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THE ECONOMIC THEORY OF A COMMON-PROPERTY RESOURCE: THE FISHERY[1]

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I. INTRODUCTION

The chief aim of this paper is to examine the economic theory of natural resource utilization as it pertains to the fishing industry. It will appear, I hope, that most 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. Fishery resources are unusual in the fact of their common-property nature; but they are not unique, and similar problems are encountered in other cases of common-property resource industries, such as petroleum production, hunting and trapping, etc. Although the theory presented in the following pages 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 individualistic competition.

II. BIOLOGICAL FACTORS AND THEORIES

The great bulk of the research that has been done on the primary production phase of the fishing industry has so far been in the field of biology. Owing to the lack of theoretical economic research,[2] biologists have been forced to extend the scope of their own thought into the economic sphere and in some cases have penetrated quite deeply, despite the lack of the analytical tools of economic theory.[3] Many others, who have paid no specific attention to the economic aspects of the problem have nevertheless recognized that the ultimate question is not the ecology of life in the sea as such, but man's use of these resources for his own (economic) purposes. Dr. Martin D. Burkenroad, for example, began a recent article on fishery management with a section on "Fishery Management as Political Economy," saying that "the Management of fisheries is intended for the benefit of man, not fish; therefore effect of management upon fishstocks cannot be regarded as beneficial *per se*."[4] The

[1] I want to express my indebtedness to the Canadian Department of Fisheries for assistance and co-operation in making this study; also to Professor M. C. Urquhart, of Queen's University, Kingston, Ontario, for mathematical assistance with the last section of the paper and to the Economists' Summer Study Group at Queen's for affording opportunity for research and discussion.

[2] The single exception that I know is G. M. Gerhardsen, "Production Economics in Fisheries," *Revista de economia* (Lisbon), March, 1952.

[3] Especially remarkable efforts in this sense are Robert A. Nesbit, "Fishery Management" ("U.S. Fish and Wildlife Service, Special Scientific Reports," No. 18 [Chicago, 1943]) (mimeographed), and Harden F. Taylor, *Survey of Marine Fisheries of North Carolina* (Chapel Hill, 1951); also R. J. H. Beverton, "Some Observations on the Principles of Fishery Regulation," *Journal du conseil permanent international pour l'exploration de la mer* (Copenhagen), Vol. XIX, No. 1 (May, 1953); and M. D. Burkenroad, "Some Principles of Marine Fishery Biology," *Publications of the Institute of Marine Science* (University of Texas), Vol. II, No. 1 (September, 1951).

[4] "Theory and Practice of Marine Fishery Management," *Journal du conseil permanent international pour l'exploration de la mer*, Vol. XVIII, No. 3 (January, 1953).

great Russian marine biology theorist, T. I. Baranoff, referred to his work as "bionomics" or "bio-economics," although he made little explicit reference to economic factors.[5] In the same way, A. G. Huntsman, reporting in 1944 on the work of the Fisheries Research Board of Canada, defined the problem of fisheries depletion in economic terms: "Where the take in proportion to the effort fails to yield a satisfactory living to the fisherman";[6] and a later paper by the same author contains, as an incidental statement, the essence of the economic optimum solution without, apparently, any recognition of its significance.[7] Upon the occasion of its fiftieth anniversary in 1952, the International Council for the Exploration of the Sea published a *Rapport Jubilaire*, consisting of a series of papers summarizing progress in various fields of fisheries research. The paper by Michael Graham on "Overfishing and Optimum Fishing," by its emphatic recognition of the economic criterion, would lead one to think that the economic aspects of the question had been extensively examined during the last half-century. But such is not the case. Virtually no specific research into the economics of fishery resource utilization has been undertaken. The present state of knowledge is that a great deal is known about the biology of the various commercial species but little about the economic characteristics of the fishing industry.

The most vivid thread that runs through the biological literature is the effort to determine the effect of fishing on the stock of fish in the sea. This discussion has had a very distinct practical orientation, being part of the effort to design regulative policies of a "conservation" nature. To the layman the problem appears to be dominated by a few facts of overriding importance. The first of these is the prodigious reproductive potential of most fish species. The adult female cod, for example, lays millions of eggs at each spawn. The egg that hatches and ultimately reaches maturity is the great exception rather than the rule. The various herrings (Clupeidae) are the most plentiful of the commercial species, accounting for close to half the world's total catch, as well as providing food for many other sea species. Yet herring are among the smallest spawners, laying a mere hundred thousand eggs a season, which, themselves, are eaten in large quantity by other species. Even in inclosed waters the survival and reproductive powers of fish appear to be very great. In 1939 the Fisheries Research Board of Canada deliberately tried to kill all the fish in one small lake by poisoning the water. Two years later more than ninety thousand fish were found in the lake, including only about six hundred old enough to have escaped the poisoning.

The picture one gets of life in the sea is one of constant predation of one species on another, each species living on a narrow margin of food supply. It reminds the economist of the Malthusian law of population; for, unlike man, the

[5] Two of Baranoff's most important papers—"On the Question of the Biological Basis of Fisheries" (1918) and "On the Question of the Dynamics of the Fishing Industry" (1925)—have been translated by W. E. Ricker, now of the Fisheries Research Board of Canada (Nanaimo, B.C.), and issued in mimeographed form.

[6] "Fishery Depletion," *Science*, XCIX (1944), 534.

[7] "The highest take is not necessarily the best. The take should be increased only as long as the extra cost is offset by the added revenue from sales" (A. G. Huntsman, "Research on Use and Increase of Fish Stocks," *Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources* [Lake Success, 1949]).

fish has no power to alter the conditions of his environment and consequently cannot progress. In fact, Malthus and his law are frequently mentioned in the biological literature. One's first reaction is to declare that environmental factors are so much more important than commercial fishing that man has no effect on the population of the sea at all. One of the continuing investigations made by fisheries biologists is the determination of the age distribution of catches. This is possible because fish continue to grow in size with age, and seasonal changes are reflected in certain hard parts of their bodies in much the same manner as one finds growth-rings in a tree. The study of these age distributions shows that commercial catches are heavily affected by good and bad brood years. A good brood year, one favorable to the hatching of eggs and the survival of fry, has its effect on future catches, and one can discern the dominating importance of that brood year in the commercial catches of succeeding years.[8] Large broods, however, do not appear to depend on large numbers of adult spawners, and this lends support to the belief that the fish population is entirely unaffected by the activity of man.

There is, however, important evidence to the contrary. World Wars I and II, during which fishing was sharply curtailed in European waters, were followed by indications of a significant growth in fish populations. Fish-marking experiments, of which there have been a great number, indicate that fishing is a major cause of fish mortality in developed fisheries. The introduction of restrictive laws has often been followed by an increase in fish populations, although the evidence on this point is capable of other interpretations which will be noted later.

