sur le nombre de salaires et la rémunération hebdomadaire moyenne du groupe majeur. Ces données ont été fournies par Statistique Canada. VA_t, VA_a sont respectivement la valeur ajoutée trimestrielle du groupe majeur pour le trimestre de signature de la convention et la VA_t est la convention collective antérieure.

$$W_{\exp}: \sum_{l=0}^{8} \bar{w}_{E_{t-l}}.$$

où $\bar{w}_{E_{t-l}}$ est le taux de variation moyen trimestriel du taux de salaire de base négocié dans le secteur exposé au trimestre $t - l$.*

$$Lw_{\exp}: Lw_{\exp} = \sum_{l=0}^{8} l\,\bar{w}_{E_{t-l}}$$

où $\bar{w}_E$ est défini comme ci-haut.*

BIBLIOGRAPHIE

Aukrust, O. (1977) 'Inflation on the open economy: a Norwegian model.' Dans L. Krause et M. Salant. *Worldwide Inflation: Theory and Recent Experience*, (Washington, D.C.: The Brookings Institution)

Auld, A., L.N. Christofides, R. Swidinsky, et D.A. Wilton (1979) *Facteurs déterminants des ententes salariales négociées au Canada (1966–1975)* (Ottawa: Commission de Lutte contre l'Inflation)

Cousineau, J.-M. et R. Lacroix (1977) *La détermination des salaires dans le monde des grandes conventions collectives: une analyse des secteurs privé et public* (Ottawa: Conseil Economique du Canada)

Decaluwe, B. (1980) 'Les salaires et les prix dans les industries manufacturières canadiennes exposées et abritées.' Texte d'une communication présentée au 20^e Congrès Annuel de la SCSE, mai 1980

Denton, F., L. Feaver, et A.L. Robb (1974) *Patterns of Unemployment Behaviour in Canada* (Ottawa: Conseil Economique du Canada)

Wilson, T.A. et F. Reid (1979) *L'évolution des salaires et des prix dans les industries manufacturières au Canada: une analyse économétrique* (Ottawa: Commission de Lutte contre l'Inflation)

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* Variables calculées à partir de la banque de données sur les conventions collectives de Travail Canada.

Fisheries, extended jurisdiction and the economics of common property resources

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(19[illegible])

Abstract. This article provides an overview both of recent theoretical developments in fisheries economics and of major policy issues in Canadian fisheries. It is argued that the chief theoretical development over the past fifteen years consisted of a decisive shift from static to dynamic analysis. The major policy issues reviewed are the limitation of entry to fisheries, the management of transboundary stocks, and co-operative arrangements with distant water nations. Far from being unique to Canada, the issues are common among coastal states implementing Extended Fisheries Jurisdiction.

Pêcheries, juridiction étendue, et économie des ressources en propriété commune. Cet article présente un survol à la fois des récents développements au plan théorique dans l'économie des pêcheries et des principaux problèmes de la politique des pêcheries au Canada. On suggère que le développement théorique majeur des derniers quinze ans a été le déplacement depuis une analyse statique vers une analyse proprement dynamique. Les problèmes majeurs de politique qu'on examine vont des barrières à l'entrée de nos pêcheries à la gestion des stocks débordant de chaque côté des frontières nationales et aux accords de coopération entre nations maritimes distantes. Les problèmes discutés, loin d'être spécifiques au Canada, sont le lot de tous les états côtiers qui implantent une juridiction étendue sur les pêcheries.

INTRODUCTION

The economics of fisheries has, along with other branches of natural resource economics, enjoyed a rapid and sustained growth over the past fifteen years. This growth can be explained by general concerns over the perceived degradation of the natural environment and, more specifically, by the United Nations Third Law of the Sea Conference, which had its first formal session in 1974. Although the U.N. Third Law of the Sea Conference may never bring forth a convention, it has led to a

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revolutionary change in the management of the world's fishery resources. The widespread implementation of Extended Fisheries Jurisdiction (EFJ), made possible by the conference, transformed the status of many fishery resources from international common property to the property of individual coastal states.[1] Important fishery resources off the coasts of Newfoundland and Nova Scotia provide cases in point.

The purpose of this article is twofold. First, it attempts to provide a survey of the major theoretical developments in fisheries economics since its inception in the mid-1950s, giving particular emphasis to those since 1965. Secondly, it attempts to outline some of the major economic policy issues current in Canadian fisheries, including, of course, those arising from EFJ. The point will be made that the policy issues are common to most of the coastal states of the world.

STATIC APPROACHES TO THE ECONOMICS OF FISHERIES

The origins of modern fisheries economics can be traced back to two articles appearing in the mid-1950s. The first, by H. Scott Gordon (1954), provided the foundation for what was subsequently to be referred as the static approach to fisheries economics. This approach was to dominate the theoretical literature in the field for the next fifteen to twenty years and continues to the present day to influence policy-makers (in Canada at least). The second article, by Anthony D. Scott (1955), was a precursor of the dynamic, or capital-theoretic, approach to fisheries economics that was to come into vogue in the 1970s.

In most parts of the world fishery resources have proved difficult to manage effectively. Indeed, in several instances the resources have been threatened with extinction. The central point in the Gordon article is that these management difficulties can be traced to the single overriding fact that with few exceptions fishery resources constitute common property. Fish are difficult to observe, except upon capture, and, with the exception of a few shellfish species, they are mobile, often travelling great distances. Consequently, fishery resources have provided excellent examples of resources in which the costs of attempting to establish property rights were perceived as exceeding by a wide margin the benefits that might be derived therefrom. If a common property fishery having commercial potential is subject to no government regulation and if the fishing industry exploiting the resource is competitive, argues Gordon, then there will be inevitable market failure in the sense that the fishery will expand to the point that economic, if not biological, overfishing can be deemed to have occurred.

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[1] A coastal state can be defined simply as a state that borders one or more oceans. Canada and the United States are obvious examples. From time to time we shall contrast coastal states with distant water nations. A distant water nation can be defined as a nation some of whose fishing fleets operate in waters other than those of the nation or those of the nation's immediate neighbours. Japan is a clear example. A country can, of course, be both a coastal state and a distant water nation, for example, the United States.

The Gordon model, which is a model of single species fishery, has, as must every acceptable economic model of the fishery, a biological model of the fishery as its foundation. Although not stated explicitly in Gordon's article, it is clear that the underlying biological model is a variant of the well-known Schaefer model (1957). The population dynamics inherent in the Schaefer model can be easily described. A fish population or biomass will, if not subject to harvesting, grow (in terms of weight) both as a consequence of the entry of new fish – recruitment – and as the result of the growth of individual fish in the population. Natural mortality will act as a check on growth. With an aquatic environment of finite size, in time the biomass will approach a natural equilibrium level at which net growth is zero. In the Schaefer model no attempt is made to distinguish among the factors influencing net growth of the biomass. Thus, the growth of the biomass can be viewed as a function of the biomass itself and the population dynamics can be modelled by the very simple differential equation:

$$\dot{x} = F(x), \tag{1}$$

where x denotes the biomass. Specifically, in the Schaefer model:

$$F(x) = rx\left[1 - \frac{x}{K}\right], \tag{2}$$

where K denotes the maximum biomass size and r, a constant, denotes the intrinsic growth rate.[2]

Upon the introduction of harvesting, equation (1) is modified to:

$$\dot{x} = F(x) - h(t), \tag{3}$$

where $h(t)$ denotes the harvest rate. The harvest production function in turn is given by:

$$h(t) = qE(t)x(t) \tag{4}$$

where $E(t)$ denotes the rate of fishing effort (flow of labour and capital services devoted to harvesting) at time t, and q, a constant, denotes the 'catchability coefficient.'

