicks, ed. J. N. Wolfe (Edinburgh: Edinburgh University Press, 1968), 1.

[4]Ibid., 1f.

investment decisions. He had made the assumption that capital decisions are irreversible. Thus in Arrow's model, depreciation does not exist, nor may a firm sell excess capital.[5]

Arrow's model is quite applicable to the fishery. In the fishery, "capital" is used in two senses, either the physical capital such as gear and boats used to catch the fish, or the fish stock itself. When the physical capital is fishery-specific, the sale of physical capital is typically not possible in a regulated fishery. Arrow had shown that a model having depreciation could be replaced with an equivalent one having no depreciation. Hence, the Arrow model used in the Quirk and Smith paper readily applies to the fishery where the amount of physical capital applied to the fishery is the variable subject to control.

The Essentials of Optimal Control Theory

Robert Dorfman provided a good intuitive understanding of optimal control theory. This method assumes that there are two variables, such as fish population and the amount of capital devoted to the fishery. But a change in either of these variables will affect the other.

> [T]he decisions taken at any time have two effects. They influence the rate at which profits

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[5]Ibid., 6.

> are earned at that time and they also influence the rate at which the capital stock is changing and thereby the capital stock that will be available at subsequent instants of time. 6

Thus it is necessary to determine recursively the optimal sequence of investments over time. Dorfman noted that the method of finding the optimum values using the maximum principle of optimal control theory involves several steps. First is to devise a formula for the value a firm can obtain over time, starting at a given time with an original capital stock and fish population. Then this formula is broken into two components. The first component involves a time period so short that output cannot be changed even if it were to be desired. So output in the first component depends upon existing capital stock and the original fish population. The second component allows the capital stock to vary over time. The objective is to maximize the value to the firm achieved by choosing the optimal time path of output recursively, where ordinary calculus can determine the optimal output at a given time.[7]

As applied to the fishery, the investment is defined

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[6]Robert Dorfman, "An Economic Interpretation of Optimal Control Theory," American Economic Review 59 (December 1969): 818.

[7]Ibid., 819.

either in terms of restricting current fishing activity to allow the stock to increase, hence enlarging future potential catches or in terms of the optimal sequencing of investments in physical capital. This then determines the optimal fish stock at the end of the period. For this projected fish stock, given the market prices and costs of fishing, a new amount of physical capital would be desired for the second period. So the firm changes its physical capital stock as necessary. In the second period, the modified physical or biological capital would affect the level of fishing intensity, hence affect the level of the fish population remaining at the end of the second period. Thus, for each new period the physical and biological capital stock would have to be redetermined. So recursively, the capital stock determines the residual population, which, in turn, determines the desired capital stock for the next period. Since the stream of net revenue from the future sale of fish can be discounted back to the present, this revenue stream can be optimized. Hence in control theory, the objective is to determine the stream of investment which maximizes the value of the fishery over time. Thus, the optimal physical capital stock can be selected by the firm. The "owner" of the fishery can determine the optimal stock of the fishery.

The objective is to find the optimal sequence of investments of physical capital so as to maximize the value of the firm over time. Using Scott's insight that a fishery can be treated as capital stock, then optimal control theory would be used to determine the optimal sequence of catches which would maximize the value of the fishery, where each period's catch is discounted back to the present at the social rate of discount. Whereas elementary calculus could be used to determine the optimal value of profits or the best number to assign a single variable, to determine the optimal time path requires very rigorous mathematics.

Hence it is necessary to devise an objective function, known as the Hamiltonian function, which incorporates the constraints, and then is maximized with respect to the control variable. For example, in the regulated fisheries, the control variable would either be the allowed rate of catch or the physical capital stock. Dorfman noted that the Hamiltonian function H over some time interval represents the total contribution of the activities going on in that time interval, including the value of capital accumulation and the total profits accruing to the firm.[8] The objective, then, is to choose the control variable so as to make H as great as possible. Hence the name

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[8]Ibid., 822.

"maximum principle."

The system requires three basic formulae. First is the basic datum of the problem, such as the biological growth equation adjusted for fishing activity following from the Gordon-Schaefer model. Second is a choice variable which is to be selected such that the marginal immediate gains from an increase in the physical capital stock equals the marginal contribution to the accumulation of capital. So the discounted present value of future income gains accruing from an additional unit of capital must coincide with the marginal cost, discounted back to the present, of adding that unit of capital. The third condition is that the depreciation of capital must coincide with the rate that it contributes to useful output.[9]

Dorfman demonstrated a formal similarity between the optimal control theory maximum principle and the Lagrangian method.

> Thus the basic equations of the maximum principle are seen to be the limiting forms of the ordinary first-order necessary conditions for a maximum applied to the same problem, and the auxiliary variables of the maximum principle are the limiting values of the Lagrangian multipliers. 10

The principal difference is that the maximal principle

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[9]Ibid.

[10]Ibid., 828.

can be applied to systems of differential equations, while the Lagrangian cannot. That is why Vernon Smith's earlier work, which employed the Lagrangian method, had to use a different approach than his precursors.[11] Without optimal control theory, one cannot make dynamic a model, such as the Gordon-Schaefer model, which is framed in terms of differential equations. But with the use of the maximum principle, the James Quirk and Vernon Smith article could use the equations that earlier researchers had been using.

Notice that optimal control theory makes a very explicit assumption as to how the economy makes its decisions. Control theory examines the iteration of decisions involving capital allocation, valuation of capital and levels of output which unfold over time. In order for this to be called a control theory, there needs to be some central planner. Were this left to the interaction of individuals in a perfectly competitive market, the actions of each individual decision maker would affect all the others so that industry-wide optimization would not be possible. The implications of control theory with a

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[11]Vernon L. Smith, "Economics of Production from Natural Resources," American Economic Review 58 (June 1968) used the Lagrangian method for optimization, unlike the article which he co-authored during the subsequent year.

common-property resource is that governmental regulation of the fisheries is inevitable.

Optimal control theory as applied to capital theory had allowed a solution to some questions theretofore incapable of being treated. John Butlin considered its application to the theory of the fishery as being a major development.

> Theoretically, perhaps the most successful extension of the theory of the fishery over the last five years has been the development of a fairly explicit dynamic model of fisheries behaviour.... The most complete exposition of this is to be found in the contribution by Quirk and Smith. 12

The Contribution of Quirk and Smith

Quirk and Smith built on the works of Gordon and of Scott. They used the Gordon-Schaefer biological growth model. Like Scott, they used the discount rate to consider the effect of a flow of revenues over time. The stated objective of their paper was to

> incorporate the externality and growth characteristics of a fishery into a dynamic model of general equilibrium and to compare such a competitive model with a model of optimal fishing over time. For the latter we employ in a straightfor-

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[12]John Butlin, "Optimal Depletion of a Replenishable Resource: An Evaluation of Recent Contributions to Fisheries Economics," in <u>The Economics of Natural Resource Depletion</u>, ed. D. W. Pearce and J. Rose, (New York: John Wiley & Sons, 1975): 91.

ward manner the Pontryagin Maximum Principle. 13 The use of optimal control theory allowed them to treat individually or collectively each of the externalities that they had identified as being in the fisheries: the effect of the size of the stock on the catch rate of fishing firms, vessel or fishing gear congestion, choice of mesh size or other gear restrictions, and public investment in breeding facilities. The model also allowed the study of the interaction of ecologically related species, either where two species might be competing with each other for the same food resource or where there is a predator-prey relationship.[14]

Vernon Smith had been interested in building dynamic models of fisheries prior to his collaboration with James Quirk. In 1968, he had written an article on production from natural resources. In this article he did discuss dynamic models of the fisheries. Smith essentially used the Gordon-Schaefer model, modifying it by treating it dynamically, and then comparing differential equations for equilibrium in a phase space. That is, he considered the interaction of a system of two different differential equations, one representing the biological growth model

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[13]Quirk and Smith, 3.

[14]Ibid., 4.

that Schaefer had used. The other behavioral equation discussed the time rate of change in capital as a function of cost, existing capital stock, and market price of fish. This system of differential equations then gives a dynamic system having a point of static equilibrium.[15]

Following Gordon's lead, Smith considered the optimal level of production, assuming sole ownership of the fishery. The optimization technique he then applied was the Lagrangian method with first order conditions so as to determine the interior maximization of the system.[16] This gave him the optimal level of capital employed and the optimal fish population, hence the optimal level of capture.