General opinion among fisheries biologists appears to have had something of a cyclical pattern. During the latter part of the last century, the Scottish fisheries biologist, W. C. MacIntosh,[9] and the great Darwinian, T. H. Huxley, argued strongly against all restrictive measures on the basis of the inexhaustible nature of the fishery resources of the sea. As Huxley put it in 1883: "The cod fishery, the herring fishery, the pilchard fishery, the mackerel fishery, and probably all the great sea fisheries, are inexhaustible: that is to say that nothing we do seriously affects the number of fish. And any attempt to regulate these fisheries seems consequently, from the nature of the case, to be useless."[10] As a matter of fact, there was at this time relatively little restriction of fishing in European waters. Following the Royal Commission of 1866, England had repealed a host of restrictive laws. The development of steam-powered trawling in the 1880's, which enormously increased man's predatory capacity, and the marked improvement of the trawl method in 1923 turned the pendulum, and throughout the interwar years discussion centered on the problem of "overfishing" and "depletion." This was accompanied by a considerable growth of restrictive regula-

[8] One example of a very general phenomenon: 1904 was such a successful brood year for Norwegian herrings that the 1904 year class continued to outweigh all others in importance in the catch from 1907 through to 1919. The 1904 class was some thirty times as numerous as other year classes during the period (Johan Hjort, "Fluctuations in the Great Fisheries of Northern Europe," *Rapports et procès-verbaux, Conseil permanent international pour l'exploration de la mer*, Vol. XX [1914]; see also E. S. Russell, *The Overfishing Problem* [Cambridge, 1942], p. 57).

[9] See his *Resources of the Sea* published in 1899.

[10] Quoted in M. Graham, *The Fish Gate* (London, 1943), p. 111; see also T. H. Huxley, "The Herring," *Nature* (London), 1881.

tions.[11] Only recently has the pendulum begun to reverse again, and there has lately been expressed in biological quarters a high degree of skepticism concerning the efficacy of restrictive measures, and the Huxleyian faith in the inexhaustibility of the sea has once again begun to find advocates. In 1951 Dr. Harden F. Taylor summarized the overall position of world fisheries in the following words:

> Such statistics of world fisheries as are available suggest that while particular species have fluctuated in abundance, the *yield of the sea fisheries as a whole or of any considerable region has not only been sustained, but has generally increased with increasing human populations*, and there is as yet no sign that they will not continue to do so. No single species so far as we know has ever become extinct, and no regional fishery in the world has ever been exhausted.[12]

In formulating governmental policy, biologists appear to have had a hard struggle (not always successful) to avoid oversimplification of the problem. One of the crudest arguments to have had some support is known as the "propagation theory," associated with the name of the English biologist, E. W. L. Holt.[13] Holt advanced the proposition that legal size limits should be established at a level that would permit every individual of the species in question to spawn at least once. This suggestion was effectively demolished by the age-distribution studies whose results have been noted above. Moreover, some fisheries, such as the "sardine" fishery of the Canadian Atlantic Coast, are specifically for *immature* fish. The history of this particular fishery shows no evidence whatever that the landings have been in any degree reduced by the practice of taking very large quantities of fish of prespawning age year after year.

The state of uncertainty in biological quarters around the turn of the century is perhaps indicated by the fact that Holt's propagation theory was advanced concurrently with its diametric opposite: "the thinning theory" of the Danish biologist, C. G. J. Petersen.[14] The latter argued that the fish may be too plentiful for the available food and that thinning out the young by fishing would enable the remainder to grow more rapidly. Petersen supported his theory with the results of transplanting experiments which showed that the fish transplanted to a new habitat frequently grew much more rapidly than before. But this is equivalent to arguing that the reason why rabbits multiplied so rapidly when introduced to Australia is because there were no rabbits already there with which they had to compete for food. Such an explanation would neglect all the other elements of importance in a natural ecology. In point of fact, in so far as food alone is concerned, thinning a cod population, say by half, would not double the food supply of the remaining individuals; for there are other species, perhaps not commercially valuable, that use the same food as the cod.

Dr. Burkenroad's comment, quoted earlier, that the purpose of practical policy is the benefit of man, not fish, was not gratuitous, for the argument has at times been advanced that commercial fishing should crop the resource in such a way as to leave the stocks of fish in the sea completely unchanged. Baranoff was largely responsible for destroying this

[11] See H. Scott Gordon, "The Trawler Question in the United Kingdom and Canada," *Dalhousie Review*, summer, 1951.

[12] Taylor, *op. cit.*, p. 314 (Dr. Taylor's italics).

[13] See E. W. L. Holt, "An Examination of the Grimsby Trawl Fishery," *Journal of the Marine Biological Association* (Plymouth), 1895.

[14] See C. G. J. Petersen, "What Is Overfishing?" *Journal of the Marine Biological Association* (Plymouth), 1900–1903.

approach, showing most elegantly that a commercial fishery cannot fail to diminish the fish stock. His general conclusion is worth quoting, for it states clearly not only his own position but the error of earlier thinking:

> As we see, a picture is obtained which diverges radically from the hypothesis which has been favoured almost down to the present time, namely that the natural reserve of fish is an inviolable capital, of which the fishing industry must use only the interest, not touching the capital at all. Our theory says, on the contrary, that a fishery and a natural reserve of fish are incompatible, and that the exploitable stock of fish is a changeable quantity, which depends on the intensity of the fishery. The more fish we take from a body of water, the smaller is the basic stock remaining in it; and the less fish we take, the greater is the basic stock, approximating to the natural stock when the fishery approaches zero. Such is the nature of the matter.[15]

The general conception of a fisheries ecology would appear to make such a conclusion inevitable. If a species were in ecological equilibrium before the commencement of commercial fishing, man's intrusion would have the same effect as any other predator; and that can only mean that the species population would reach a new equilibrium at a lower level of abundance, the divergence of the new equilibrium from the old depending on the degree of man's predatory effort and effectiveness.

The term "fisheries management" has been much in vogue in recent years, being taken to express a more subtle approach to the fisheries problem than the older terms "depletion" and "conservation." Briefly, it focuses attention on the quantity of fish caught, taking as the human objective of commercial fishing the derivation of the largest sustainable catch. This approach is often hailed in the biological literature as the "new theory" or the "modern formulation" of the fisheries problem.[16] Its limitations, however, are very serious, and, indeed, the new approach comes very little closer to treating the fisheries problem as one of human utilization of natural resources than did the older, more primitive, theories. Focusing 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 references 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. On the whole, biologists tend to treat the fisherman as an exogenous element in their analytical model, and the behavior of fishermen is not made into an integrated element of a general and systematic "bionomic" theory. In the case of the fishing industry the large numbers of fishermen permit valid behavioristic generalization of their activities along the lines of the standard economic theory of production. The following section attempts to apply that theory to the fishing industry and to demonstrate that the "overfishing problem" has its roots in the economic organization of the industry.