If at any given biomass level, x, $h(t) = F(x)$, then obviously $\dot{x} = 0$, and one can talk of the resource being harvested on a sustainable basis. Hence $F(x)$ can now be viewed as the sustainable yield or harvest associated with a given biomass level. Since $h(t)$ is a function of E, as well as of x, one can, from the Schaefer model, establish the following sustained yield-fishing effort relationship:

$$Y = \alpha E - \beta E^2, \tag{5}$$

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[2] The equation, is in fact, the famous logistic equation of population dynamics.

where Y denotes sustainable yield, $\alpha = qK$ and $\beta = q^2K/r$.[3]

With the biological model complete, prices and costs can now be introduced. Gordon (1954) assumes that both the demand for harvested fish and the supply of effort are perfectly elastic and that the price of fish and marginal cost of effort accurately reflect the marginal benefit of harvested fish to society and marginal social cost of effort respectively. Sustainable yield multiplied by the price of fish becomes sustainable revenue from fishing and cost and revenue relationships in the fishery can be depicted as follows.[4]

We accompany figure 1, which appears widely in the fisheries economics literature, with a much less common figure that relates sustainable revenue from fishing and the costs of fishing not to fishing effort but rather to the biomass. Figure 2 will prove helpful in making the transition to the capital theoretic approach to fisheries economics discussed in the next section.

In figure 2 sustainable revenue is simply $pF(x)$, where p denotes the dockside price of fish. Total cost of harvesting is to be interpreted as the total cost of harvesting the sustainable yield.[5]

Return to figure 1. If the fishery were managed in a socially optimal manner, it is argued, the fishery would be stabilized at the point where sustainable resource rent (sustainable revenue minus total cost of fishing effort) is maximized at E_0. At this point, continues the argument, the marginal cost and value of the marginal product of

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[3] If harvesting is taking place on a sustained yield basis, we have $qEx = F(x)$. But in the Schaefer model,

$$F(x) = rx\left(1 - \frac{x}{K}\right)$$

Hence

$$qEx = rx\left(1 - \frac{x}{K}\right)$$

from which we can derive the following expression for x:

$$x = K\left(1 - \frac{q}{r}E\right)$$

Now substitute for x in equation (4). We then have an equation expressing sustainable yield as a function of E:

$$Y = qEK\left(1 - \frac{q}{r}E\right)$$

[4] The total cost of fishing effort can be expressed as: $C(E) = aE$, where a, a constant, denotes unit cost of effort.

[5] From fn. 4 we have $C(E) = aE$. From the harvest production function we can express E as: $E = h/qx$. Hence total harvesting cost $C(x, h)$ can be expressed as: $C(x, h) = ah/qx$. If harvesting is taking place on a sustained yield basis, then $h = F(x)$. Hence the total cost of harvesting the sustainable yield can be expressed:

$$C(F(x), x) = a\,\frac{F(x)}{qx} = \frac{ar}{q}(1 - x/K).$$

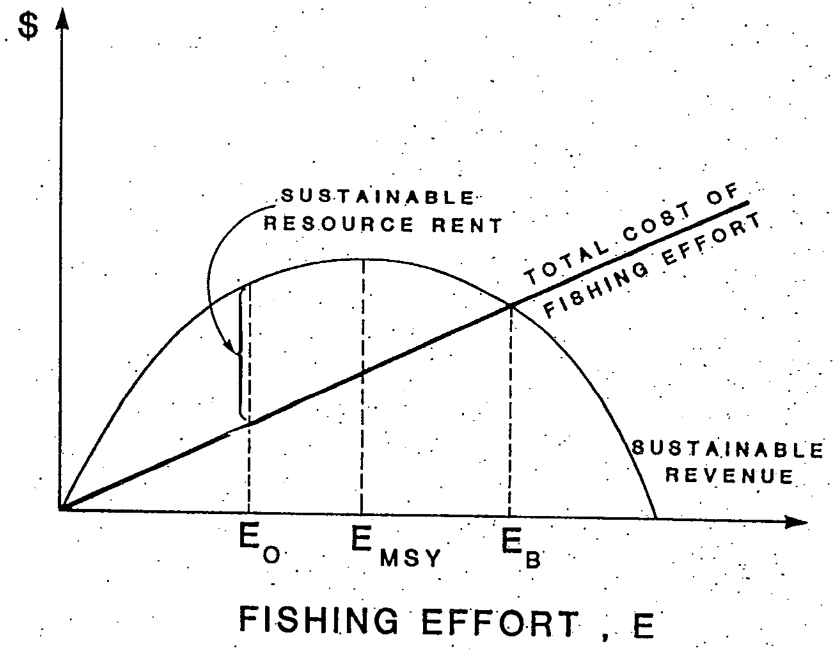

FIGURE 1

fishing effort are equal – *economic* over-fishing can thus be deemed to occur if the fishery expands beyond E_0.

If common property fishery is unregulated (and competitive), then the fishery cannot be in equilibrium at E_0. Since there is no marine equivalent of a landlord (sea-lord) to appropriate the resource rents, any rents generated by the fishery must accrue to the labour and capital engaged in harvesting. Thus, if the fishery were at the point where resource rents were being maximized (E_0), labour and capital in the fishery would be enjoying super-normal returns. The fishery would inevitably expand; hence economic overfishing would inevitably occur. Indeed, the fishery would not be in equilibrium until it had expanded to the point that resource rent had been fully dissipated. The point of equilibrium, E_B in figure 1, was characterized by Gordon as 'bionomic equilibrium' in the sense that it constituted both biological and economic equilibrium.

In figure 2 the resource depletion consequences of an unregulated, common property fishery are apparent. The biomass level associated with bionomic equilibrium, x_B, is significantly below that associated with maximum sustainable resource rent, x_0. Thus, in examining figures 1 and 2, it can be seen that if the fishery is competitive and unregulated, the common property nature of a fishery result in both

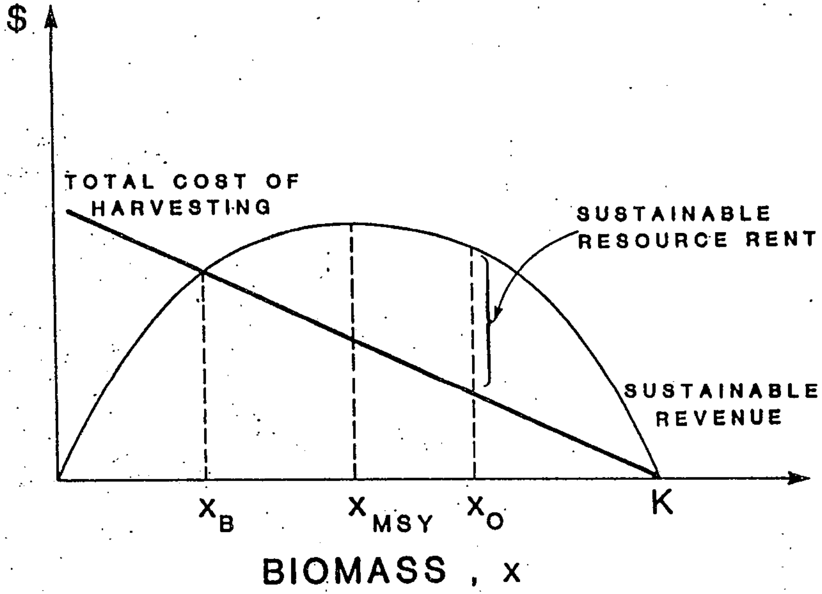

FIGURE 2

an over-allocation of labour and capital to the fishery and an excessive depletion of the resource itself.[6]

Gordon's article did more than demonstrate the fate of an unregulated common property fishery. It provided a critical evaluation of the then current policies of fisheries management in North America and elsewhere. Fisheries management in North America has traditionally been the responsibility of marine biologists, whose primary concern, not surprisingly, has been the conservation of the resource. From the end of the Second World War until recent years, the central management criterion employed by the biologists was that of 'full utilization' of the resource. This implies stabilizing the fishery at the point where the sustainable yield was maximized (E_{MSY} in figure 1; x_{MSY} in figure 2).[7] From the biologists' point of view 'overfishing' could be deemed to have occurred if the fishery expanded to the point that the biomass was reduced below the maximum sustained yield (MSY) level.