Likewise, in his 1969 article, Smith applied the Lagrangian method to the model he devised.[17] Smith had followed the approach of R. J. H. Beverton and S. J. Holt in assuming that the fish population size was a function of the size of the mesh of the nets employed in the fishery.[18] This was the first use of the Beverton-Holt model by

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[15]Smith, 414ff.

[16]Ibid., 426f.

[17]Vernon L. Smith, "On Models of Commercial Fishing," Journal of Political Economy 77 (April 1969): 190.

[18]Ibid., 182. Unlike the Gordon-Schaefer model, the

economists. Colin Clark later used that model in some of his articles.[19]

Smith had rightly criticized the standard analysis as not being dynamic.

> [T]he standard analysis does not provide a dynamic theory; it is not explicit about the various types of externalities that may arise; nor does it explicitly distinguish the effect of such variables as vessel catch rate, fish population mass, investment, and mesh size. 20

He did note that the James Crutchfield and Arnold Zellner work was an exception to this general lack. But he also contrasted his approach to theirs as having a more general formula for fish populations; they had used the quadratic form of the biological differential equa-

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Beverton-Holt model considers the biomass of the cohorts, or fish born in a specific year, of a given species. Over time, a given cohort will increase in weight due to growth, which is offset by mortality due to predation and harvesting. The conclusion of the Beverton-Holt model is that there is an optimal size to catch. Hence, they would, as a policy recommendation, prescribe optimal mesh sizes, allowing younger specimens which grow at a faster rate to survive. This also assures at least one season of fertility prior to capture.

[19]See, for example, Colin W. Clark, Gordon Edwards, and Michael Friedlaender, "The Beverton-Holt Model of Commercial Fisheries: Optimal Dynamics," Journal of the Fisheries Research Board of Canada 30 (1973): 1629-40, or Colin W. Clark, Mathematical Bioeconomics: The Optimal Management of Renewable Resources, 2d ed. (New York: Wiley-Interscience, 1990): 204-11.

[20]Smith, "On Models of Commercial Fishing,"196f.

tion.[21]

Significantly, in both of these articles, Smith, in devising a dynamic system, built a model where he employed the Lagrangian method. The Lagrangian method gives a static optimum. It is not appropriate for a system of differential equations, which Smith should have used. To get the dynamic equilibrium, he had resorted to the use of a phase diagram, showing the tendency of the system when the population or capital stocks were not at the static equilibrium. Smith did not use the more powerful Pontryagin Optimization approach, which was used in the 1969 work in which he collaborated with Quirk.

It was this Pontryagin Optimization Principle that Quirk and Smith introduced to the economics of the fishery in 1969. They used the population time rate of change equation from the Gordon-Schaefer model, the inverted parabola formula, as the basic bionomic equation.

As was true of other models of the fishery, Quirk and Smith's approach showed the competitive model to be suboptimal.

> The competitive model is compared with that of a dynamic welfare maximizing model. Because of the production externality in the harvesting of fish, the competitive model does not maximize welfare. It is shown that a unit tax on fishing firms re-

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[21]Ibid., 196n.

flecting the implicit capital value of the stock of fish, serves to internalize costs associated with the fish population and leads to efficient competitive allocation. Alternatively, if the fishery resource lends itself to appropriation, as when there are many independent fishing grounds, the competitive model is efficient. 22

John Butlin observed that

[t]he first contribution that this paper ... make[s] is that [it] enable[s] one to examine the behaviour of the fishery out of equilibrium. Prior to the work of Quirk and Smith, the behavioural theory of the fishery had been formulated entirely in terms of equilibrium solutions....
[Another] principal advance in theory that comes out of Quirk and Smith's paper is the attempt to integrate, into an economic model of a fishery, interactions between species. 23

The Quirk and Smith article represented a significant advance in the economic theory of the fishery. The presumption that the fishery was in equilibrium or would tend towards equilibrium, no longer was made. So the model could show levels of capital stock or of fish population, or rates of growth in the fish population as compared to the social discount rate which would throw the system out of equilibrium. Conversely, it could model changes in capital which would result from exogeneous changes in fish populations or in rates of growth.

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[22]Quirk and Smith, 4f.

[23]Butlin, 92f.

The basic results of the Gordon-Schaefer model, as modified by Scott, remained, since Quirk and Smith used the same biological growth function from the Gordon- Schaefer model. Quirk and Smith, like Scott, treated the fishery as a capital stock to be optimized over time. They recognized the same issues of externalities, and hence the regulatory authorities would need to guide the growth of the capital stock optimally over time.

C. G. Plourde's Development of the Quirk and Smith Model

C. G. Plourde was the first fishery economist to build on Quirk and Smith's foundational article. Plourde used the quadratic population growth function from which was subtracted the rate of catch. Plourde recognized that in order to optimize utility achieved from consuming fish subject to the bionomic equilibrium condition, it is necessary to have an imputed demand price of a unit of unharvested resource in terms of present consumption foregone in order for the Hamiltonian to be maximized in terms of consumption at a point in time.[24] This shadow price is easily computed by the Maximization Principle

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[24]C. G. Plourde, "A Simple Model of Replenishable Natural Resource Exploitation," American Economic Review 60 (June 1970): 519.

technique.

Like Quirk and Smith, Plourde showed that

> [w]hen production does not involve variable inputs other than the natural resource itself, it is shown here that maximum sustained yield programs are nonoptimal. . . . [W]hen production costs are introduced the result is to increase the optimal steady-state resource population. 25

Likewise, he observed that when the social discount rate is positive, the rate of consumption increases, and hence the steady state population decreases as compared to when the social discount rate is zero.

Plourde's second article extended the model from being a partial equilibrium model to being a general equilibrium model. Thus, using his dynamic model, he was able to determine optimal fishing levels consistent with the desired level of all other goods and services.

Like Quirk and Smith, Plourde preferred a system of taxation to guide the level of fishing to the optimal level.

> Control may take the form of quotas, but it is easy to devise dynamic tax rates that are equivalent in effect and have the added advantage of providing signals to the controller if changes in parameters take place. The tax has the effect of internalizing the common-property externality through appropriation. It may be the case that auctioning of fishing rights is preferable to per unit taxes. 26

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[25]Ibid., 521.

[26]C. G. Plourde, "Exploitation of Common-Property

Although Plourde, like his precursors, used the quadratic growth function of the Gordon-Schaefer model, he was the first to raise issues regarding its appropriateness.

> Current research suggests the [growth function] curve may not be a logistic. With slight modification the analysis above can be applied to any functional form of the growth law that achieves a maximum and for which dN/dt = 0 for N sufficiently large. 27

The logistic growth curve is what gives the inverted parabola curve in the Gordon-Schaefer model. Here, N is the population of the fishery, and hence, dN/dt is the time rate of change in the population. Thus his condition that dN/dt = 0 requires the population to reach some level where further population expansion ceases.

The Contributions of Colin Clark

Finally, we turn to the work of the individual who brought the economics of the fishery to its present form, Colin W. Clark. Clark is a Professor of mathematics at the University of British Columbia, and as such, he came to his interest in the economics of the fisheries from a rigorously mathematical perspective.

Because Clark initially came to the problem of the

Replenishable Resources," Western Economic Journal 9 (September 1971): 265.

[27]Ibid.

economics of marine fisheries as a mathematician rather than as an economist, he did not initially build on the foundation laid by previous fishing economists, nor even on the neo-classical model. He did not use the Gordon-Schaefer model in his original 1971 work.[28] Nor was the basic insight of Gordon even applied--that fisheries are a common property resource. Clark's 1972 paper used the common property nature.[29] It is evident that subsequent to his initial contribution, Clark had studied the literature of the economics of the fisheries more thoroughly than he had done earlier. Having done so, his subsequent work was more in line with the approach generally accepted by other marine fishery economists. Likewise, his early articles did not consider the significance of a price system in which sole owners are controlling catch rates. As he continued his work in this area, however, his appreciation for the neo-classical foundations increased.

Clark's first contribution to the economics of the fisheries, "Economically Optimal Policies for the Utilization of Biologically Renewable Resources," which was

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[28]Clark, Colin W., "Economically Optimal Policies for the Utilization of Biologically Renewable Resources," Mathematical Biosciences 12 (December 1971): 245-60.