III. ECONOMIC THEORY OF THE FISHERY

In the analysis which follows, the theory of optimum utilization of fishery re-

[15] T. I. Baranoff, "On the Question of the Dynamics of the Fishing Industry," p. 5 (mimeographed).

[16] See, e.g., R. E. Foerster, "Prospects for Managing Our Fisheries," *Bulletin of the Bingham Oceanographic Collection* (New Haven), May, 1948; E. S. Russell, "Some Theoretical Considerations on the Overfishing Problem," *Journal du conseil permanent international pour l'exploration de la mer*, 1931, and *The Overfishing Problem*, Lecture IV.

sources and the reasons for its frustration in practice are developed for a typical demersal fish. Demersal, or bottom-dwelling fishes, such as cod, haddock, and similar species and the various flatfishes, are relatively nonmigratory in character. They live and feed on shallow continental shelves where the continual mixing of cold water maintains the availability of those nutrient salts which form the fundamental basis of marine-food chains. The various feeding grounds are separated by deep-water channels which constitute barriers to the movement of these species; and in some cases the fish of different banks can be differentiated morphologically, having varying numbers of vertebrae or some such distinguishing characteristic. The significance of this fact is that each fishing ground can be treated as unique, in the same sense as can a piece of land, possessing, at the very least, one characteristic not shared by any other piece: that is, location.

(Other species, such as herring, mackerel, and similar pelagic or surface dwellers, migrate over very large distances, and it is necessary to treat the resource of an entire geographic region as one. The conclusions arrived at below are applicable to such fisheries, but the method of analysis employed is not formally applicable. The same is true of species that migrate to and from fresh water and the lake fishes proper.)

We can define the optimum degree of utilization of any particular fishing ground as that which maximizes the net economic yield, the difference between total cost, on the one hand, and total receipts (or total value production), on the other.[17] Total cost and total production can each be expressed as a function of the degree of fishing intensity or, as the biologists put it, "fishing effort," so that a simple maximization solution is possible. Total cost will be a linear function of fishing effort, if we assume no fishing-induced effects on factor prices, which is reasonable for any particular regional fishery.

The production function—the relationship between fishing effort and total value produced—requires some special attention. If we were to follow the usual presentation of economic theory, we should argue that this function would be positive but, after a point, would rise at a diminishing rate because of the law of diminishing returns. This would not mean that the fish population has been reduced, for the law refers only to the *proportions* of factors to one another, and a fixed fish population, together with an increasing intensity of effort, would be assumed to show the typical sigmoid pattern of yield. However, in what follows it will be assumed that the law of diminishing returns in this pure sense is inoperative in the fishing industry. (The reasons will be advanced at a later point in this paper.) We shall assume that, as fishing effort expands, the catch of fish increases at a diminishing rate but that it does so because of the effect of catch upon the fish population.[18] So far as the argument of the next few pages is concerned, all that is formally necessary is to assume that, as fishing intensity increases, catch will grow at a diminishing rate. Whether this reflects the pure law of diminishing returns or the reduction

[17] Expressed in these terms, this appears to be the monopoly maximum, but it coincides with the social optimum under the conditions employed in the analysis, as will be indicated below.

[18] Throughout this paper the conception of fish population that is employed is one of *weight* rather than *numbers*. A good deal of the biological theory has been an effort to combine growth factors and numbers factors into weight sums. The following analysis will neglect the fact that, for some species, fish of different sizes bring different unit prices.

of population by fishing, or both, is of no particular importance. The point at issue will, however, take on more significance in Section IV and will be examined there.

Our analysis can be simplified if we retain the ordinary production function instead of converting it to cost curves, as is usually done in the theory of the firm. Let us further assume that the functional relationship between average production (production-per-unit-of-fishing-effort) and the quantity of fishing effort is uniformly linear. This does not distort the

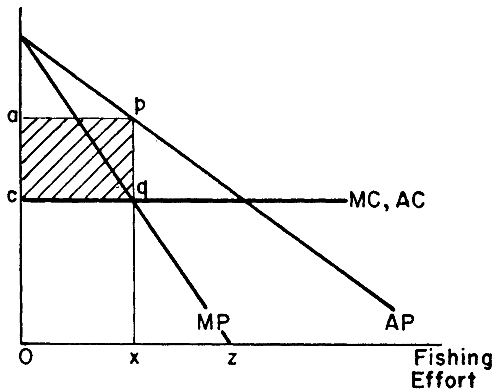

FIG. 1

results unduly, and it permits the analysis to be presented more simply and in graphic terms that are already quite familiar.

In Figure 1 the optimum intensity of utilization of a particular fishing ground is shown. The curves *AP* and *MP* represent, respectively, the average productivity and marginal productivity of fishing effort. The relationship between them is the same as that between average revenue and marginal revenue in imperfect competition theory, and *MP* bisects any horizontal between the ordinate and *AP*. 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, as shown by the curve *MC, AC*.[19] These costs are assumed to include an opportunity income for the fishermen, the income that could be earned in other comparable employments. Then *Ox* is the optimum intensity of effort on this fishing ground, and the resource will, at this level of exploitation, provide the maximum net economic yield indicated by the shaded area *apqc*. The maximum sustained physical yield that the biologists speak of will be attained when marginal productivity of fishing effort is zero, at *Oz* of fishing intensity in the chart shown. Thus, as one might expect, the optimum economic fishing intensity is less than that which would produce the maximum sustained physical yield.

The area *apqc* in Figure 1 can be regarded as the rent yielded by the fishery resource. Under the given conditions, *Ox* is the best rate of exploitation for the fishing ground in question, and the rent reflects the productivity of that ground, not any artificial market limitation. The rent here corresponds to the extra productivity yielded in agriculture by soils of better quality or location than those on the margin of cultivation, which may produce an opportunity income but no more. In short, Figure 1 shows the determination of the intensive margin of utilization on an intramarginal fishing ground.

We now come to the point that is of greatest theoretical importance in understanding the primary production phase of the fishing industry and in distinguishing it from agriculture. In the sea fish-

[19] Throughout this analysis, fixed costs are neglected. The general conclusions reached would not be appreciably altered, I think, by their inclusion, though the presentation would be greatly complicated. Moreover, in the fishing industry the most substantial portion of fixed cost—wharves, harbors, etc.—is borne by government and does not enter into the cost calculations of the operators.

eries the natural resource is not private property; hence the rent it may yield is not capable of being appropriated by anyone. The individual fisherman has no legal title to a section of ocean bottom. Each fisherman is more or less free to fish wherever he pleases. The result is a pattern of competition among fishermen which culminates in the dissipation of the rent of the intramarginal grounds. This can be most clearly seen through an analysis of the relationship between the intensive margin and the extensive margin of resource exploitation in fisheries.