Achieving the goal of maximum sustained yield (MSY) meant (to the biologists) that the total harvest from a given fishery resource should not exceed an acceptable level on a season-by-season basis. Thus, once the target of x_{MSY} (figure 2) was reached, the total harvest should not exceed $F(x_{MSY})$.[8]

Economists from Gordon onwards objected to this approach to fisheries management of the grounds that it focused solely upon physical yields (and stocks) and ignored economic considerations. The economic consequences of the policy were seen as twofold. First, the emphasis on the regulation of the total harvest alone seemed guaranteed to ensure that resource rent would be dissipated, even if the managers were entirely successful in preventing excessive depletion of the stock.

Return to figure 2 and note that the total cost curve represents the *minimum* cost of harvesting the sustainable yield. Now suppose that the authorities succeed in stabilizing the resource at x_{MSY} by means of a global harvest quota but impose no restrictions on entry to the fishery. Suppose further that, momentarily at least, the sustainable yield is harvested with the minimum required labour and capital. Resource rent will be forthcoming. The rent, however, is unsustainable. Additional fishermen and vessels will be attracted to compete with the existing fleet for shares of the allowable harvest. The inflow of redundant labour and capital to the fishery will in turn cause the total cost of harvesting curve in figure 2 to shift clockwise. The inflow will continue until the harvesting cost curve intersects the sustainable revenue curve at x_{MSY} and the resource rent has been fully dissipated.[9]

Secondly, the very goal of MSY seemed from an economic perspective to be ill-conceived. In figures 1 and 2 it appears obvious that, even if the redundancy

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[6] The fact that an unregulated, common property fishery will lead to rent dissipation and overexploitation of the resource was in fact recognized many years before Gordon's article appeared. It was discussed by the Danish economist Jens Warming in a 1911 article. I am indebted to Peder Andersen of the Institute of Economics, University of Aarhaus for an English translation of the Warming (1911) article.

It should also be pointed out that the penalties associated with failure to regulate a common property fishery are exaggerated by the assumptions of perfectly elastic demand for fish and supply of fishing effort functions. [redacted] demonstrated that if either one of these assumptions is relaxed, society will enjoy some net economic benefits from the fishery at bionomic equilibrium.

By the way of contrast, if the fishery were not competitive, but rather were subject to the control of a profit maximizing sole owner, the fishery would be managed in a socially optimal manner (Gordon, 1954; Scott, 1955).

It may seem far-fetched to suppose that it would ever be possible politically to subject a fishery to sole ownership. In a submission to the Canadian Commission on Pacific Fisheries Policy, however, the largest fishing company in BC suggested that the processing sector be consolidated into a privately or government-owned monopsony (British Columbia Packers Limited, 1981). The consequences for management of such a step are analysed in [redacted] and Schworm (1981).

[7] MSY = Maximum Sustained Yield

[8] Fishery resources are subject to fluctuations. Thus, to be more precise, we shold say that total harvests should not exceed $F(x_{MSY})$ *on average*.

[9] An example of a fishery in which global harvest controls unaccompanied by restraints on entry to the fishery led to biological success and economic disaster is provided by the Pacific halibut fishery, exploited jointly by Canada and the United States. In the 1920s Canadian and American fisheries managers undertook a co-operative stock (and yield) restoration program. The stocks were rebuilt, but the fishery remained an open access one. A detailed and thorough discussion of the economic consequences of this policy is to be found in Crutchfield (1956).

Fisheries managers did at times attempt to control fishing activity directly, but they did so by deliberately inhibiting technological developments. Thus, for example, until the early 1950s fishermen in the large Bristol Bay (Alaska) salmon fishery were restricted to the use of sailboats. Economists, of course, were incensed by this sort of policy. See Anderson (1977) for a discussion of this issue.

On the other hand, in yet other instances government authorities were not content to allow free entry to fisheries but encouraged entry by means of subsidy programs. It has been argued, for example, that the various aspects of the Canadian unemployment insurance program actively encouraged entry into Newfoundland's inshore fisheries (Ferris and Plourde, 1980).

problem can be avoided, the MSY policy must lead inevitably to *economic* overfishing (i.e., $E_0 < E_{MSY}; x_0 > x_{MSY}$), unless the cost of fishing effort equalled zero. In short, the biologists were not sufficiently conservationist in their resource management policy.

The economist's static analysis of fisheries management did have and continues to have an impact upon policy-makers. The impact was felt in two stages. In the first stage the authorities gave recognition to the fact that global controls on harvests alone are seriously inadequate from an economic standpoint. The initial focus of recognition was Canada's largest fishery in terms of value of landings: the British Columbia salmon fishery. Here the redundancy problem was stark and obvious. It was estimated, for example, that at the end of the 1960s the salmon fleet was twice as large as was necessary to take the allowable harvests (Pearse and Wilen, 1979). The authorities undertook a major effort (commencing in 1969) both to limit entry to the fishery and to eliminate redundant labour and capital currently in the fishery. The experiment subsequently served as a model for other limited entry programs in Canada and elsewhere. More will be said about the experiment at a later point.

Exp. IIP mandated

The second stage occurred in the mid-1970s as a consequence of the experience that Canada had in managing major groundfish (e.g., cod, flounder) resources off its Atlantic coast. Canada managed these resources in the pre-EFJ era in concert with other members of the International Commission for the Northwest Atlantic Fisheries (ICNAF) and did so on an MSY basis. By the early to mid-1970s it was clear that the MSY-based management policy had led, from Canada's perspective at least, to economic disaster (Munro, 1980). In consequence, the MSY criterion was abandoned as a basis of management of Atlantic stocks both by Canada and by ICNAF.[10]

A new management rule, proposed by the famous marine biologist John Gulland, called for biomass targets somewhat larger than those associated with MSY. The rule gained acceptance in ICNAF, and since EFJ it has come to serve as a reference point for Canadian managers of Atlantic coast fishery resources (Canada, Department of Fisheries and Oceans, 1981).

An examination of Gulland's rationale for the new rule (Gulland and Boerema, 1973; Gulland and Robinson, 1973) makes it clear that the rule rests upon the economist's static model of the fishery. Ironically, however, the apparent triumph of the economist's static analysis of the fishery came at a time when economists themselves were becoming concerned about the limitations of the static analysis and were turning to dynamic, or capital-theoretic, models of the fishery.

CAPITAL THEORY AND THE ECONOMICS OF FISHERIES

To shift a fishery from bionomic equilibrium to a position in which sustainable resource rent is being maximized involves more than a reduction of fishing effort. The resource itself must be rebuilt, a point that is made transparently obvious by figures 1 and 2. For the resource to be rebuilt, the harvest rate must be reduced below the sustainable yield until the target biomass has been reached. Even if the harvest rate can be reduced temporarily to zero, the desired rebuilding may take several years to accomplish.