[29]Clark, Colin W., "The Dynamics of Commercially Exploited Natural Animal Populations," Mathematical Biosciences 13 (February 1972): 149-64.

written in 1971, came in response to the assertion by Kenneth Boulding and others that purely economic motives are inadequate for the conservation of natural resources.[30]

Clark was writing more as a mathematician than an economist in this first article. He used a very rigorous mathematical theorem-proof approach. The mathematics he used was of finite or infinite sequences of numbers, for which he used point-set topology tools such as compactness, Banach spaces[31] of real bounded sequences, and weak* topologies.[32]

Clark defined the sequence $\{h_i\}$ where $h_i >= 0$ represents the harvest rate for year i as a utilization policy. For a given discount rate, and by assuming that the net revenues are proportional to the amount of fish caught, he was able to define the present value of the utilization policy, P(h). The problem was to determine the

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[30]Colin W. Clark, "Economically Optimal Policies for the Utilization of Biologically Renewable Resources," 245.

[31]A Banach space is a topological space consisting of all bounded sequences of real numbers. Essentially it is an infinite-dimensional vector space.

[32]Point-set topology abstracts certain characteristics of the real number line to sets in general, allowing a more powerful theory to emerge. If we take the set of all linear functions defined over the real numbers, the relativized topology for this set is known as a weak* topology. A weak* topology is that topology having the fewest number of open sets which are needed for the desired functions to be continuous.

maximum utilization policy over a range of policies, or rather to determine the optimal harvest policy which maximizes the present value of the net revenues.[33]

Clark discussed the existence of an optimal sequence of periodic harvests of fish which would maximize the discounted present value of the fishery.[34] Three implicit assumptions were made: (1) the discount rate remains constant over time, (2) some entity can control harvest policy, either under sole ownership or by regulation, and (3) the price or the net revenues from the fishery remains constant over time. The first of these assumptions is not critical. The second assumption was made explicit in his 1972 article.[35]

The third is fatal. By assuming that net revenues from the fishery on a per unit basis remain constant over

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[33]Clark, "Economically Optimal Policies," 246.

[34]Clark's approach of using a bounded sequence in a Banach space is useful for showing the existence of an optimal sequence of harvests. What the optimal control theory approach did was to provide a technique of calculating each term in the sequence. Hence, optimal control theory is a more useful approach in that it constructs the optimal sequence of harvests over time. Eventually, Clark himself employed this latter technique.

[35]Colin W. Clark, "The Dynamics of Commercially Exploited Natural Animal Populations," 150. In his 1971 paper, Clark was apparently unaware of the significance of the common property nature of the fishery. But in this article, he showed that common ownership leads to an overutilization of the resource.

time, he could show that, in some instances, it would be optimal to harvest the fishery to the point of extinction in the first period. This result ignored the classic article of Hotelling who showed that for the non-renewable resource, prices must increase over time at the rate of high grade bond yields.[36] Otherwise either all of the resource would be extracted in the first period, or all in the final period. Clark's omission of price increases in the case of a sole owner of the resource set up the case for extinction where the rate of growth of the fishery was less than the current interest rate. A modification of that assumption would give substantially different results.

Clark showed that when his optimization problem is computed over a finite interval, then using the topological property of compactness,[37] the problem must have a solution. This solution can be obtained through dynamic programming techniques. Here he cited Bellman's Dynamic Programming.[38] He noted that whereas a computer program

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[36]Harold Hotelling, "The Economics of Exhaustible Resources," Journal of Political Economy 39 (April 1931).

[37]Compactness is the topological property that every open covering of a space has a finite subcovering. Here, compactness is important to assure us that the solution does not have infinitely many steps.

[38]Bellman, R., Dynamic Programming (Princeton:

might approximate the maximum value for P(h), it cannot approximate the optimal harvest policy.[39]

It is noteworthy that this mathematician, in developing his model, referred to one cited by Arrow as a precursor to optimal control theory. But Clark did not use optimal control theory, even though it had already been in used within the economics of the fishery. True, by setting up the problem as a sequence of harvests over time, he was able to avoid generating a model stated in terms of differential equations, hence one requiring optimal control theory. But, except for the case where extinction would be the optimal policy, he showed the rate of harvest would be determined where the rate at which the fish population grows coincides with the social rate of interest. This is less than the maximum sustained yield level of population. Since Clark then lacked an appreciation for the common-property nature of the fishery, no discussion was made regarding the loss of economic rent in his 1971 paper.

In his 1972 article, Clark built on his model, adding the possibility that an initial investment of physical capital could be made. No depreciation was permitted, nor

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Princeton University Press, 1957).

[39]Clark, "Economically Optimal Policies," 246f.

was any subsequent investment possible. He showed that under his assumptions, since the investment would have been made prior to the fishery coming to equilibrium, an excessive amount of capital would exist once the fishery comes to an equilibrium. In this 1972 article, Clark did make explicit the assumption regarding the common ownership nature of the fishery. He recognized that the common ownership could lead to overinvestment. He continued to emphasize a concept devised by Ciriacy-Wantrup, "safe minimum standard." The safe minimum standard had been defined by Clark as follows:

> A supramarginal resource stock may be reduced by overexploitation to such a low level that it becomes submarginal; the level at which this transition occurs is called the safe minimum standard of conservation. 40

If the safe minimum standard were to be observed by fishery regulators, then extinction would not likely occur. Otherwise, market pressures could lead to specific extinction.

> The existence of a safe minimum standard emphasizes the importance of observing the phenomenon of overcapitalization at equilibrium.... If overcapitalization is not taken into account soon enough, the stock will fall to such a low level that regeneration is no longer profitable. 41

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[40] Clark, "Economically Optimal Policies," 245.

[41] Clark, "Dynamics," 150.

Again, this second article used the topological properties of bounded sequences in a Banach space to reach its conclusions. With the exception of expressing an awareness of the common-property nature of the fishery, the weaknesses of the 1971 paper remained.

In 1973, Clark wrote a pair of articles which raised the possibility that extinction may be economically optimal under certain conditions. Clark showed an increased appreciation for the existing literature in the economics of the fishery relative to his earlier works. Clark used the population growth model, which had become standard in the literature by that time. In "Profit Maximization," Clark used a form of the $dx/dt = f(x)$ function for the growth rate of fish populations. But, unlike earlier workers, he used a recursive formula, where $x_{i+1} = f(x_i)$.[42]

Although Clark cited the Quirk and Smith article, and hence was aware of optimal control theory, he continued to use the approach of his earlier articles. He showed the

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[42]Colin W. Clark, "Profit Maximization and the Extinction of Animal Species," Journal of Political Economy 81 (August 1973): 952. A difference equation is more appropriate than a differential equation in the case of the fishery where reproduction is usually seasonal. How- ever, the accepted approach was to use the differential equation form. Clark later accepted this convention himself.

existence of an optimal sequence of harvests, using functional analysis techniques from advanced mathematics. There are, mathematically speaking, two reasons for having done so. First, the method has the advantage of dealing with difference equations rather than differential equations. This is more relevant when considering periodic events such as harvesting fisheries. The second reason he gave is that it is intuitively more desirable.[43]

Clark showed that where the derivative of the marginal cost function is an increasing negative function and the derivative of the reproduction function is a decreasing function, then if the price exceeds the marginal cost function evaluated at zero, and if 1 + i exceeds the square of the derivative of the growth function evaluated at zero, where i is the social rate of interest, then maximizing the present value leads to extinction.[44] He illustrated this in the case of blue whales, where the rate of population growth was estimated to be 10%. In that case, where interest rates exceed 21%, depletion of the species is economically optimal.[45]

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[43]Colin W. Clark, "The Economics of Overexploitation," Science 181 (August 17, 1973): 632.

[44]Clark, "Profit Maximization," 957.

[45]Clark did not distinguish between real and nominal interest rate here, only to assert that the relevant cost

While Clark was cognizant that harvesting costs rise with decreasing fish population,[46] his model assumed that prices and costs would remain constant over time. This is a critical flaw in his approach. If costs rose faster than prices, extinction would not be economically optimal, regardless of the interest rate. Granted, he stated his case for whales, where the fertility rate is quite low. But even there, a decrease in the whale population causes the search costs to rise.

The second of these two articles, "The Economics of Overexploitation," was written in a somewhat populist, alarmist manner, asserting that the human capacity to consume and destroy natural resources is moving to the critical stage.[47]

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of capital to the firm applied. Here he was assuming the firm to be the sole owner of the fishery.