In Figure 2, two fishing grounds of different fertility (or location) are shown. Any given amount of fishing effort devoted to ground *2* will yield a smaller total (and therefore average) product than if devoted to *1*. The maximization problem is now a question of the allocation of fishing effort between grounds *1* and *2*. The optimum is, of course, where the marginal productivities are equal on both grounds. In Figure 2, fishing effort of Ox on *1* and Oy on *2* would maximize the total net yield of $Ox + Oy$ effort if marginal cost were equal to Oc. But if under such circumstances the individual fishermen are free to fish on whichever ground they please, it is clear that this is not an equilibrium allocation of fishing effort in the sense of connoting stability. A fisherman starting from port and deciding whether to go to ground *1* or *2* does not care for *marginal* productivity but for *average* productivity, for it is the latter that indicates where the greater total yield may be obtained. If fishing effort were allocated in the optimum fashion, as shown in Figure 2, with Ox on *1*, and Oy on *2*, this would be a disequilibrium situation. Each fisherman could expect to get an average catch of Oa on *1* but only Ob on *2*. Therefore, fishermen would shift from *2* to *1*. Stable equilibrium would not be reached until the average productivity of both grounds was equal. If we now imagine a continuous gradation of fishing grounds, the extensive margin would be on that ground which yielded nothing more than outlaid costs plus opportunity income—in short, the one on which average productivity and average cost were equal. But, since average cost is the same for all grounds and the average productivity of all grounds is also brought to equality by

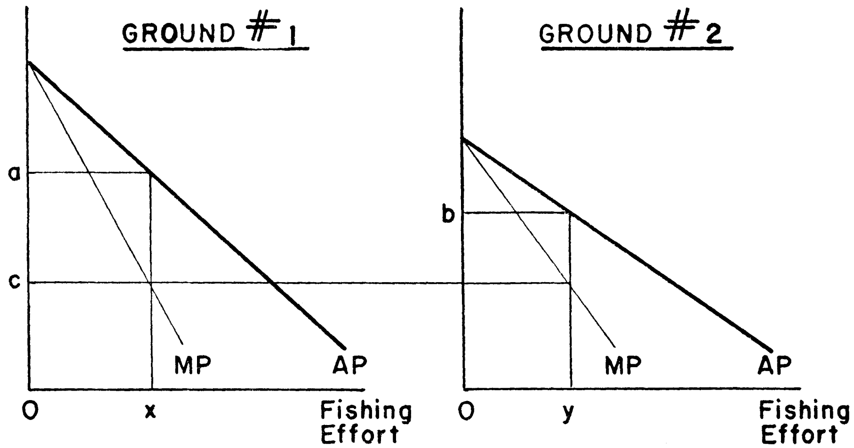

FIG. 2

the free and competitive nature of fishing, this means that the intramarginal grounds also yield no rent. It is entirely possible that some grounds would be exploited at a level of *negative* marginal productivity. What happens is that the rent which the intramarginal grounds are capable of yielding is dissipated through misallocation of fishing effort.

This is why fishermen are not wealthy, despite the fact that the fishery resources of the sea are the richest and most indestructible available to man. By and large, the only fisherman who becomes rich is one who makes a lucky catch or one who participates in a fishery that is put under a form of social control that turns the open resource into property rights.

Up to this point, the remuneration of fishermen has been accounted for as an opportunity-cost income comparable to earnings attainable in other industries. In point of fact, fishermen typically earn less than most others, even in much less hazardous occupations or in those requiring less skill. There is no effective reason why the competition among fishermen described above must stop at the point where opportunity incomes are yielded. It may be and is in many cases carried much further. Two factors prevent an equilibration of fishermen's incomes with those of other members of society. The first is the great immobility of fishermen. Living often in isolated communities, with little knowledge of conditions or opportunities elsewhere; educationally and often romantically tied to the sea; and lacking the savings necessary to provide a "stake," the fisherman is one of the least mobile of occupational groups. But, second, there is in the spirit of every fisherman the hope of the "lucky catch." As those who know fishermen well have often testified, they are gamblers and incurably optimistic. As a consequence, they will work for less than the going wage.[20]

The theory advanced above is substantiated by important developments in the fishing industry. For example, practically all control measures have, in the past, been designed by biologists, with sole attention paid to the production side of the problem and none to the cost side. The result has been a wide-open door for the frustration of the purposes of such measures. The Pacific halibut fishery, for example, is often hailed as a great achievement in modern fisheries management. Under international agreement between the United States and Canada, a fixed-catch limit was established during the early thirties. Since then, catch-per-unit-effort indexes, as usually interpreted, show a significant rise in the fish population. W. F. Thompson, the pioneer of the Pacific halibut management program, noted recently that "it has often been said that the halibut regulation presents the only definite case of sustained improvement of an overfished deep-sea fishery. This, I believe, is true and the fact should lend special importance to the principles which have been deliberately used to obtain this improvement."[21] Actually, careful study of the statistics indicates that the estimated recovery of halibut stocks could not have been due principally to the control measures, for the average catch was, in fact, greater during the recovery years than during the years of

[20] "The gambling instinct of the men makes many of them work for less remuneration than they would accept as a weekly wage, because there is always the possibility of a good catch and a financial windfall" (Graham, *op. cit.*, p. 86).

[21] W. F. Thompson, "Condition of Stocks of Halibut in the Pacific," *Journal du conseil permanent international pour l'exploration de la mer*, Vol. XVIII, No. 2 (August, 1952).

decline. The total amount of fish taken was only a small fraction of the estimated population reduction for the years prior to regulation.[22] Natural factors seem to be mainly responsible for the observed change in population, and the institution of control regulations almost a coincidence. Such coincidences are not uncommon in the history of fisheries policy, but they may be easily explained. If a long-term cyclical fluctuation is taking place in a commercially valuable species, controls will likely be instituted when fishing yields have fallen very low and the clamor of fishermen is great; but it is then, of course, that stocks are about due to recover in any case. The "success" of conservation measures may be due fully as much to the sociological foundations of public policy as to the policy's effect on the fish. Indeed, Burkenroad argues that biological statistics in general may be called into question on these grounds. Governments sponsor biological research when the catches are disappointing. If there are long-term cyclical fluctuations in fish populations, as some think, it is hardly to be wondered why biologists frequently discover that the sea is being depleted, only to change their collective opinion a decade or so later.