Described as such, a program of rebuilding a fishery resource is quite simply a program of resource investment. This in turn suggests that the economics of fisheries, like all of the other branches of natural resource economics, ought properly to be cast in a dynamic or capital-theoretic framework.

Far from being novel, this view was expressed at the inception of modern fisheries economics. Anthony Scott's famous 1955 article was really a first attempt to recast the Gordon model in a dynamic framework (Scott, 1955). Scott Gordon, himself, in a 1956 conference paper (Gordon, 1956) gave as forceful and eloquent a statement on the need for a dynamic approach to fisheries economics as one is likely to find anywhere in the literature.

> The conservation problem is essentially one which requires a dynamic formulation ... 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. In the fishing industry we may allow our fish to grow and to reproduce so that the stock at a future date will be greater than it would be if we attempted to catch as much as possible at the present time ... In theoretical terms this means that the optimum degree of exploitation of a fishery must be defined as a time function of some sort. That is to say, it is necessary to arrive at an optimum which is a catch per unit of time, and one must reach this objective through consideration of the interaction between the rate of catch, the dynamics of fish populations, and the economic time-preference schedule of the community or the interest rate on invested capital. This is a very complicated problem and I suspect that we will have to look to the mathematical economists for assistance in clarifying it.[11]

Note the emphasis on the difficulty of producing a workable dynamic fisheries model. At the time, the task was indeed formidable. An attempt was made by Crutchfield and Zellner (1962) a few years later using standard calculus of variations. The analysis proved difficult to penetrate, while the decision rules emerging from the analysis defied economic interpretation. It is not surprising, therefore, that economists generally retreated to the simpler static models. While the static models might not be without their limitations, at least they produced results that were comprehensible and thus useful for policy purposes.

The breakthrough came with the development of optimal control theory, which can be seen essentially as an improvement upon and an extension of the standard calculus of variations. Economists were quick to adopt it (Dorfman, 1969) using it extensively, for example, in growth theory. It was only a matter of time before it came to be applied in fisheries economics.

The first major attempts to apply optimal control theory to fisheries economics appeared in the early 1970s with pioneering work being done by Plourde (1970; 1971), Quirk and Smith (1970), and others. An extensive and thorough treatment of the subject appeared in 1976 with the publication of Colin Clark's *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*.

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[10] In 1976, with the publication of a major policy document on fisheries, Canada's abandonment of the MSY criterion became official (Canada, Department of the Environment, Fisheries and Marine Service, 1976).

[11] Gordon (1956).

While some of the earlier attempts to apply optimal control theory to fisheries economics were horrific in their complexity, the fundamental aspects of dynamic fisheries economics are now sufficiently clear that they can readily be taught to senior undergraduates (Munro, 1981a). The nature of the optimal control problem can be stated as follows.[12] The biomass constitutes the state variable or variable to be controlled. One can control x through time by adjusting the harvest rate; for example, if the harvest rate is reduced below the sustainable yield, x will increase. Thus, the harvest rate can be seen as the control variable.[13] The problem then is to control $x(t)$ over time through the harvest rate in such a manner as to maximize the present value of the stream of net economic benefits or returns from the fishery.

Consider now a given fishery and let all of the assumptions employed in developing the Gordon static model of the fishery apply.[14] Assume as well that the price of landed fish, unit cost of effort, and the social rate of discount are all independent of time. The flow of net economic benefits from the fishery at any point in time t will be identical to the flow of resource rent and can be expressed as follows:

$$\Pi(x, h) = [p - c(x)]h, \tag{6}$$

where p is the price of landed fish, h the harvest rate, and $c(x)$ unit harvest costs.[15] The objective functional is then:

$$\text{PV} = \int_0^\infty e^{-\delta t}\,\Pi(x(t), h(t))dt, \tag{7}$$

where δ is the social rate of discount.

Formally the problem is to determine the optimal control $h(t) = h^*(t)$, $t \geqslant 0$, and the corresponding optimal biomass $x(t) = x^*(t)$, $t \geqslant 0$, subject to equation (3) (now referred to as the state equation) and to the constraints:

$$x(t) \geqslant 0 \tag{8}$$

$$0 \leqslant h(t) \leqslant h_{\max}.^{16} \tag{9}$$

One can think of the problem being solved in two stages. In the first stage $x^*(t)$ is determined, while in the second the optimal approach path from the initial biomass level to $x^*(t)$ is determined.

In solving the optimal control problem, answers to two basic capital-theoretic questions are provided. In determining $x^*(t)$ the question of the extent to which it is worth society's while to invest in the resource is answered, while in determining the optimal approach path an answer is provided to the question of the optimal rate of resource investment (disinvestment) before $x^*(t)$ is achieved. Consider first the determination of $x^*(t)$.

The rule for determining $x^*(t)$ is, in fact, simplicity itself. It states that one should invest (disinvest) in the resource up to the point that the yield or return on the marginal investment in the resource is equal to the social rate of discount. The equilibrium equation can be expressed formally as follows (Clark and Munro, 1975):

$$\frac{((d/dx^*)[\pi(x^*, F(x^*))])}{(\partial\pi(x^*, h)/\partial h)_{h=F(x^*)}} = \delta. \tag{10}$$

The left-hand side of equation (10) is the marginal sustainable resource rent resulting from an incremental investment in the resource divided by the cost of undertaking the investment, the forgone rent from current harvesting. As such the left-hand side of equation (10) can be viewed as the 'own rate of interest' of the resource.

If we carry out the differentation on the left-hand side of equation 10, the equation can be re-expressed as:

$$F'(x^*) + \left.\frac{\partial\Pi/\partial x^*}{\partial\Pi/\partial h}\right|_{h = F(x^*)} = \delta. \tag{10a}$$

Expressed in this fashion, the own rate of interest can be seen as consisting of two components, the instantaneous marginal product of the resource (i.e., marginal sustainable yield) and what has been termed the marginal stock effect. The marginal stock effect is a measure of the impact of incremental resource investment upon harvesting costs. Observe that $c'(x) < 0$[17]; that is, the denser the stock the less costly it is to harvest fish.

Observe as well as that the solution to equation (10), x^*, is *not* a function of time; that is, the solution is a steady state one. Hence the equilibrium harvest policy is given by:

$$h^*(t) = F(x^*).^{18} \tag{11}$$

Some comparisons with the static model are now possible. Let us first note two points of agreement. There is no quarrel with the proposition that an unregulated,

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[12] The discussion to follow on dynamic models draws heavily upon Clark and Munro (1975). There are, of course, many alternative treatments of the subject. See, for example, Brown (1974), Dasgupta and Heal (1979), Peterson and Fisher (1977), Levhari, Michener, and Mirman (1981), Long (1977), Neher (1974), and Smith (1977).

[13] Alternatively, one can use the rate of fishing effort as the control variable. Either is perfectly acceptable. I generally prefer the harvest rate, because it makes the underlying economics particularly transparent.

[14] That is, we abstract from all second-best considerations, assume that both the demand for harvested fish and the supply of fishing effort are perfectly elastic, and assume that the Schaefer model is the relevant underlying biological model.

[15] Return to fn. 5, where total harvest costs are defined as: $C(x, h) = ah/qx$. Thus, $c(x) = a/qx$.

[16] This is an arbitrary upper bound on harvesting capacity. For a discussion of this point see Clark and Munro (1975).