[46]Clark, "Profit Maximization," 951. There he remarked that "[a]nalysis of controlled fisheries have often been based on the concept of rent maximization, that is, maximization of net annual revenues. It has been noted that, if harvesting costs rise with decreasing population levels, a rent-maximizing policy will automatically lead to biological conservation, with an equilibrium population in excess of the population corresponding to maximum sustained yield. It is perhaps more reasonable to suppose, however, that the 'sole owner' of a resource population would in fact choose to maximize the present value of his harvest sequence, discounting future revenues at some fixed rate." Based on his model, price and cost considerations apparently do not enter into the case of the sole owner.

[47]Clark, "Economics of Overexploitation," 630.

Here again, Clark's lack of appreciation for the price system becomes apparent. He confused externalities and property rights. He cited Harden's "Tragedy of the Commons"[48] as why externalities might exist, and then referred to owners of property rights in biological resources.[49] But where ownership in property rights exist, prices, both existing and expected future prices, govern the rate of harvest.

Clark referred to the work by Pontryagin in this article in treating the fishery as a problem within the theory of capital.[50] However, he used his topological approach to develop his model, as he had done in prior articles.

Clark, in suggesting that economists were raising the issue regarding the adequacy of rent dissipation as an explanation for overfishing,[51] cited Steven Cheung. Yet

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[48]Hardin, Garret, "The Tragedy of the Commons," Science 162 (December 13, 1968): 1234-48.

[49]Clark, "Economics of Overexploitation," 630.

[50]Ibid., 633.

[51]"Economists themselves have begun to question the adequacy of the rent dissipation argument to explain current developments. The fact that ... extinction is theoretically impossible has been called 'one of the more serious deficiencies of the received doctrines.' But the principal shortcoming of the existing theories is their disregard of the time variable, both biologically and economically." Clark, "Economics of Overexploitation," 631.

Cheung had advocated a form of property rights, known as stinting, to preserve the fishery rather than the use of governmental regulations or taxes.[52]

Clark asserted that there are two reasons why extinction might occur, economically speaking: either as a result of common-property exploitation, or from the maximization of present value when the rate of discount is adequately high.[53]

These two articles written in 1973 show a greater awareness of the literature of the economics of the fisheries than do his earlier works. Also, there is an increased understanding of the principles of economics. Yet at a couple of embarrassing points, Clark's faulty conclusions were the result of an inadequate understanding of price theory. That is not to deny all of his results. He observed correctly that fishing to extinction does not necessarily entail the fishing down to the last specimen. Rather, fishing may push the population level down to the point where natural dynamic forces will irreversibly tend

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[52]Steven N. S. Cheung, "Contractual Arrangements and Resource Allocation in Marine Fisheries," in Economics of Fisheries Management: A Symposium Held at the University of British Columbia, March 24-25, 1969 ed. Anthony D. Scott (Vancouver: University of British Columbia, 1970): 97-108.

[53]Clark, "Economics of Overexploitation," 632, 634.

to reduce the population to the final extinction.

Clark's next article, co-authored with Gordon Munro, an economist at the University of British Columbia, developed a full treatment of the fishery using optimal control theory.[54] This article made full use of the received theory: the Gordon-Schaefer logistic equation, and Scott's treatment of the fishery within the theory of capital. It also discussed briefly the development of the theory of capital through Arrow's application of optimal control theory.

They recognized that even though Scott and others had appropriately formulated the economics of the fishery in capital-theoretic terms, much of the work subsequent to Scott's 1955 article continued to be framed in a non-dynamic approach due to the inadequacy of capital theory as it then existed. But with the advent of optimal control theory, the economics of the fishery could more readily be stated in capital-theoretical terms.

Rather than to use the notion of wealth effect as normally found in capital theory, Clark and Munro discussed the stock effect which they saw as being analogous,

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[54]Clark, Colin W. and Gordon R. Munro, "The Economics of Fishing and Modern Capital Theory: A Simplified Approach," Journal of Environmental Economics and Management 2 (December 1975): 92-106.

and which naturally applied to the fish biomass.[55]

Clark and Munro also discussed the possibility of models which are non-linear both in terms of costs as a function of effort and of the demand for fish being perfectly elastic.[56] Their conclusion in this case was that

> once one relaxes the assumption that the demand for fish is perfectly elastic and relaxes the assumption that effort costs are linear in effort, one can no longer express the object of social utility maximization solely in terms of resource rent.... In effect, one now has to take into account consumers' surplus and producers' surplus as well. 57

Clark and Munro further showed that with these modified assumptions, it would be possible that no single equilibrium level of fishing activity would exist, frustrating the authorities who seek to regulate the fishery. They asserted that hopefully most of these other equilibria would be unstable, and hence could be disregarded by

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[55]Ibid., 96.

[56]Parzival Copes had treated this possibility earlier in his "The Backward-Bending Supply Curve of the Fishing Industry," Scottish Journal of Political Economy 17 (1970): 69-77. Later, Clark picked up on this, showing that in the Schaefer model, in the context of an open-access fishery, the supply curve is backward bending. Colin Clark, Mathematical Bioeconomics: The Optimal Management of Renewable Resources, 2d ed. (New York: Wiley-Interscience, 1990): 131f.

[57]Clark and Munro, 101.

the regulating authorities.[58]

Subsequent to the article that he co-authored with Munro, Clark endorsed the Gordon-Schaefer model as the central model of marine fisheries, although he continued to explore the ramifications of other models. His two books on marine fisheries, Bioeconomic Modelling[59] and Mathematical Bioeconomics both treat the Gordon-Schaefer model, as dynamically understood by Scott, as the central theory of fishery economics.

In these two books, Clark also demonstrated a thorough understanding of the implications for the neo-classical theory as it applies to marine fisheries. His understanding of the significance of price systems in particular was substantially more complete than he displayed in his earlier writings. Together with Lee Anderson's volume,[60] these two works comprise the current statement of the economics of marine fisheries.

Clark, as is the case of most contemporary fishery economists, held that governmental regulation of the

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[58]Ibid.

[59]Clark, Colin W., Bioeconomic Modelling and Fisheries Management (New York: John Wiley & Sons, 1985).

[60]Anderson, Lee G., The Economics of Fisheries Management, rev. ed. (Baltimore: Johns Hopkins Press, 1986).

fishery is essential to avoid biological depletion of the fishery. Clark, as do most present fisheries economists, used the notion of externalities to explain the resource misuse within the fishery.[61]

Specifically, he asserted that for most fisheries, excepting such fisheries as the ground fishery, creating of property rights would not provide adequate protection.[62] Consequently, he discussed a method of taxation as being a potential approach for limiting the level of fishing activity, as well as appropriating the rent to the community. But he recognized the political difficulties of implementing such.[63]

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[61]Clark stated that "[o]ne way of conceptualizing the problem of resource misuse employs the notion of externalities.... A related concept is that of common property. Competitive users of a common property resource fail to take into account the costs that their use may impose on other users. Consequently, the resource is often over-exploited." Colin Clark, Mathematical Bioeconomics, vi.

[62]Presently only a few fisheries economists hold out the creation of property rights as a means of protecting the fisheries. One such example is Steven Cheung. See, for example, Steven N. S. Cheung, "Contractual Arrangements and Resource Allocation in Marine Fisheries," 97-108, or his "The Structure of a Contract and the Theory of a Nonexclusive Resource," Journal of Law and Economics 13 (1970): 49-70.

[63]"[S]everal severe difficulties are associated with taxation in fisheries. Foremost, fishermen are always unanimously opposed to it. They would still receive zero rents, or at best intramarginal rents, and the marginal fishermen would be eliminated entirely. The economic

But he was in favor of a system of individually allocated, transferable catch quotas, where a specific number of permits are granted for a specific fishery. These permits may be transferred, hence allowing them to be used by parties who are the most efficient. And, over time, the state might retire some of the permits. He observed that

> [a] system of individually allocated, transferable catch quotas counteracts both problems of excess individual effort and excess entry. Entry is limited to quota holders, who can only increase their catch by purchasing extra quota rights from other owners at a market price. 64

It is in this modified sense that Clark advocated property rights, where there are a limited number of individuals who have fishing rights for specific fisheries. Such an approach eliminates the current problem of excess capital being applied and excess labor being used.[65] It also encourages the introduction of appropriate technology, unlike some fisheries which are regulated throught the

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rents, now optimized, would accrue to the taxation authority." Clark, Mathematical Bioeconomics, 255. He also recognized the problem with international fisheries, where no governmental authority exists to assess and enforce the tax policy.