Quite aside from the *biological* argument on the Pacific halibut case, there is no clear-cut evidence that halibut fishermen were made relatively more prosperous by the control measures. Whether or not the recovery of the halibut stocks was due to natural factors or to the catch limit, the potential net yield this could have meant has been dissipated through a rise in fishing costs. Since the method of control was to halt fishing when the limit had been reached, this created a great incentive on the part of each fisherman to get the fish before his competitors. During the last twenty years, fishermen have invested in more, larger, and faster boats in a competitive race for fish. In 1933 the fishing season was more than six months long. In 1952 it took just twenty-six days to catch the legal limit in the area from Willapa Harbor to Cape Spencer, and sixty days in the Alaska region. What has been happening is a rise in the average cost of fishing effort, allowing no gap between average production and average cost to appear, and hence no rent.[23]

Essentially the same phenomenon is observable in the Canadian Atlantic Coast lobster-conservation program. The method of control here is by seasonal closure. The result has been a steady growth in the number of lobster traps set

[22] See M. D. Burkenroad, "Fluctuations in Abundance of Pacific Halibut," *Bulletin of the Bingham Oceanographic Collection*, May, 1948.

[23] The economic significance of the reduction in season length which followed upon the catch limitation imposed in the Pacific halibut fishery has not been fully appreciated. E.g., Michael Graham said in summary of the program in 1943: "The result has been that it now takes only five months to catch the quantity of halibut that formerly needed nine. This, *of course*, has meant profit, where there was none before" (*op. cit.*, p. 156; my italics). Yet, even when biologists have grasped the economic import of the halibut program and its results, they appear reluctant to declare against it. E.g., W. E. Ricker: "This method of regulation does not necessarily make for more profitable fishing and certainly puts no effective brake on waste of effort, since an unlimited number of boats is free to join the fleet and compete during the short period that fishing is open. However, the stock is protected, and yield approximates to a maximum if quotas are wisely set; as biologists, perhaps we are not required to think any further. Some claim that any mixing into the economics of the matter might prejudice the desirable biological consequences of regulation by quotas" ("Production and Utilization of Fish Population," in a Symposium on Dynamics of Production in Aquatic Populations, Ecological Society of America, *Ecological Monographs*, XVI [October, 1946], 385). What such "desirable biological consequences" might be, is hard to conceive. Since the regulatory policies are made by man, surely it is necessary they be evaluated in terms of human, not piscatorial, objectives.

by each fisherman. Virtually all available lobsters are now caught each year within the season, but at much greater cost in gear and supplies. At a fairly conservative estimate, the same quantity of lobsters could be caught with half the present number of traps. In a few places the fishermen have banded together into a local monopoly, preventing entry and controlling their own operations. By this means, the amount of fishing gear has been greatly reduced and incomes considerably improved.

That the plight of fishermen and the inefficiency of fisheries production stems from the common-property nature of the resources of the sea is further corroborated by the fact that one finds similar patterns of exploitation and similar problems in other cases of open resources. Perhaps the most obvious is hunting and trapping. Unlike fishes, the biotic potential of land animals is low enough for the species to be destroyed. Uncontrolled hunting means that animals will be killed for any short-range human reason, great or small: for food or simply for fun. Thus the buffalo of the western plains was destroyed to satisfy the most trivial desires of the white man, against which the long-term food needs of the aboriginal population counted as nothing. Even in the most civilized communities, conservation authorities have discovered that a bag-limit *per man* is necessary if complete destruction is to be avoided.

The results of anthropological investigation of modes of land tenure among primitive peoples render some further support to this thesis. In accordance with an evolutionary concept of cultural comparison, the older anthropological study was prone to regard resource tenure in common, with unrestricted exploitation, as a "lower" stage of development comparative with private and group property rights. However, more complete annals of primitive cultures reveal common tenure to be quite rare, even in hunting and gathering societies. Property rights in some form predominate by far, and, most important, their existence may be easily explained in terms of the necessity for orderly exploitation and conservation of the resource. Environmental conditions make necessary some vehicle which will prevent the resources of the community at large from being destroyed by excessive exploitation. Private or group land tenure accomplishes this end in an easily understandable fashion.[24] Significantly, land tenure is found to be "common" only in those cases where the hunting resource is migratory over such large areas that it cannot be regarded as husbandable by the society. In cases of group tenure where the numbers of the group are large, there is still the necessity of co-ordinating the practices of exploitation, in agricultural, as well as in hunting or gathering, economies. Thus, for example, Malinowski reported that among the Trobriand Islanders one of the fundamental principles of land tenure is the co-ordination of the productive activities of the gardeners by the person possessing magical leadership in the group.[25] Speaking generally, we may say that stable primitive cultures appear to have discovered the dangers of common-property tenure and to have de-

[24] See Frank G. Speck, "Land Ownership among Hunting Peoples in Primitive America and the World's Marginal Areas," *Proceedings of the 22nd International Congress of Americanists* (Rome, 1926), II, 323–32.

[25] B. Malinowski, *Coral Gardens and Their Magic*, Vol. I, chaps. xi and xii. Malinowski sees this as further evidence of the importance of magic in the culture rather than as a means of co-ordinating productive activity; but his discussion of the practice makes it clear that the latter is, to use Malinowski's own concept, the "function" of the institution of magical leadership, at least in this connection.

veloped measures to protect their resources. Or, if a more Darwinian explanation be preferred, we may say that only those primitive cultures have survived which succeeded in developing such institutions.

Another case, from a very different industry, is that of petroleum production. Although the individual petroleum producer may acquire undisputed lease or ownership of the particular plot of land upon which his well is drilled, he shares, in most cases, a common pool of oil with other drillers. There is, consequently, set up the same kind of competitive race as is found in the fishing industry, with attending overexpansion of productive facilities and gross wastage of the resource. In the United States, efforts to regulate a chaotic situation in oil production began as early as 1915. Production practices, number of wells, and even output quotas were set by governmental authority; but it was not until the federal "Hot Oil" Act of 1935 and the development of interstate agreements that the final loophole (bootlegging) was closed through regulation of interstate commerce in oil.

Perhaps the most interesting similar case is the use of common pasture in the medieval manorial economy. Where the ownership of animals was private but the resource on which they fed was common (and limited), it was necessary to regulate the use of common pasture in order to prevent each man from competing and conflicting with his neighbors in an effort to utilize more of the pasture for his own animals. Thus the manor developed its elaborate rules regulating the use of the common pasture, or "stinting" the common: limitations on the number of animals, hours of pasturing, etc., designed to prevent the abuses of excessive individualistic competition.[26]

There appears, then, to be some truth in the conservative dictum that everybody's property is nobody's property. Wealth that is free for all is valued by none because he who is foolhardy enough to wait for its proper time of use will only find that it has been taken by another. The blade of grass that the manorial cowherd leaves behind is valueless to him, for tomorrow it may be eaten by another's animal; the oil left under the earth is valueless to the driller, for another may legally take it; the fish in the sea are valueless to the fisherman, because there is no assurance that they will be there for him tomorrow if they are left behind today. 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 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.