[17] Observe that, if $x > x_{\text{MSY}}$, an incremental (positive) investment in the resource will involve a trade-off between sustainable yield and reduced harvesting costs, that is, $F'(x) < 0$.

[18] The simplicity of the results, of course, reflect to no small degree the underlying assumptions. Once these are relaxed, the simplicity vanishes. Then, for example, one can be confronted with the possibility of multiple equilibria (Clark and Munro, 1975) or the possibility that pulse fishing, rather than sustained yield fishing will be optimal (Clark, Edwards, and Friedlander, 1973; Hannesson, 1975; Lewis and Schamlensee, 1979), or indeed, even the possibility that it will be optimal to drive the resource to extinction (Clark, 1973; Clark and Munro, 1978; Gould, 1972).

What about the rule of equating the marginal cost of effort with the value of the marginal product of effort? If we look more closely at the static model, we can see that the rule really should be stated: marginal cost of effort equal to the value of the marginal *sustainable* product of effort. It is not at all obvious why optimality implies this equality. Indeed it does not, unless $\delta = 0$.

Critics A Atmos.

open access, common property fishery will lead to excessive (from society's point of view) exploitation of the resource. Bionomic equilibrium will be optimal, if and only if, $\delta = \infty$.[19] This, of course, is the essence of the common property problem, namely, that as an asset to be maintained, the resource has no value to those who exploit it.

Secondly, there is no quarrel with the proposition that global harvest quotas unaccompanied by controls on fishing effort will prove to be highly unsatisfactory. Indeed, it can be argued that without such controls, investment in the resource will be a futile undertaking (Munro, 1980).

On the other hand, the conclusion arrived from the static model that optimal management of the fishery implies the maximization of sustainable resource rent is now shown to be valid, if and only if, $\delta = 0$. If the social rate of discount is positive, then sustainable resource rent maximization implies overinvestment in the resource from society's point of view.[20] From this it follows that the assertion that the MSY policy must necessarily lead to economic overfishing is invalid. It is quite possible that an MSY policy could result in economic *under*exploitation of a resource.[21]

Now let us turn to the second issue, that of the optimal approach path. Consider, by way of example, a resource newly acquired by a coastal state as a consequence of the state's implementation of Extended Jurisdiction. Suppose that the resource had previously been subject to heavy exploitation, which the coastal state authorities now consider excessive. The authorities embark, therefore, on a program of stock restoration. Suppose further that the optimal biomass is determined and that measures are implemented to prevent redundant labour and capital emerging in the fishery as the resource is restored. There yet remains the problem of whether the optimal biomass target should be approached rapidly or gradually, that is, of determining the appropriate *rate* of investment in the resource.[22]

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[19] Return to Equation (10) and re-express the equation as:

$$\frac{d}{dx^*}\{\pi(x^*, F(x^*))\}/\delta = \partial\pi(x^*, h)/\partial h.$$

It will be true that $x^* = x_B$, that is, $\partial\pi(x^*, h)/\partial h = 0$, if $\delta = \infty$. If $\delta < \infty$, then obviously $x^* > x_B$.

[20] Turn yet again to Equation (10) and observe that maximizing sustainable resource rent implies that:

$$\frac{d}{dx}\{\pi(x, F(x))\} = 0.$$

[21] That is, $x^* < x_{MSY}$ (Clark and Munro, 1975).

The conclusion forthcoming from the static model that the MSY policy will always lead to economic overfishing unless the costs of fishing effort costs are zero rests upon the existence of a positive marginal stock effect. It can be seen from equation (10a) that if $\delta = 0$ and if $(\partial\Pi/\partial x^*)/(\partial\Pi/\partial h) > 0$, it must be true that $F'(x^*) < 0$; that is, $x^* > x_{MSY}$. This fact is obscured in the standard presentation of the static model.

It is known, however, that in some fisheries the marginal stock effect is very weak (Clark and Munro, 1980). If the marginal stock effect is negligible, the quilibrium equation reduces to

$$F'(x^*) = \delta. \tag{10b}$$

If, in addition, $\delta = 0$, then MSY will be in fact the optimal economic policy.

[22] An actual case in point is the single most important resource to the fishing industry of Newfoundland, a cod stock complex extending from southern Labrador to south-eastern Newfoundland known popularly as northern cod. It has been the subject of intense policy discussion and debate in recent years. One of the issues has been the speed with which the stock should be restored (Canada, Department of Fisheries and Oceans, 1979; Newfoundland and Labrador, 1980; Munro, 1980).

The answer provided by the dynamic model is the one that standard investment theory would lead us to expect. If there are no penalties associated with rapid investment in the resource, then rapid investment is indeed the appropriate policy. We illustrate this point by supposing that all the assumptions employed so far in our discussion of the dynamic model remain unchanged, with one exception. The one exception is concerned with the malleability of capital embodied in the fleet, in the processing plants, and in the skills of fisherman and plant workers. In the discussion so far it has been assumed implicitly that all the capital is perfectly malleable in that it can be shifted easily to alternative uses.[23]

If this assumption is retained, then, given our other assumptions, the optimal program will be to invest in the resource at the maximum rate until the optimal biomass level is reached. From equation (3) it can be seen that the maximum rate of investment in the resource is achieved by setting $h(t) = 0$, that is, by implementing the drastic policy of shutting down the fishery entirely while the resource is being rebuilt.

On the other hand, if we allow for non-malleable capital (a phenomenon readily observable in actual fisheries (Baker, 1980)), then the optimal resource investment program may be altered radically. For example, let it be supposed that, while the fishermen are mobile and while the processing plants can draw supplies from other fisheries, the capital embodied in the fleet is highly non-malleable in that the vessels can be sold only for scrap. We shall suppose, however, that the depreciation rate of the vessels is positive. It can then be shown that the optimal biomass level should be approached gradually. The optimal rate of resource investment will be relatively low, implying that extensive harvesting of the resource should continue during the stock restoration program[24] (Clark, Clarke, and Munro, 1979).

Before turning to specific policy issues, we should make reference to areas in which some work has been done to extend the dynamic model but in which much remains to be done in the future. The first is in the area of uncertainty. It is a commonplace to observe that all investment in fishery resources must take place under conditions of great uncertainty, biological as well as economic. Thus, it may be eminently desirable to progress beyond deterministic dynamic models to stochastic ones.[25] A second area in which we can expect substantial work in the future is optimal management of multi-species fisheries. Another commonplace in fisheries management is that species interact; hence models based upon single species fisheries may be seriously inadequate for management purposes. The major impediment to the development of economic models of multi-species fisheries, however, is the dearth of acceptable biological models of such fisheries.[26]

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[23] Alternatively we can think of it's being possible to sell off the non-human capital without danger of capital loss. The concept, of course, is closely related to the financial concept of liquidity.

[24] At the commencement of the management program, the only fleet costs that are relevant are the operating costs of the vessels. This will remain true until the vessels are to be replaced. Hence harvesting costs are temporarily low. If the fishery were to be shut down, this temporary cost advantage would be lost.

[25] See Andersen and Sutinen (1981), Charles and Munro (1981), Lewis (1981), Ludwig (1979), and Reed (1979).

[26] Some work has been done, however, in this area. See Clark (1976), and Silvert and Smith (1977). There are, of course, many other aspects to the multi-species problem in addition to the fact that

Finally, a comment should be made on empirical estimation of dynamic models. It must be reported that the work is still very much in its early stages, with several important estimation problems yet to be fully resolved (Uhler, 1980).[27] It should be stressed, however, that the estimation problems do not arise from the dynamic nature of the economic models. Rather, they are associated with the estimation of the parameters of the underlying growth and harvest production functions. Static models offer no escape from these problems.