[64]Clark, Mathematical Bioeconomics, 259.

[65]He recognized that the social marginal cost of otherwise unemployed persons is zero. Hence a case might be made that, given the geographical and vocational immobility of the typical fisherman, underexploitation of the fisheries occurs, since the firm's cost, wages to the employee, exceeds the socially optimal cost. Clark, Mathematical Bioeconomics, 77.

means of requiring antiquated capital, hence increasing costs, as an approach to limiting the catch.[66]

Clark did discuss several extensions of the Gordon-Schaefer model, such as considering the interaction of different species of fish within a certain location. He observed that

> [i]n the single species Gordon-Schaefer model extinction cannot occur, because as x --> 0, the unit harvesting cost eventually exceeds the price. The present analysis shows that when two populations are exploited jointly, one population may be driven to extinction, whereas the other population continues to support the fishery in bionomic (one-species) equilibrium. 67

Clark also considered models with delayed fertility, such as the whale, and depensation, where the biological forces would cause an irreversible population decline to the point of extinction even though the harvest had not reduced the population to zero.

But the Gordon-Schaefer model, to which capital theory has been applied remains the central model of fishery economics.

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[66]Ibid., 264.

[67]Clark, Mathematical Bioeconomics, 313.

CONCLUDING OBSERVATIONS

Although the impetus for the economics of marine fisheries had come initially from biologists, who recognized that the biological dimension to regulating marine fisheries was not sufficient, and from the Canadian government, which was concerned about the persistently low incomes among fishermen, economists, once attracted to the topic, developed a sophisticated theory.

The development of the theory followed its own internal logic, even though the interest in the topic initially was driven by external factors, such as biologists looking for a more complete understanding of the demand for fish, or the government seeking to improve the welfare of a group of its citizens. Several steps to developing the completed theory were necessary.

In 1954, Scott Gordon combined the biologist's model with the neoclassical insights of economics. True, he had taken a dynamic fisheries model, considered the optimal level of production as a function of the fish population, and treated that point as a static component within his static model. Nevertheless, Gordon made significant contributions to the theory. He was the first to combine biological and economic insights into a single theory. And he was the first to recognize the common-property nature of the fishery as being fundamental to the problem of over-fishing. So he was the first economist who saw the need to limit fishing activity for the sake of the long-term viability of the fishery.

Unlike the biologists who defined overfishing in terms of catching fish at a rate in excess of the ability of that species to sustain its population level, Gordon saw two dimensions to overfishing: the biological dimension and the economic dimension. Biological overfishing has to do with fishing at rates higher than the fish population is capable of replacing. Economic overfishing has to do with excess levels of labor or capital being devoted to the harvest. Gordon recognized that, unlike the then existing fishery regulators operated, both aspects had to be dealt with.

The initial work of Gordon started within the neoclassical approach. Gordon, while recognizing the dynamic nature of the fish population, used a static approach. He assumed that the population would be held at equilibrium at the optimal rate of harvest. So he could determine the economic optimal harvest rate and assume that this would remain at that level. Those that built on the initial Gordon model continued in this neoclassical vein.

The biologist Milner Schaefer combined Gordon's economic insights with the biological model as it then existed to devise the standard Gordon-Schaefer model which was to become the foundation for all subsequent work in the economics of marine fisheries.

In 1955, Anthony Scott, recognizing the weakness of Gordon's static approach, restructured Gordon's model to make it dynamic. Unfortunately, the then existing mathematics were insufficient to incorporate Scott's insights into a workable model, that is, one which could be used by regulatory authorities to determine the optimal levels of catch with respect to both the biological and the economic dimensions.

Scott showed that the weakness of Gordon's model was that it was static rather than dynamic. Scott modified the approach, making it dynamic. Since Scott held that natural resources should be treated with capital theory, it was natural that the rate of consumption over time was treated as a dynamic problem. While Gordon recognized the superiority of Scott's approach over his own, he also recognized the practical problems in applying it.

Scott's other main contribution to marine fisheries was that he was the first to treat the problem within capital theory. Together with Ciracy Wantrup, Scott had pioneered the application of capital theory to natural resources. His dissertation at the London School of Economics treated natural resources in general as a form of capital. Thus rates of consumption of resources or substitution of physical capital for natural capital could be treated within a general capital theory. Very soon after the publication of his dissertation he applied this insight to the economics of the fishery.

Scott's shift to the dynamic approach continued within the neoclassical approach. He was merely using the theory of capital which considers changes that are necessary as time is introduced into the analysis. While his insight to treat the environment as a form of capital was novel, having made that insight, his application of economic theory to that insight was essentially off the shelf. Indeed, it was the lack of development within economic theory as it then existed that limited Scott's approach.

During the 1970's, Colin Clark, who was trained as a mathematician, attempted to apply a more sophisticated mathematical model to Scott's results. Clark's first contributions to marine fisheries were to apply the property of the compactness of Banach spaces to sequences of fish populations over time. True, he was able to show the existence of optimal levels of fishing effort, as a mathematical insight into the problem. But his approach was mathematically too sophisticated for most readers. And his approach gave no guidance for a governmental regulator to determine the optimal level of harvest.

It was not until nearly fifteen years later than Scott's initial work that, as optimal control theory was being introduced to problems in capital theory, C. G. Plourde and James P. Quirk and Vernon L. Smith applied it to marine fisheries. So shortly after Kenneth Arrow had begun the application of optimal control theory to capital theory, control theory was applied to the economics of fishing.

So Gordon's combination of biological equilibrium and economic equilibrium was preserved within the fully developed theory. Scott's treatment of natural resources as a form of capital was preserved. So once there were advances in the basic capital theory, it became possible to continue to build the theory of marine fishery.

Many of the important contributions after the work of Scott to the economics of the fishery came from teams of scholars rather than from individuals. For example, James Crutchfield had applied the static model of Gordon to several fisheries.[1] But is was the article which he had

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[1]See, for example, James A. Crutchfield, "Common-Property Resources and Factor Allocation," The Canadian Journal of Economics and Political Science 22 (August 1956): 292-300, his "Conservation and Allocation in the Pacific Coast Fisheries," Proceedings of the Western Economics Association (1955): 69-72, his "Economic Value of Washington State Fisheries, 1955" Pacific Northwest Business (July 1957): 5-15, or his "The Economics of Salmon Management," Tenth Alaska Science Conference 71

collaborated with Arnold Zellner[2] which introduced the dynamic approach, which was more consistent with Scott's development. Apparently, Zellner, who elsewhere had demonstrated more mathematical rigor,[3] combined his mathematical skills with Crutchfield's more thorough understanding of the economics of the fishery. Without this improved mathematical technique, theoretical advancement would not have been possible.

Likewise, Vernon L. Smith had written a couple of articles which were consistent with Scott's approach.[4] But the article which he co-authored with James Quirk[5]

(1959).

[2]James A. Crutchfield and Arnold Zellner, "Economic Aspects of the Pacific Halibut Fishery," Fishery Industrial Research vol I #1, (Washington: US Department of the Interior, 1962): 1-173.

[3]See, for example, Arnold Zellner, "Application of Mathematical Programming Techniques to Commercial Fishery Conservation Problems," in Economic Effects of Fishery Regulation, ed. Robert Hamlisch (Expert Meeting on the Economic Effects of Fishery Regulation), 515-34. (Rome: Food and Agricultural Organization of the United Nations Fisheries Report #5, 1962).

[4]See, for example, Vernon L. Smith, "Economic of Production from Natural Resources," American Economic Review 58 (June 1968): 409-31, or his "On Models of Commercial Fishing," Journal of Political Economy 77 (April 1969): 181-98.

[5]James P. Quirk and Vernon L. Smith, "Dynamic Economic Models of Fishing," in Economics of Fisheries Management: A Symposium, ed. Anthony D. Scott, (Vancouver: University of British Columbia, Institute of Animal Resource Ecology, 1970): 3-32.

was where optimal control theory was introduced into the economic theory of the fishery. That article showed significant mathematical sophistication over the earlier articles by Smith, which suggests that Quirk was responsible for the mathematical insights and Smith the economic understanding.