IV. THE BIONOMIC EQUILIBRIUM OF THE FISHING INDUSTRY

The work of biological theory in the fishing industry is, basically, an effort to delineate the ecological system in which a particular fish population is found. In the main, the species that have been extensively studied are those which are subject to commercial exploitation. This is due not only to the fact that funds are forthcoming for such research but also because the activity of commercial fishing vessels provides the largest body of data upon which the biologist may work.

[26] See P. Vinogradoff, *The Growth of the Manor* [London, 1905], chap. iv; E. Lipson, *The Economic History of England* [London, 1949], I, 72.

Despite this, however, the ecosystem of the fisheries biologist is typically one that excludes man. Or, rather, man is regarded as an exogenous factor, having influence on the biological ecosystem through his removal of fish from the sea, but the activities of man are themselves not regarded as behaviorized or determined by the other elements of a system of mutual interdependence. The large number of independent fishermen who exploit fish populations of commercial importance makes it possible to treat man as a behavior element in a larger, "bionomic," ecology, if we can find the rules which relate his behavior to the other elements of the system. Similarly, in their treatment of the principles of fisheries management, biologists have overlooked essential elements of the problem by setting maximum physical landings as the objective of management, thereby neglecting the economic factor of input cost.

An analysis of the bionomic equilibrium of the fishing industry may, then, be approached in terms of two problems. The first is to explain the nature of the equilibrium of the industry as it occurs in the state of uncontrolled or unmanaged exploitation of a common-property resource. The second is to indicate the nature of a socially optimum manner of exploitation, which is, presumably, what governmental management policy aims to achieve or promote. These two problems will be discussed in the remaining pages.

In the preceding section it was shown that the equilibrium condition of uncontrolled exploitation is such that the net yield (total value landings *minus* total cost) is zero. The "bionomic ecosystem" of the fishing industry, as we might call it, can then be expressed in terms of four variables and four equations. Let P represent the population of the particular fish species on the particular fishing bank in question; L the total quantity taken or "landed" by man, measured in value terms; E the intensity of fishing or the quantity of "fishing effort" expended; and C the total cost of making such effort. The system, then, is as follows:

$$P = P(L) , \qquad (1)$$

$$L = L(P, E) , \qquad (2)$$

$$C = C(E) , \qquad (3)$$

$$C = L . \qquad (4)$$

Equation (4) is the equilibrium condition of an uncontrolled fishery.

The functional relations stated in equations (1), (2), and (3) may be graphically presented as shown in Figure 3. Segment *1* shows the fish population as a simple negative function of landings. In segment *2* a map of landings functions is drawn. Thus, for example, if population were P_3, effort of *Oe* would produce *Ol* of fish. For each given level of population, a larger fishing effort will result in larger landings. Each population contour is, then, a production function for a given population level. The linearity of these contours indicates that the law of diminishing returns is not operative, nor are any landings-induced price effects assumed to affect the value landings graphed on the vertical axis. These assumptions are made in order to produce the simplest determinate solution; yet each is reasonable in itself. The assumption of a fixed product price is reasonable, since our analysis deals with one fishing ground, not the fishery as a whole. The cost function represented in equation (3) and graphed in segment *3* of Figure 3 is not really necessary to the determination, but its inclusion makes the matter somewhat clearer. Fixed prices of input factors—"fishing effort"—is assumed, which is reasonable again on the assumption that a small part of the total fishery is being analyzed.

Starting with the first segment, we see that a postulated catch of Ol connotes an equilibrium population in the biological ecosystem of Op. Suppose this population to be represented by the contour P_3 of segment *2*. Then, given P_3, Oe is the effort required to catch the postulated landings Ol. This quantity of effort involves a total cost of Oc, as shown in segment *3* of the graph. In full bionomic equilibrium, $C = L$, and if the particular values Oc and Ol shown are not equal, other quantities of all four variables, L, P, E, and C, are required, involving movements of these variables through the functional system shown. The operative movement is, of course, in fishing effort, E. It is the equilibrating variable in the system.

The equilibrium equality of landings (L) and cost (C), however, must be a position of stability, and $L = C$ is a necessary, though not in itself sufficient, condition for stability in the ecosystem. This is shown by Figure 4. If effort-cost and effort-landings functions were both linear, no stable equilibrium could be found. If the case were represented by C and L_1, the fishery would contract to zero; if by C and L_2, it would undergo an infinite expansion. Stable equilibrium requires that either the cost or the landings function be nonlinear. This condition is fulfilled by the assumption that population is reduced by fishing (eq. [1] above). The equilibrium is therefore as shown in Figure 5. Now Oe represents a fully stable equilibrium intensity of fishing.

The analysis of the conditions of stable equilibrium raises some points of general theoretical interest. In the foregoing we have assumed that stability results from the effect of fishing on the fish population. In the standard analysis of economic theory, we should have employed the law of diminishing returns to produce a landings function of the necessary shape. Market factors might also have been so employed; a larger supply of fish, forthcoming from greater fishing effort, would reduce unit price and thereby produce a landings function with the necessary negative second derivative. Similarly, greater fishing intensity might raise the unit costs of factors, producing a cost function with a positive second derivative. Any one of these three—population effects, law of diminishing re-

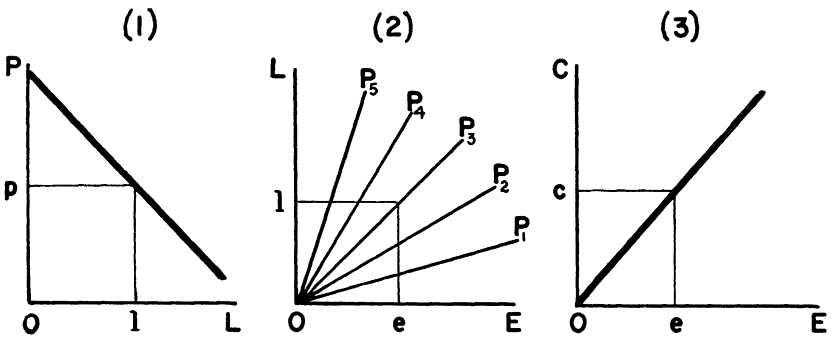

FIG. 3

turns, or market effects—is alone sufficient to produce stable equilibrium in the ecosystem.