REGULATING THE COMMON PROPERTY FISHERY: LIMITED ENTRY AND OTHER MEASURES

In turning now to major fisheries policy issues in Canada we begin with the problem of redundant labour and capital in the fishery. If it is not possible to deal effectively with the problem, the value of much of fisheries management can be called into serious question. It could then well be the case in many instances that the costs of management will prove to be far in excess of the benefits to be derived therefrom.

As we pointed out earlier, the Canadian authorities recognized the problem at least two decades ago and undertook a major attempt to address the redundancy problem in the potentially wealthy British Columbia salmon fishery. Since the BC salmon limited entry program has served as a model for other limited entry programs in Canada and elsewhere, it is worthwhile reviewing the history of the program to see what lessons it has to offer.

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The program commenced in 1969. Its object was quite simply to remove the existing excess labour and capital from the fishery, while ensuring that the redundancy problem did not re-emerge. The authorities introduced a strict vessel licensing system in the fishery with participants being awarded A or B licences according to their degree of participation. It was understood that B-licence vessels would be phased out over a ten-year period. A boat-for-boat rule was then introduced to the effect that a new vessel could be brought into the fishery only if an existing vessel in the fleet were removed simultaneously. Finally, a buy-back program was implemented in which the authorities sought to buy A-licence vessels (plus their licences) and remove them from the fishery (Fraser, 1979).

On the surface, the limited entry program appeared to be successful. By 1980 the number of vessels had been reduced by more than 20 per cent (Canada, Commission on Pacific Fisheries Policy, 1981). The decline, however, was misleading. The market signals that had led to the redundancy problem in the first place had not been altered, with the result that the participants in the fishery were left with every incentive to thwart the intent of the regulations. Thus, when the program was initiated, small vessels were replaced with larger vessels that had correspondingly greater harvesting power. When the authorities countered by changing the boat-for-boat rule to a ton-for-ton rule, the practice of 'pyramiding' quickly arose, in which *sets* of small vessels (e.g., gillnets) were removed from the fleet and their licences combined to permit greater use of larger vessels (e.g., seiners) capable of carrying more equipment per ton. The authorities have only recently undertaken measures to cope effectively with pyramiding.

The buy-back program was short-lived. In purchasing an A-licence vessel the authorities had to purchase the licence, which was marketable, along with the vessel. Since the market prices of licences reflected the present value of expected rents from the fishery, the very anticipation that the limited entry program would have some measure of success led to substantial increases in the prices of the licences. The buy-back scheme became prohibitively expensive for the authorities and was abandoned in 1973 (Fraser, 1979).

It is estimated that between 1969 and the late 1970s the amount of capital employed in harvesting BC salmon may actually have increased by as much as 50 per cent (Fraser, 1979). In 1981 Peter Pearse was authorized to establish a commission of inquiry into the state of Canada's Pacific fisheries. In his preliminary report he described the harvesting capacity in the salmon fishery as 'grossly excessive' (Canada, Commission on Pacific Fisheries Policy, 1981, 53), a view that had the strong support of both the fishing companies and the fishermen's union (Fisheries Association of British Columbia, 1981; United Fishermen and Allied Worker's Union, 1981). The best that can be said for the limited entry program is that, had it not been implemented, the redundancy problem in the fishery might well be worse than it actually is.

The BC salmon fishery is a small boat fishery with many thousands of participants. The lesson of the BC salmon fishery program appears to be that, given the severe policing problem in such a fishery, it is extremely difficult to regulate fishing effort effectively with a system of quantitative controls alone, if it is introduced *after* the redundancy problem has become acute.[28]

If quantitative restrictions on fishing effort prove to be less than satisfactory, presumably one should seek out other means that do what quantitative restrictions fail to do, namely, alter the misleading market signals. Essentially, two methods have been suggested. The first involves the imposition of what amounts to royalties – taxes on landings (or alternatively, upon fishing effort). There exist many theoretical models (e.g., Brown, 1974) that demonstrate that by adjusting market signals such taxes will lead to an optimal level of exploitation of the resource and will prevent the emergence of redundant labour and capital in the fishery.

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species interact with one another. Fleet operations are more often than not carried out on a multi-species basis. Fleets may shift from one species to another over the year, or in the course of their normal fishing operations they may capture fish of several different species simultaneously. See Huppert (1979).

[27] At the time of writing, a major project focused on groundfish stocks off Newfoundland is underway at Memorial University of Newfoundland under the direction of W. Schrank, E. Tsoa, and N. Roy (personal communication).

[28] From this it follows that there is reason to worry about the efficacy of the limited entry programs now being implemented in Canadian Atlantic coast inshore fisheries.

It is interesting to note that the Australians have had considerable success with limited entry programs in small boat fisheries that were introduced *before* the redundancy problem became acute (Parzival Copes, Simon Fraser University, personal communication).

The use of taxes, however, has serious political disadvantages. Imposing a heavy landings tax on large numbers of fishermen in a depressed fishery is certain to have repercussions that any politically sensitive minister would find intolerable. To the author's knowledge, there have been no attempts to use taxes as the sole basis of regulating a fishery. Pearse, however, has recommended that a continued limited entry program and renewed buy-back program in the BC salmon fishery should be supplemented with a landings tax (Canada, Commission on Pacific Fisheries Policy, 1981, 59).[29]

The second method involves establishing a system of individual harvest quotas. Under this approach the authorities determine the total allowable seasonal harvest and then proceed, by any number of means, to assign harvest shares or quotas among individual fishermen (and/or companies). In effect, the fishermen would be awarded property rights, not over the resource itself but over segments of the harvest. Each fisherman would be guaranteed a minimum share of the harvest, and if the quotas were transferable, fishermen could adjust their harvest shares through the market. Thus, it is argued, fishermen would have no incentive to waste labour and capital by competing for harvest shares (Clark, 1980; Maloney and Pearse, 1979).

The individual harvest quota approach does not appear to have the political disadvantages associated with taxes. The approach has over time gained considerable support among economists, both academic and non-academic (e.g., Economic Council of Canada, 1980; Scott and Neher, 1981). Furthermore, the federal government has recently introduced a system of such quotas on a company-by-company basis for Atlantic coast offshore groundfisheries (*Canadian Fishing Report*, February 1982, 3).

One cannot safely assume, however, that the approach can be applied universally. In those fisheries in which the Total Allowable Catches (TACs) are stable and reasonably predictable, such as the aforementioned Atlantic coast offshore groundfisheries, systems of individual harvest quotas are indeed appealing (Munro and McCorquodale, 1981). On the other hand, in those fisheries where the TACs are highly uncertain on a season-to-season basis, the feasibility of individual harvest quotas is open to serious question. It is interesting to note that in his interim report Pearse recommended individual harvest quotas for the halibut fishery (the most valuable BC groundfishery) but declined to do so for the salmon fishery, in which year-to-year harvests are subject to wide and unpredictable fluctuations (Canada, Commission on Pacific Fisheries Policy, 1981, chapters 5 and 6).[30]

EXTENDED FISHERIES JURISDICTION: SOME IMPLICATIONS

Extended Fisheries Jurisdiction has arisen out of attempts by coastal states since 1945 to extend their property rights over resources in the seas and seabed off their coasts. As a consequence of EFJ, Canada has acquired de facto, if not de jure, property rights over fishery resources within the so-called Exclusive Economic Zones (EEZs) that extend 200 miles off its coasts. In this section we discuss very briefly two issues arising from EFJ. These are the role to be played by so-called distant water nations in the EEZs of Canada and other coastal states and the management of transboundary stocks.