Another debate among economists emerged within the economics of marine fisheries: the extent to which market failures exist within the economy. A few writers had held that despite the common-property nature of the fishery, property rights could theoretically be created to resolve the problem. Most of the contributors, however, held that property rights could not be adequately established. Taxation of fisheries to extract economic rent would be appropriate to determine the level of fishing activity.

Unlike most of those who built upon Gordon's foundation, Gordon did not emphasize market failure, even though he had introduced the common-property aspect to the analysis of the fisheries. He held that redefining property rights would resolve the issue of economic overfishing.

But, starting with Scott, the philosophical predisposition was towards governmental solutions through taxing and regulating economic activity rather than through redefining property rights. And, indeed, the application of optimal control theory presupposes that some central authority needs to regulate the fishery to obtain the optimal level of harvest. So mostly the "Chicago" approach[6] of restructuring the property rights of fishing firms has been ignored in favor of governmental control.

Ironically, the debate among the economists as how to achieve the optimal catch, either through redefined property rights or through regulation and taxation of existing fisheries has been ignored. Regulatory authorities generally have continued to optimize the catch in biological terms without taking economic aspects into consideration.[7] For example, the allowable 1991 Pacific halibut

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[6]Steven N. S. Cheung was among the very few who took this approach. He was consciously following the lead of Ronald Coase in suggesting ways that property rights could be applied to the fisheries. Steven N. S. Cheung, "Contractual Arrangements and Resource Allocation in Marine Fisheries," in Economics of Fisheries Management: A Symposium Held at the University of British Columbia, March 24-25, 1969, ed. Anthony D. Scott, (Vancouver: University of British Columbia, 1970): 97-108, or his "The Structure of a Contract and the Theory of a Nonexclusive Resource," Journal of Law and Economics 13 (1) (1970): 49-70.

[7]Judge W. C. Arnold suggested that the US Fish and Wildlife Service lacked the authority to limit entry into the fishery. Also, he asserted that there is a reluctance on the part of the public to create property rights benefiting a few at the expense of others. Consequently, the approach of regulatory agencies has been on gear restrictions, boat size, and closed seasons. W. C. Arnold, "Financial Problems of the Alaska Salmon Industry," in Biological and Economic Aspects of Fisheries Management, ed. James A. Crutchfield (Seattle: University of Washington Press, 1959): 97.

catch was caught in a single day by 6000 boats.[8] Much of this capital is halibut specific. So the argument that, in the absence of better-defined property rights or regulation that takes economic considerations into account, economic overfishing will occur has been ignored at least by the International Fishing Commission. A similar observation might also be made for the Pacific salmon industry.

Nor are the international bodies able to limit the catch in other fisheries. Countries which are not signatory to existing treaties have no reason to abide by treaties which cut them out of profitable fisheries. And so, Russian or Korean fishing boats continue to ravish the oceans, mining the fish without regard to future catches. While the International Whaling Commission has been able to prevent harvests for a period to allow the various whale populations to recover, now that some species have begun to recover, the rush to harvest these species has started. Some countries are wishing to withdraw from the treaty to benefit from this renewed resource.

Thus, for many of the marine fisheries, the effect of the economics of marine fisheries has been nugatory. Nei-

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[8]Michael Satchell, "The Rape of the Oceans," U. S. News and World Report 22 June 1992, 75.

ther the property rights approach nor the central planning approach has been allowed to provide optimal usage of labor or capital. Like many governmental regulatory agencies, the input into regulatory procedures has been sought from the industry. The industry is not going to suggest methods which cut some individuals out of the catch at the benefit of other individuals.

Part of the blame for the lack of application of the theory is due to a shift that has occurred with the development of the theory, a shift that has occurred in many academic disciplines. The early writers in the economics of the fishery were immanently practical. The focus of the work of Gordon, Schaefer, Crutchfield, and Scott was to have a theory that can be used by regulatory agencies to lower the cost of fishing while maintaining a sustainable catch.

But starting with the more abstract, theoretical work of Clark, the focus shifted to theoretical possibilities. While Clark significantly developed his understanding of the economics of the fishery, he was still trained as a mathematician. Thus, his approach was to consider each theoretical possibility, to devise a theory capable of handling various conceivable contingencies rather than to solve a specific problem. True, there were substantial gaps in the work of Gordon or of Scott which needed addressing. But Clark was not focused on giving regulators and administrators something that they could use.

Likewise, the application of control theory to the fishery is mathematically much more rigorous and elegant than earlier approaches. But it, too, is extremely hard to apply to practical situations. Perhaps, if the theoreticians in the economics of the fishery were to regain the focus of problem solving in the practical area, then their work would influence regulators. Then the economic over-fishing that still exists could be reduced.

BIBLIOGRAPHY

BIBLIOGRAPHY

Ackerman, Edward A. New England's Fishing Industry. Chicago: University of Chicago Press, 1941.

Andersen, Peder. "On Rent of Fishing Grounds: A Translation of Jens Warming's 1911 Article, with an Introduction." History of Political Economy 15 (Fall 1983): 391-96.

Anderson, Lee G. The Economics of Fisheries Management, rev. ed. Baltimore: Johns Hopkins Press, 1986.

Arnold, W. C. "Financial Problems of the Alaska Salmon Industry." In Biological and Economic Aspects of Fisheries Management, ed. James A. Crutchfield, 96-97. Seattle: University of Washington Press, 1959.

Arrow, Kenneth. J. Application of Control Theory to Economic Growth. Stanford University: Institute for Mathematical Studies in the Social Sciences, July 14, 1967. Technical Report #2.

-----. "Optimal Capital Policy, the Cost of Capital, and Myopic Decision Rules." Annuals of the Institute of Statistical Mathematics 16 (1) (1964): 21-30.

-----. "Optimal Capital Policy with Irreversible Investment." In Value, Capital, and Growth: Papers in Honour of Sir John Hicks, ed. J. N. Wolfe, 1-20. Edinburgh: Edinburgh University Press, 1968.

Baranov, Feodor I. "On the Question of the Biological Basis of Fisheries." Reports from the Division of Fish Management and Scientific Study of the Fishing Industry (Moscow) 1 (1918): 81-128. trans. William E. Ricker. Bloomington: University of Indiana (mimeo), 1945.

-----. "On the Question of the Dynamics of the Fishing Industry." Bulletin of the Fisheries Administration (Moscow) 8 (Aug 1925): 7-11. trans. William E. Ricker. Bloomington: University of Indiana (mimeo), 1945.

Bellman, R. Dynamic Programming. Princeton: Princeton University Press, 1957.

Beverton, R. J. H. "Some Observations on the Principles of

Fishery Regulation." Journal du conseil (International Council for the Exploration of the Sea) 19 (May 1953): 56-68.

Beverton, R. J. H. and S. J. Holt. On the Dynamics of Exploited Fish Population. Fisheries Investigations, series 2, 19 London: Her Majesty's Stationary Office, 1957

Burkenroad, Martin D. "Some Principles of Marine Fishery Biology." Publications of the Institute of Marine Science, vol II #1, by the University of Texas, September 1951, 177-212.

Butlin, John. "Optimal Depletion of a Replenishable Resource: An Evaluation of Recent Contributions to Fisheries Economics." In The Economics of Natural Resource Depletion, ed. D. W. Pearce and J. Rose, 85-114. New York: John Wiley & Sons, 1975.

Cheung, Steven N. S. "Contractual Arrangements and Resource Allocation in Marine Fisheries." In Economics of Fisheries Management: A Symposium Held at the University of British Columbia, Mar 24-25, 1969, ed. Anthony D. Scott, 97-108. Vancouver: University of British Columbia, 1970.

-----. "The Structure of a Contract and the Theory of a Nonexclusive Resource." Journal of Law and Economics 13 (1) (1970): 49-70.

Ciriacy-Wantrup, Siegfried von. Resource Conservation--Economics and Politics, 3d ed. Berkeley: University of California Press, 1968.

Clark, Colin W. Bioeconomic Modelling and Fisheries Management. New York: John Wiley & Sons, 1985.

-----. "The Dynamics of Commercially Exploited Natural Animal Populations." Mathematical Biosciences 13 (February 1972): 149-64.

-----. "Economically Optimal Policies for the Utilization of Biologically Renewable Resources." Mathematical Biosciences 12 (December 1971): 245-60.