As to the law of diminishing returns, it has not been accepted per se by fisheries biologists. It is, in fact, a principle that becomes quite slippery when one applies it to the case of fisheries. Indicative of this is the fact that Alfred Marshall, in whose *Principles* one can find extremely little formal error, misinterprets the application of the law of diminishing returns to the fishing industry, arguing, in effect, that the law exerts its influence through the reducing effect of fishing on the fish population.[27] There have been some interesting expressions of the law or, rather, its essential varying-proportions-of-factors aspect, in the biological literature. H. M. Kyle, a German biologist, included it in 1928 among a number of reasons why catch-per-unit-of-fishing-effort indexes are not adequate measures of population change.[28] Interestingly enough, his various criticisms of the indexes were generally accepted, with the significant exception of this one point. More recently, A. G. Huntsman warned his colleagues in fisheries biology that "[there] may be a decrease in the take-per-unit-of-effort without any decrease in the total take or in the fish population. . . . This may mean that there has been an increase in fishermen rather than a decrease in fish."[29] While these statements run in terms of average rather than marginal yield, their underlying reasoning clearly appears to be that of the law of diminishing returns. The point has had little influence in biological circles, however, and when, two years ago, I advanced it, as Kyle and Huntsman had done, in criticism of the standard biological method of estimating population change, it received pretty short shrift.

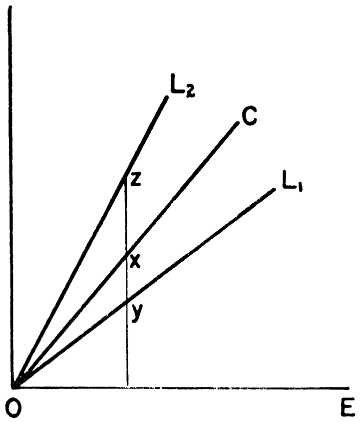

FIG. 4

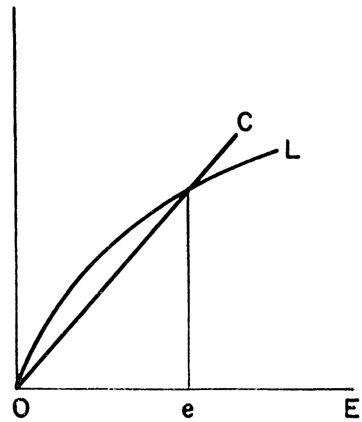

FIG. 5

[27] See H. Scott Gordon, "On a Misinterpretation of the Law of Diminishing Returns in Alfred Marshall's *Principles*," *Canadian Journal of Economics and Political Science*, February, 1952.

[28] "Die Statistik der Seefischerei Nordeuropas," *Handbuch der Seefischerei Nordeuropas* (Stuttgart, 1928).

[29] A. G. Huntsman, "Fishing and Assessing Populations," *Bulletin of the Bingham Oceanographic Collection* (New Haven), May, 1948.

In point of fact, the law of diminishing returns is much more difficult to sustain in the case of fisheries than in agriculture or industry. The "proof" one finds in standard theory is not empirical, although the results of empirical experiments in agriculture are frequently adduced as subsidiary corroboration. The main weight of the law, however, rests on a *reductio ad absurdum*. One can easily demonstrate that, were it not for the law of diminishing returns, all the world's food could be grown on one acre of land. Reality is markedly different, and it is because the law serves to render this reality intelligible to the logical mind, or, as we might say, "explains" it, that it occupies such a firm place in the body of economic theory. In fisheries, however, the pattern of reality can easily be explained on other grounds. In the case at least of developed demersal fisheries, it cannot be denied that the fish population is reduced by fishing, and this relationship serves perfectly well to explain why an infinitely expansible production is not possible from a fixed fishing area. The other basis on which the law of diminishing returns is usually advanced in economic theory is the prima facie plausibility of the principle as such; but here, again, it is hard to grasp any similar reasoning in fisheries. In the typical agricultural illustration, for example, we may argue that the fourth harrowing or the fourth weeding, say, has a lower marginal productivity than the third. Such an assertion brings ready acceptance because it concerns a process with a zero productive limit. It is apparent that, ultimately, the land would be completely broken up or the weeds completely eliminated if harrowing or weeding were done in ever larger amounts. The law of diminishing returns signifies simply that such a zero limit is *gradually approached*, all of which appears to be quite acceptable on prima facie grounds. There is nothing comparable to this in fisheries at all, for there is no "cultivation" in the same sense of the term, except, of course, in such cases as oyster culture or pond rearing of fish, which are much more akin to farming than to typical sea fisheries.

In the biological literature the point has, I think, been well thought through, though the discussion does not revolve around the "law of diminishing returns" by that name. It is related rather to the fisheries biologist's problem of the interpretation of catch-per-unit-of-fishing-effort statistics. The essence of the law is usually eliminated by the assumption that there is no "competition" among units of fishing gear—that is, that the ratio of gear to fishing area and/or fish population is small. In some cases, corrections have been made by the use of the compound-interest formula where some competition among gear units is considered to exist.[30] Such corrections, however, appear to be based on the idea of an increasing catch-population ratio rather than an increasing effort-population ratio. The latter would be as the law of diminishing returns would have it; the idea lying behind the former is that the total population in existence represents the maximum that can be caught, and, since this maximum would be gradually approached, the ratio of catch to population has some bearing on the efficiency of fishing gear. It is, then, just an aspect of the population-reduction effect. Similarly, it has been pointed out that, since fish are recruited into the

[30] See, e.g., W. F. Thompson and F. H. Bell, *Biological Statistics of the Pacific Halibut Fishery*, No. 2: *Effect of Changes in Intensity upon Total Yield and Yield per Unit of Gear: Report of the International Fisheries Commission* (Seattle, 1934).

catchable stock in a seasonal fashion, one can expect the catch-per-unit-effort to fall as the fishing season progresses, at least in those fisheries where a substantial proportion of the stock is taken annually. Seasonal averaging is therefore necessary in using the catch-effort statistics as population indexes from year to year. This again is a population-reduction effect, not the law of diminishing returns. In general, there seems to be no reason for departing from the approach of the fisheries biologist on this point. The law of diminishing returns is not necessary to explain the conditions of stable equilibrium in a static model of the fishery, nor is there any prima facie ground for its acceptance.

Let us now consider the exploitation of a fishing ground under unified control, in which case the equilibrium condition is the maximization of net financial yield, $L - C$.