The first issue revolves around the desirability, or lack thereof, of co-operative fisheries arrangements in which distant water nations are invited to participate in the exploitation of fishery resources in coastal state zones. Since the coastal state retains property rights over the resources, it has the right to expect to enjoy a return from distant water nation participation. Thus, the question, from the point of view of the coastal state, of distant water nation participation, is quite simply whether or not such participation by distant water nations will enhance the coastal state's return from the relevant fisheries. The economics of such arrangements is a reasonably straightforward blend of the economics of fisheries management and the economics of international trade (Munro, 1981b). It will come as no surprise to learn that the economic theory of such arrangements suggests that coastal states and distant water nations should be able to look forward, to their mutual benefit, to establishing such arrangements on an indefinite basis (Chan, 1978).

Canada, however, like many other coastal states at the dawn of EFJ, advocated what was essentially a policy of ultimate marine autarky.[31] Over time, however, the economic disadvantages of marine autarky have become manifest, and Canada, once again like many other coastal states, has come to look with greater favour upon co-operative arrangements.[32]

The second issue arises by virtue of the mobility of fish. Many coastal states have discovered that several of their newly acquired fishery resources cross either into the zones of neighbouring coastal states or into the high seas.[33] Examples of both types of transboundary stocks are to be found off Canada's Atlantic coast.

The economic theory of transboundary stocks management indicates that, if the joint owners of such resources succeed in co-operating, it will be possible to establish

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[29] The proposal brought forth vehement objections from the fishermen's union. 'Union fishermen wage war on Pearse,' *Vancouver Province*, 13 December 1981, B2.

[30] We have talked as if taxes and individual harvest quotas were entirely separate approaches. There is, of course, no reason why combinations cannot be used.

[31] In 1974 the then federal minister responsible for fisheries stated, in looking forward to EFJ, that 'The long-term is for Canadians. Canada is not only going to reach out and encompass all of the living resources on her continental shelf and slope, we are going to make sure that they are harvested by Canadians in Canadian-owned vessels, and processed in Canada as well' (cited in Tomlinson and Vertinsky, 1975, 2570).

[32] In a recent speech, the current federal minister responsible for fisheries warned his listeners that 'we must not … perpetuate some myth that we must catch every fish in our zone. Such a concept is fool's gold' (Le Blanc, 1981).

An example of a co-operative arrangement whose life expectency appears to be more than short-term involves a hake (groundfish) fishery off British Columbia. Canadian fishing vessels harvest the resource and then deliver the catch to foreign processing vessels, for example, Soviets and Poles. Since the Canadian fleet is not large enough to take the entire TAC deemed appropriate by the Canadian authorities, foreigners are also given rights to harvest the resource, for a price. In other words, the resource is in part rented out to the foreigners (Munro, 1981b).

[33] Transboundary stocks existed before EFJ, of course, but EFJ has produced a quantum increase in their number and hence a substantial increase in the importance of the transboundary resource management (Gulland, 1980).

a compromise optimal management program. This will be true, even though each joint owner strives to maximize its share of the return from the resource and even though the joint owners differ in their goals and interests to the extent that each has a different perception of the optimal management strategy (Munro, 1979). The theory also indicates, however, that if the joint owners fail to co-operate, common property conditions will re-emerge with all that that implies (Levhari and Mirman, 1980).

Canada's experience with transboundary resources to date has been mixed. While some limited progress has been made on the Pacific coast with resources owned jointly with the United States, the progress on the Atlantic coast has been disappointing. Despite this lack of progress, Canadian-American transboundary resources problems appear straightforward in comparison with those to be found in other parts of the world, such as the North Sea and the South Pacific. Unquestionably the problem of transboundary fishery resources will be a source of study (and employment) for renewable resource economists for many years to come.

CONCLUSIONS

The major theoretical development in fisheries economics over the past two decades has taken the form of recasting the theory in dynamic or capital-theoretic terms. The need for such a development was recognized at the birth of modern fisheries economics three decades ago, but the development had to wait upon the development in turn of adequate mathematical tools.

The shift from static to dynamic analysis in fisheries economics does not alter the fact that the central problem in fisheries management is the same as it was when H. Scott Gordon published his seminal article in 1954. Fishery resources are by their very nature common property, with the consequence that fishermen are given every incentive to discount wholly future returns from the resources. Most of the major economic policy issues in fisheries stem from this fundamental fact.

The coming of Extended Fisheries Jurisdiction has mitigated the common property problem in the management of world fishery resources. It has not, however, solved the problem. If the coastal state beneficiaries of EFJ, such as Canada, are incapable of improving their economic management of fishery resources, the benefits of EFJ may well prove to be emphemeral.

REFERENCES

Andersen, Peder and Jon G. Sutinen (1981) 'A survey of stochastic bioeconomics: methods and results.' Paper presented to the Workshop on Uncertainty and Fisheries Economics, University of Rhode Island

Anderson, Lee G. (1977) *The Economics of Fisheries Management* (Baltimore: Johns Hopkins).

Baker, D. (1980) *The Capital Development Fund: A Capital Assistance Plan for Fishermen.* Report prepared for the Government of Canada, Department of Fisheries and Oceans (Halifax)

British Columbia Packers Limited (1981). 'Submission to the Commission on Pacific Fisheries Policy,' Vancouver

Brown, G. Jr (1974) 'An optimal program for managing common property resources with congestion externalities.' *Journal of Political Economy* 82, 163–74

Canada, Commission on Pacific Fisheries Policy (1981) 'Conflict and opportunity: toward a new policy for Canada's Pacific fisheries.' *Preliminary Report* Vancouver

Canada, Department of the Environment, Fisheries and Marine Service (1976) *Policy for Canada's Commercial Fisheries* (Ottawa)

Canada, Department of Fisheries and Oceans (1979) *Northern Cod Seminar: Final Report* (Ottawa)

— (1981) *Resource Prospects for Canada's Atlantic Fisheries 1981–1987* (Ottawa)

Chan, Kenneth Shun-Yuen (1978) 'The economic consequences of the 200-mile seabed zone.' This JOURNAL 11, 314–18

Charles, Anthony and Gordon R. Munro (1981) 'Irreversible investment and optimal fisheries management: a stochastic analysis.' Paper presented to the Workshop on Uncertainty and Fisheries Economics, University of Rhode Island

Clark, Colin W. (1973) 'Profit maximization and the extinction of animal species.' *Journal of Political Economy* 81, 950–61

— (1976) *Mathematical Bioeconomics: The Optimal Management of Renewable Resources* (New York: Wiley)

— (1980) 'Towards a predictive model for the economic regulation of fisheries.' *Canadian Journal of Fisheries and Aquatic Sciences* 37, 1111–29

— Frank H. Clarke, and Gordon R. Munro (1979) 'The optimal exploitation of renewable resource stocks: problems of irreversible investment.' *Econometrica* 47, 25–47

— G. Edwards, and M. Friedlaender (1973) 'Beverton-Holt model of a commercial fishery: optimal dynamics.' *Journal of the Fisheries Research Board of Canada* 30, 1629–40

— and Gordon R. Munro (1975) 'The economics of fishing and modern capital theory: a simplified approach.' *Journal of Environmental Economics and Management* 2, 92–106

— and Gordon R. Munro (1978) 'Renewable resource management and extinction.' *Journal of Environmental Economics and Management* 5, 198–205

— and Gordon R. Munro (1980) 'Fisheries and the processing sector: some implications for management policy.' *The Bell Journal of Economics* 11, 603–16