-----. "The Economics of Overexploitation." Science 181 (August 17, 1973): 630-34.

-----. Mathematical Bioeconomics: The Optimal Management of Renewable Resources, 2d ed. New York: Wiley-Interscience, 1990.

-----. "Profit Maximization and the Extinction of Animal Species." Journal of Political Economy 81 (August 1973): 950-60.

Clark, Colin W., Gordon Edwards, and Michael Friedlaender. "The Beverton-Holt Model of Commercial Fisheries: Optimal Dynamics." Journal of the Fisheries Research Board of Canada 30 (1973): 1629-40.

Clark, Colin W. and Gordon R. Munro. "The Economics of Fishing and Modern Capital Theory: A Simplified Approach." Journal of Environmental Economics and Management 2 (December 1975): 92-106.

Clark, Colin W., Gordon R. Munro, and Anthony T. Charles. "Fisheries, Dynamics, and Uncertainty." In Progress in Natural Resource Economics, ed. Anthony Scott, 99-129. New York: Oxford University Press, 1985.

Copes, Parzival. "The Backward-Bending Supply Curve of the Fishing Industry." Scottish Journal of Political Economy 17 (1970): 69-77.

Crutchfield, James A., ed. Biological and Economic Aspects of Fisheries Management. Seattle: University of Washington Press, 1959.

-----. "Common-Property Resources and Factor Allocation." The Canadian Journal of Economics and Political Science 22 (August 1956): 292-300.

-----. "Conservation and Allocation in the Pacific Coast Fisheries." Proceedings of the Western Economics Association 1955, 69-72.

-----. "An Economic Evaluation of Alternative Methods of Fishery Regulation." Journal of Law and Economics 4 (October 1961): 131-43.

-----. "Economic Value of Washington State Fisheries, 1955." Pacific Northwest Business (July 1957): 5-15.

-----. "The Economics of Salmon Management." Tenth Alaska Science Conference 71 (1959):

-----. The Fisheries: Problems in Resource Management. Seattle: University of Washington Press, 1965.

-----. "The Marine Fisheries: A Problem in International Cooperation." American Economic Review -- Proceedings 54 (May 1964): 207-18.

Crutchfield, James A. and Giulio Pontecorvo. The Pacific Salmon Fisheries: A Study of Irrational Conservation. Baltimore: Johns Hopkins Press, 1969.

Crutchfield, James A. and Arnold Zellner. "Economic Aspects of the Pacific Halibut Fishery." Fishery Industrial Research vol I, # 1. pp. 1-173. Washington: US Department of the Interior, 1962.

Dorfman, Robert. "An Economic Interpretation of Optimal Control Theory." American Economic Review 59 (December 1969): 817-31.

Eatwell, John, Murray Millgate, and Peter Newman, eds. The New Palgrave: A Dictionary of Economics. New York: Stockton Press, 1987. S.v. "User Cost," by Paul Davidson.

Garstang, Walter. "The Impoverishment of the Sea." Journal of the Marine Biological Association, n.s. 6 (1900): 1-69.

Gerhardsen, G. M. "Production Economics in Fisheries." Revista de Economia (Lisbon) 5 (March 1952): 1-12

Gordon, H. Scott. "An Economic Approach to the Optimum Utilization of Fishery Resources." Journal of the Fisheries Research Board of Canada 10 (September 1953): 442-57.

-----. "The Economic Theory of a Common Property Resource: The Fishery." Journal of Political Economy 62 (April 1954): 124-42.

-----. "Economics and the Conservation Question." Journal of Law and Economics 1 (October 1958): 110-21.

-----. "Obstacles to Agreement on Control in the Fishing Industry." In The Economics of Fisheries, ed. Ralph Turvey and Jack Wiseman, 65-72. Rome: FAO, 1957.

-----. "On a Misinterpretation of the Law of Diminishing

Returns in Marshall's Principles." Canadian Journal of Economics and Political Science 18 (February 1952): 96-98.

Graham, Michael. "Modern Theory of Exploiting a Fishery, an Application to North Sea Trawling." Journal du Conseil (International Council for the Exploration of the Sea) 10 (December 1935): 264-74.

-----. "Overfishing and Optimal Fishing." Rapports et Proces-Verbaux des Reunions (International Council for the Exploration of the Sea) 132 (1952): 72-78.

-----. "Rates of Fishing and Natural Mortality from the Data of Marking Experiments." Journal du Conseil (International Council for the Exploration of the Sea) 13 (April 1938): 76-90.

-----. "The Sigmoid Curve and the Overfishing Problem." Rapports et Proces-Verbaux des Reunions (International Council for the Exploration of the Sea) 110 (1939): 15-20.

Gregory, Homer E. and Kathleen Barnes. North Pacific Fisheries, with Special Reference to Alaska Salmon. New York: American Council of the Institute of Pacific Relations, 1939.

Hamlisch, Robert ed. Economic Effects of Fishery Regulation. Rome: F.A.O. Fisheries Report #5, 1962.

Hardin, Garrett. "The Tragedy of the Commons." Science 162 (December 13, 1968): 1234-48.

Herrington, William C. "Some Methods of Fisheries Management and Their Usefulness in a Management Program." Special Scientific Report #18, 3-22. U.S. Fish and Wildlife Service, 1943.

Hjort, Johan, Gunnar Jahn, and Per Ottestad. "The Optimum Catch." Hvalradets Skrifter (Oslo) 7 (1933): 92-127.

Hotelling, Harold. "The Economics of Exhaustible Resources." Journal of Political Economy 39 (April 1931): 137-175.

Huntsman, Archibald G. "Fishery Depletion." Science 99 (June 30, 1944): 534f.

Keynes, John Maynard. The General Theory of Employment, Interest, and Money. New York: Harcourt, Brace, and World, 1936.

Knight, Frank H. "Some Fallacies in the Interpretation of Social Cost." Quarterly Journal of Economics 38 (August 1924): 582-606.

Marshall, Alfred. Principles of Economics, 9th (Variorum) ed. London: Macmillan & Co, Ltd., 1961.

Nesbit, Robert A. "Biological and Economic Problems of Fishery Management." US Fish and Wildlife Service, 23-53, Special Scientific Report #18, 1943.

Petersen, C. G. Joh. "On the Decrease of Flat-Fish Fisheries." Beretning, Dansk Biologisk Station 4 (1893): 48-85.

-----. "What is Overfishing?" Journal of the Marine Biological Association, UK, n.s. 6 (1903): 587-94.

Pigou, A. C. The Economics of Welfare. London: Macmillan, 1918.

Plourde, C. G. "Exploitation of Common-Property Replenishable Resources." Western Economic Journal 9 (September 1971): 256-66.

-----. "A Simple Model of Replenishable Natural Resource Exploitation." American Economic Review 60 (June 1970): 518-22.

Pontryagin, Lev Semenovich, V. Boltyanskii, R. Gamkrelidze, and E. Mischenko. The Mathematical Theory of Optimal Processes. Translated by D. E. Brown. New York: Macmillan Co., 1964.

Quirk, James P. and Vernon L. Smith. "Dynamic Economic Models of Fishing." In Economics of Fisheries Management: A Symposium, ed. Anthony D. Scott, 3-32. Vancouver: University of British Columbia, Institute of Animal Resource Ecology, 1970.

Ricker, William E. "Relations of 'Catch per Unit Effort' to Abundance and Rate of Exploitation." Journal of the Fisheries Research Board of Canada 5 (1940): 43-70.

Russell, Edward S. "An Elementary Treatment of the Overfishing Problem." Rapports et Proces-Verbaux des Reunions (International Council for the Exploration of the Sea) 110 (1939): 6-14.

-----. The Overfishing Problem. London: Cambridge University Press, 1942.

-----. "Some Principles Involved in Regulation of Fisheries by Quota." Canadian Fish Culturist 22(May 1958): 1-6.

Satchell, Michael. "The Rape of the Oceans." U.S. News and World Report 22 June 1992, 75.

Schaefer, Milner B. "Biological and Economic Aspects of the Management of Marine Fisheries." Transactions of the American Fisheries Society 88 (April 1959): 100-04.

-----. "Fisheries Dynamics and the Concept of Maximum Equilibrium Catch." Proceedings of the Gulf and Caribbean Fisheries Institute, 6th Annual Session (1954): 53-64.