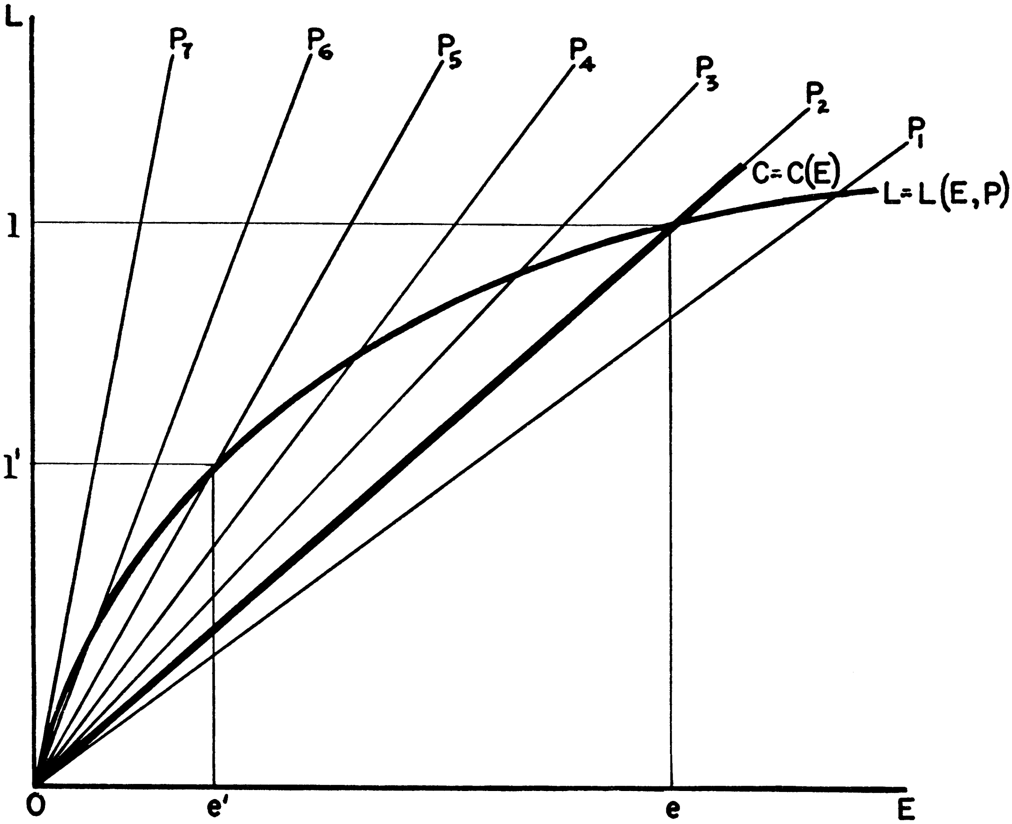

FIG. 6

The map of population contours graphed in segment *2* of Figure 3 may be superimposed upon the total-landings and total-cost functions graphed in Figure 5. The result is as shown in Figure 6. In the system of interrelationships we have to consider, population changes affect, and are in turn affected by, the amount of fish landed. The map of population contours does not include this roundabout effect that a population change has upon itself. The curve labeled L, however, is a landings function which accounts for the fact that larger landings reduce the population, and this is why it is shown to have a steadily diminishing slope. We may regard the landings function as moving progressively to lower population contours P_7, P_6, P_5, etc., as total landings increase in magnitude. As a consequence, while each population contour represents many hypothetical combinations of E, L, and P, only one such combination on each is actually compatible in this system of interrelationships. This combination is the point on any contour where that contour is met by the landings function L. Thus the curve labeled L may be regarded as tracing out a series of combinations of E, L, and P which are compatible with one another in the system.

The total-cost function may be drawn as shown, with total cost, C, measured in terms of landings, which the vertical axis represents.[31] This is a linear function of effort as shown. The optimum intensity of fishing effort is that which maximizes $L - C$. This is the monopoly solution; but, since we are considering only a single fishing ground, no price effects are introduced, and the social optimum coincides with maximum monopoly revenue. In this case we are maximizing the yield of a natural resource, not a privileged position, as in standard monopoly theory. The rent here is a social surplus yielded by the resource, not in any part due to artificial scarcity, as is monopoly profit or rent.

If the optimum fishing intensity is that which maximizes $L - C$, this is seen to be the position where the slope of the landings function equals the slope of the cost function in Figure 6. Thus the optimum fishing intensity is Oe' of fishing effort. This will yield Ol' of landings, and the species population will be in continuing stable equilibrium at a level indicated by P_5.

The equilibrium resulting from uncontrolled competitive fishing, where the rent is dissipated, can also be seen in Figure 6. This, being where $C = L$, is at Oe of effort and Ol of landings, and at a stable population level of P_2. As can be clearly seen, the uncontrolled equilibrium means a higher expenditure of effort, higher fish landings, and a lower continuing fish population than the optimum equilibrium.

Algebraically, the bionomic ecosystem may be set out in terms of the optimum solution as follows. The species population in equilibrium is a linear function of the amount of fish taken from the sea:

$$P = a - bL\,. \tag{1}$$

In this function, a may be described as the "natural population" of the species—the equilibrium level it would attain if not commercially fished. All natural factors, such as water temperatures, food supplies, natural predators, etc., which affect the population are, for the purposes of the system analyzed, locked up in a. The magnitude of a is the vertical intercept of the population function graphed in segment *1* of Figure 3. The slope of this function is b, which may be described as the "depletion coefficient," since it indicates the effect of catch on population. The landings function is such that no landings are forthcoming with either zero effort or zero population; therefore,

$$L = cEP\,. \tag{2}$$

[31] More correctly, perhaps, C and L are both measured in money terms.

The parameter c in this equation is the technical coefficient of production or, as we may call it simply, the "production coefficient." Total cost is a function of the amount of fishing effort.

$$C = qE .$$

The optimum condition is that the total net receipts must be maximized, that is,

$$L - C \text{ to be maximized} .$$

Since q has been assumed constant and equal to unity (i.e., effort is counted in "dollars-worth" units), we may write $L - E$ to be maximized. Let this be represented by R:

$$R = L - E , \tag{3}$$

$$\frac{dR}{dE} = 0 . \tag{4}$$

The four numbered equations constitute the system when in optimality equilibrium. In order to find this optimum, the landings junction (2) may be rewritten, with the aid of equation (1), as:

$$L = cE(a - bL) .$$

From this we have at once

$$L(1 + cEb) = cEa ,$$

$$L = \frac{caE}{1 + cbE} .$$

To find the optimum intensity of effort, we have, from equation (3):

$$\frac{dR}{dE} = \frac{dL}{dE} - \frac{dE}{dE}$$

$$= \frac{(1 + cbE)(ca) - caE(cb)}{(1 + cbE)^2} - 1 ,$$

$$= \frac{ca}{(1 + cbE)^2} - 1 ;$$

for a maximum, this must be set equal to zero; hence,

$$ca = (1 + cbE)^2 ,$$

$$1 + cbE = \pm \sqrt{ca} ,$$

$$E = \frac{-1 \pm \sqrt{ca}}{cb} .$$

For positive E,

$$E = \frac{\sqrt{ca} - 1}{cb} .$$

This result indicates that the effect on optimum effort of a change in the production coefficient is uncertain, a rise in c calling for a rise in E in some cases and a fall in E in others, depending on the magnitude of the change in c. The effects of changes in the natural population and depletion coefficient are, however, clear, a rise (fall) in a calling for a rise (fall) in E, while a rise (fall) in b means a fall (rise) in E.