Copes, P. (1972) 'Factor rents, sole ownership and the optimal level of fisheries exploitation.' *Manchester School of Economic and Social Studies* 40, 145–64

Crutchfield, James (1956) 'Common property resources and factor allocation.' *Canadian Journal of Economics and Political Science* 22, 292–300

— and Arnold Zellner (1962 'Economic aspects of the Pacific halibut fishery.' U.S. Department of the Interior, *Fishery Industrial Research* 1:1 (Washington D.C.: USGPO)

Dasgupta, P.S. and G.M. Heal (1979) *Economic Theory and Exhaustible Resources* (Cambridge: Cambridge University Press)

Dorfman, R. (1969) 'An economic interpretation of optimal control theory.' *American Economic Review* 59, 817–31

Economic Council of Canada (1980) *Newfoundland: From Dependence to Self-Reliance* (Ottawa: EEC)

Ferris, S. and C. Plourde (1980) 'Fisheries management and employment in the Newfoundland economy.' Economic Council of Canada Discussion Paper No. 173

Fisheries Association of British Columbia (1981) 'Submission to the Commission on Pacific Fisheries Policy.' (Vancouver)

Fraser, G. A. (1979) 'Limited entry: experience of the British Columbia salmon fishery. *Journal of Fisheries Research Board of Canada* 36, 754–63

Gordon, H. Scott (1954) 'The economic theory of a common-property resource: the fishery.' *Journal of Political Economy* 62, 124–42

— (1956) 'Obstacles to agreement on control in the fishing industry.' In Ralph Turvey and Jack Wiseman, eds, *The Economics of Fisheries* (Rome: Food and Agriculture Organization of the United Nations), 65–72

Gould, J.R. (1972) 'Extinction of a fishery by commercial exploitation: a note.' *Journal of Political Economy* 75, 274–86

Gulland, J.A. (1980) 'Some problems of the management of shared stocks.' Food and Agriculture Organization of the United Nations *Fisheries Technical Paper*, no. 206 (Rome: FAO)

— and L.K. Boerema (1973) 'Scientific advice on catch levels.' *Fishery Bulletin* 71, 325–35

— and M.A. Robinson (1973) 'Economics of fishery management.' *Journal of the Fisheries Research Board of Canada* 30, 2042–50

Hannesson, R. (1975) 'Fishery dynamics: a North Atlantic cod fishery.' This JOURNAL 8, 151–73

Huppert, D.D. (1979) 'Implications of multipurpose fleets and mixed stocks for control purposes.' *Journal of the Fisheries Research Board of Canada* 36, 845–54

Le Blanc, Roméo, minister of fisheries (1981) 'Notes for an address following the Christening of the Fisheries Patrol Vessel Cygnus: October 3rd.' Marystown, Newfoundland

Levhari, D., R. Michener, and L.J. Mirman (1981) 'Dynamic programming models of fisheries.' *American Economic Review* 71, 649–61

— and L.J. Mirman (1980) 'The great fish war: an example using a dynamic Cournot-Nash solution.' *The Bell Journal of Economics* 11, 322–34

Lewis, Tracy R. (1981) 'Exploitation of a renewable resource under uncertainty.' This JOURNAL 14, 422–39

— and R. Schmalensee (1979) 'Non-convexity and optimal harvesting strategies for renewable resources.' This JOURNAL 12, 677–91

Long, N.V. (1977) 'Optimal exploitation and replenishment of a natural resource.' In John Pitchford and Steven Turnovsky, eds, *Application of Control Theory to Economic Analysis* (Amsterdam: North Holland), 81–106.

Ludwig, Donald (1979) 'Optimal harvesting of a randomly fluctuating resource. I: applications of perturbation methods.' *SIAM Journal of Applied Mathematics* 37, 166–84

Maloney, D.G. and P.H. Pearse (1979) Quantitative rights as an instrument for regulating commercial fisheries.' *Journal of the Fisheries Research Board of Canada* 36, 859–66

Munro, Gordon R. (1979) 'The optimal management of transboundary renewable resources.' This JOURNAL 12, 355–376

— (1980) *A Promise of Abundance: Extended Fisheries Jurisdiction and the Newfoundland Economy* (Ottawa: Economic Council of Canada) imp

— (1981a) 'The economics of fishing: an introduction.' In John A. Butlin, ed., *Economics and Resources Policy* (Longman: London)

— (1981b) 'Co-operative fisheries arrangements between Pacific coastal states and distant water nations: prospects for the long-run.' Mimeo. Paper presented to the Twelfth Pacific Trade and Development Conference, Vancouver

— and Susan McCorquodale (1981) 'The northern cod fishery of Newfoundland.' Economic Council of Canada Technical Report No. 18 imp

Neher, P.A. (1974) 'Notes on the Volterra quadratic fishery.' *Journal of Economic Theory* 6, 39–49

Newfoundland and Labrador (1980) *Managing All Our Resources: A Development Plan for Newfoundland and Labrador 1980–1985* (St John's: Government of Newfoundland and Labrador) imp

Peterson, Frederick M. and Anthony C. Fisher (1977) 'The exploitation of extractive resources: a survey.' *The Economic Journal* 87, 681–721

Pearse, P.H. and J.E. Wilen (1979) 'Impact of Canada's Pacific salmon fleet control program.' *Journal of the Fisheries Research Board of Canada* 36, 518–22

Plourde, G.C. (1970) 'A simple model of replenishible resource exploitation.' *American Economic Review* 60, 518–22

— (1971) 'Exploitation of common-property replenishible resources.' *Western Economic Journal* 9, 256–66

Quirk, J.P. and V.L. Smith (1970) 'Dynamic economic models of fishing.' In A.D. Scott, ed., *Economics of Fisheries Management: A Symposium* (Vancouver: University of British Columbia, Institute for Animal Resource Ecology)

Reed, William J. (1979) 'Optimal escapement levels in stochastic and deterministic harvesting models.' *Journal of Environmental Economics and Management* 6, 350–63

Schaefer, M.B. (1957) 'Some considerations of population dynamics and economics in relation to the management of marine fisheries.' *Journal of the Fisheries Research Board of Canada* 14, 669–81

Schworm, William E. (1981) 'Monopsonistic control of a common property renewable resource.' University of British Columbia, Department of Economics, Discussion Paper No. 81-34

Scott, Anthony D. (1955) 'The fishery: the objectives of sole-ownership.' *Journal of Political Economy* 63, 116–24

— and Philip A. Neher (1981) *The Public Regulation of Commercial Fisheries in Canada.* (Ottawa: Economic Council of Canada) inf

Silvert, William and William R. Smith (1977) 'Optimal exploitation of a multi-species community.' *Mathematical Biosciences* 33, 121–34

Smith, V.L. (1977) 'Control theory applied to natural and environmental resources: an exposition.' *Journal of Environmental Economics and Management* 4, 1–24

Tomlinson, J.W.C. and J. Vertinsky (1975) 'International joint ventures in fishing and 200-mile economic zones.' *Journal of the Fisheries Research Board of Canada* 32, 2569–79

Uhler, R.S. (1980) 'Least squares regression estimates of the Schaefer production model: some Monte Carlo results.' *Canadian Journal of Fisheries and Aquatic Sciences* 37, 1284–94

United Fishermen and Allied Workers Union (1981) 'Brief presented to the Commission on Pacific Fisheries Policy.' Vancouver

Warming, Jens (1911) 'Om grundrente of fiskgrunde.' *Nationalokonomisch* Fidsskrift 49, 499–505. (An English translation of this article with introduction by Peder Andersen is forthcoming in *History of Political Economy*.)