-----. "Some Aspects of the Dynamics of Populations Important to the Management of the Commercial Marine Fisheries." Bulletin of the Inter-American Tropical Tuna Commission 1 (1954): 25-56.

-----. "Some Considerations of Population Dynamics and Economics in Relation to the Management of Marine Fisheries." Journal of the Fisheries Research Board of Canada 14 (September 1957): 669-81.

Scott, Anthony D. "Conservation Policy and Capital Theory." Canadian Journal of Economics and Political Science. 20 (November 1954): 504-13.

-----. "Development of Economic Theory on Fisheries Regulation." Journal of the Fisheries Research Board of Canada 36 (July 1979): 725-41.

-----. Economics of Fisheries Management: A Symposium. Institute of Animal Resource Ecology. Vancouver: University of British Columbia, 1970.

-----. "The Economics of Regulating Fisheries." In Economic Effects of Fishery Regulation, ed. Robert Hamlisch. (Expert Meeting on the Economic Effects of Fishery Regulation), 23-96. Rome: Food and Agriculture

Organization of the United Nations, 1962.

-----. "The Fishery: The Objectives of Sole Ownership." Journal of Political Economy 63 (April 1955): 116-24.

-----. Natural Resources: The Economics of Conservation. Toronto: University of Toronto Press, 1955.

-----. "Notes on User Cost." Economic Journal 63 (June 1953): 368-84.

-----. "Optimal Utilization and the Control of Fisheries." In The Economics of the Fisheries, ed. Ralph Turvey and Jack Wiseman, 42-56. Rome: FAO, 1957.

Sette, O. E. "Studies on the Pacific Pilchard or Sardine." Special Scientific Report # 19 US Fishery and Wildlife Service, 1943.

Smith, Adam. The Wealth of Nations, ed. Edwin Canaan. New York: Random House, 1937.

Smith, Vernon L. "Economics of Production from Natural Resources." American Economic Review 58 (June 1968): 409-31.

-----. "On Models of Commercial Fishing." Journal of Political Economy 77 (April 1969): 181-98.

Taylor, Harden F. Survey of Marine Fisheries in North Carolina, with a Comprehensive View of the Economics of National and World Fisheries. Chapel Hill: University of North Carolina Press, 1951.

Thompson, William F. "Conservation of the Pacific Halibut." Annual Report Smithsonian Institution June 1935 (1936): 361-84.

-----. "Theory of the Effects of Fishing on the Stock of Halibut." Report of the International Fisheries Commission 12 (1937): 5-22.

Thompson, William F. and F. Heward Bell. "Biological Statistics of the Pacific Halibut Fishery, (2) Effect of Changes in Intensity upon Total Yield and Yield per Unit of Gear." Report of the International Fisheries Commission 8 (1934): 9-49.

Turvey, Ralph, and Jack Wiseman, ed. The Economics of

Fisheries. Rome: FAO, 1957.

White, Donald J. The New England Fishing Industry. Cambridge: Harvard University Press, 1954.

Zellner, Arnold. "Application of Mathematical Programming Techniques to Commercial Fishery Conservation Problems." In Economic Effects of Fishery Regulation, ed. Robert Hamlisch (Expert Meeting on the Economic Effects of Fishery Regulation), 515-34. Rome: Food and Agriculture Organization of the United Nations Fisheries Report #5, 1962.

APPENDIX

APPENDIX

COMMENTS ON RENT IN THE FISHERIES

Within economic theory, rent has been used to describe unearned surplus, usually arising from land. So David Ricardo, in his discussion of rent, referred to the superior output of land above the cost of capital and labor on that land. The rent then went to the owner of the land. When referring to agriculture, since most land ownership is well-defined, the rent accrues to a specific individual. The ability to get rent presupposes property rights. But with regards to marine fisheries, the ownership of the seas has not been established. So, as discussed in the dissertation, the lack of property rights leads to overfishing and the possible depletion of certain fish species.

But there is another concern with undefined ownership of the seas. The income of the fisherman is based upon his share of the harvest. Thus, the income of the fisherman would include his share of the rent, should any rent actually occur. If anything causes the dissipation of rent, the incomes of the fishermen suffers. So, at a given market price, any diminution of harvest would affect the income of the individual fisherman.

As fishermen move into a theretofore unfished region, the income from their harvest may exceed their labor and capital costs by a substantial amount. This unearned income would attract additional fishing effort. In the absence of property rights, there is no way to prevent others from coming into that fishery in order to capture some of that unearned income for themselves. Just as is the case for economic profits under a competitively structured industry, the existence of rents in a fishery attracts additional firms into that fishery until the rent is depleted.

However, given the price of the fish being determined by demand as well as supply, the price may well exceed the cost to fish as stated in terms of labor costs, return on capital and a normal profit. That is, it may be economically feasible to fish a region above the biological optimal level. Once capital is attracted to the fishery, it is difficult for it to be shifted elsewhere. And so, excess capacity would remain in that fishery.

For most fishermen, their "wages" are not a set hourly amount, but "shares" in the catch. As long as these shares exceed the opportunity cost of their fishing, they would continue to fish. But, given the location of the fishing villages from which many come, isolated both geographically and occupationally from other sources of income, the opportunity cost is often minimal. Thus, the necessary incomes for these fishermen are more determined by subsistence than by opportunity cost. Thus, as long as their expected share exceeds subsistence income levels, they would continue to fish.

When land is owned, the owners will obtain their rental incomes as long as they control the resource and as long as there is a sufficient demand for the produce marketed by the tenants. But with unowned resources, such as fisheries, the lack of property rights means that others are free to seek their share of unearned income.

With wages being determined by subsistence rather than opportunity cost and with the hope of capturing as much rent as possible, it is more than likely that the fishing effort would exceed the biological capacity of that fishery, leading to biological as well as economic overfishing. The issue of the tragedy of the commons is that in the absence of property rights, the attempt to capture this unearned income leads to the exhaustion of any rent, so no one has any. Thus the possibility of rent is tied to property rights.

Hence, it is necessary to establish some way to limit access to the fisheries. This explains the paradox that Scott Gordon initially faced: why is it that, in spite of the bounty of the oceans, fishermen characteristically had low incomes. His analysis of the common-property nature of the fisheries provided the correct basis for an explanation. All subsequent contributors to the economics of marine fisheries have come to see this common-property characteristic as being fundamental to the problem.

But the methods used to prevent overfishing, both in the biological and economic sense, necessarily coincide with the question of how to divide the economic rent. Gordon held that by restricting fishing effort, rent would be captured by those having access to the fisheries. Hence, with a restricted access, there is greater incentive to limit fishing effort and the incomes of those having access would be greater, since there would be rent available as well as subsistence income. Unlike the case with land based resources, there has been a reluctance to define property rights in fisheries which would enrich one at the expense of denying others access to the fishery. Hence, although Steven Cheung[1] and others have recognized that the establishment of property rights to fisheries would generate a market solution to overfishing, the implicit denial to others of the rent from the fishery has made courts and the legislators reluctant to define property rights, even if it were

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[1]Steven N. S. Cheung, "Contractual Arrangements and Resource Allocation in Marine Fisheries," in <u>The Economics of Natural Resource Depletion</u>, ed. D. W. Pearce and J. Rose (New York: John Wiley & Sons, 1975).

possible.[2]

Since it is infeasible to define property rights in most of the marine fisheries, together with the concern regarding enriching some with the rent from the fisheries at the expense of others being denied access to that rent, most theorists have recommended some form of taxation.

Taxation would have two objectives. First, rather than rent going to only some individuals, taxation would mean that the rent, being captured by the tax, would be available to the community as a whole. And so there would be a more equitable distribution of the rent from the fishery. Second, taxes properly levied would diminish the incentive to fish so that the actual fishing effort would coincide with the ideal fishing effort defined in terms of maintaining the biologically optimal harvest over time. That is, the appropriate tax would eliminate economic overfishing. Stated differently, economic overfishing is due to the attempt to capture a portion of the rent. Where there is potential for gain through the claiming of unowned property, effort will be made to realize that gain. The problem with the fishery is precisely that the attempt to

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[2]See W. C. Arnold, "Financial Problems of the Alaska Salmon Industry," in Biological and Economic Aspects of Fisheries Management, ed. James A. Crutchfield (Seattle: University of Washington Press, 1959).

capture that gain has the potential to destroy the long-run viability of that gain.

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