Capital Theory and the Economics of Fisheries: Implications for Policy

Colin W. Clark* and Gordon R. Munro**

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* Professor Emeritus, Department of Mathematics, University of British Columbia, Vancouver, Canada

** Professor Emeritus, Vancouver School of Economics and Institute of Oceans and Fisheries, University of British Columbia, Vancouver, Canada

I Introduction

What we shall attempt to do in this paper is first to review briefly what we think we accomplished, starting some 40 years ago, and then follow up with the question: did these accomplishments in fact really matter for policy purposes, or are they of theoretical interest only? We shall next want to recognize a few limitations to our earlier analysis, and indicate how those limitations can be addressed.

In reviewing what we think that we may have accomplished going back 40 years, we must at the outset recognize the immense contributions of those who have followed. Many have extended our early analysis; many others have subjected that early analysis to empirical validation or correction. We cannot begin to list the many here (for a listing, which we hope is not too incomplete, see: Bjørndal and Munro, 2012,).

Following all of this, we want to point to areas of future research, which we are convinced are worth pursuing, and which we find to be interlinked. The first relates to the economics of the large investments in capture fishery resources, called for by the FAO, World Bank, OECD and others. The other relates to a theme that has been dear to the heart of one of the authors for several years, namely that of cooperative management of intra-EEZ (and intra-EU) fishery resources and the increasing relevance to such management of the theory of strategic interaction (game theory).

II Capital Theory and Fisheries

We are probably best known in economic circles for having brought the theories and capital and investment firmly into fisheries economics (Munro and Sumaila, 2015). We have been at some pains, however, to insist that the recognition of the importance of these two theories to fishery economics preceded the coming together of Colin Clark and Gordon Munro by decades.

February 2015 saw the passing of Anthony Scott, the first recipient of an IIFET Fellow Award in 2010. Anthony Scott was a pioneer, not just of modern fisheries economics, but of natural resource economics in general. In the 1953, Scott completed his PhD dissertation, which two years later was to be published in revised form as the book:

Natural Resource Economics: The Economics of Conservation (Scott, 1955a). In the book, and in articles arising from his dissertation, Scott was the first to make it absolutely clear that the economics of natural resources is first and foremost an application of the economist's theories of capital and investment. Thus, for example, in the article, "Conservation Policy and Capital Theory", which preceded the publication of his book by a few months, Scott states that: " ---- the important thing --- is that natural resources are the capital of a region, just as man-made equipment is; and that conservation is investment, just as augmenting the supply of machines is investment" (Scott, 1954, p. 506). Others before Scott had hinted at all of this. They did so, however, without clarity (Munro, 2015; Brown, et al., forthcoming).

Scott is best known to fisheries economists for his 1955 *Journal of Political Economy* article, "The Fishery: The Objectives of Sole Ownership" (Scott, 1955b). Scott's 1955 *JPE* article is essentially an application of his insights from *Natural Resource Economics: The Economics of Conservation* to the economics of fisheries (Munro, 2015).

In spite of Scott's insights, however, fisheries economics continued to be based largely on the static analysis of fisheries management, which can be traced back to Warming in 1911 (Warming, 1911), and which was most fully developed in the famous 1954 *JPE* article of H. Scott Gordon, "The Economic Theory of a Common Property Resource: The Fishery" (Gordon, 1954). What were the reasons for this? The reasons, we would suggest, were the inherent difficulties of applying capital theoretic analysis in detail to natural resources as complex as capture fishery resources. These difficulties were set forth lucidly by Gordon, the author of the famous static analysis of the fishery, in a 1956 FAO conference paper. In that paper, Gordon states:

> The conservation [positive investment in a natural resource] 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 utilisation 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 (Gordon, 1956; cited in: Bjørndal and Munro, 2012, p. 36).

The American macro-economist, Gardner Ackley, argues that a clear distinction must be made between the theory of capital and the theory of investment, although they are obviously very closely related. The theory of capital is about stocks, addressing the question of what is the optimal stock of a particular type of capital. The theory of investment is about flows, addressing the question of what the optimal rate is, at which a stock of capital should be increased, or depleted, if current stock of the capital is below or above the optimal stock level (Ackley, 1978). Thus, Gordon's "very complicated problem" is one of two parts.

We modestly lay claim to having been the first to achieve a tractable solution to the Gordon two part problem, in that we were able to bring forth reasonable fisheries natural capital investment decision rules (Clark and Munro, 1975). This was done through the application of optimal control theory, which was unavailable to H. Scott Gordon and Anthony Scott in the mid-1950s. When our fellow economists talk about the Clark-Munro model, they are more often than not referring to the 1975 linear, autonomous version of that model, which has as its foundation the famous Schaefer biological model. Consider the now well known equation from that version of the model:

$$F'(x^*) - \frac{c'(x^*)F(x^*)}{(p - c(x^*))} = \delta \qquad (1)$$

where x denotes the biomass of the resource, x*, the optimal biomass level, F(x) the net natural growth rate of the resource, c(x) unit cost of harvesting p the price of harvested fish, and δ the social rate of discount. Consider, as well, the also well known accompanying equation:

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$$h^*(t) = \begin{cases} h_{max}, \text{if } x(t) > x^* \\ F(x^*), \text{if } x(t) = x^* \\ 0, \text{if } x(t) < x^* \end{cases} \qquad (2)$$

where h(t) is the harvest rate.

Eq. (1) is the theory of capital equation, answering the question of the optimal stock of the natural capital, x*, and as such is a version of the Modified Golden Rule of Capital Accumulation from elementary capital theory. It states simply, invest in x up to the point that "own rate of interest" (or internal rate of return) of the marginal investment in x is equal to the social rate of discount. Our colleagues Trond Bjørndal and Daniel Gordon kindly describe the equation as "---readily comprehensible and intuitively appealing, to economists" (Bjørndal and Gordon, 2007). We now concede, however, that the equation is unnecessarily complex for non-academic economists, policy makers in particular. We will demonstrate that the basic idea behind the equation can be presented in a much simpler form.

Furthermore, the equation conceals the intrinsic growth rate of the resource. It stands to reason that our willingness to invest in a fishery resource will be influenced by whether the resource is slow growing, fast growing, or somewhere in between. The answer is that the intrinsic growth rate will in fact have a profound influence, which you would be hard pressed to detect in Eq. (1). This concealment we now recognize is a significant limitation to our "readily comprehensible and intuitively appealing" equation. Finally , we recognize that we have to provide a sharper defintion of the term "social rate of discount", δ, than we have in the past. This is a seemingly very esoteric matter, but the definition does have policy implications. More on all of this later.

Eq (2) is the theory of investment equation prescribing the optimal rate of investment/disinvestment in x. It states that, if $x(0) < x^*$, the optimal rate of positive investment in the resource is the *maximum* rate; if $x(0) > x^*$, the opitmal rate of disinvestment is the *maximum* rate. What could be simpler? This simple theory of investment rule has had great appeal, and has, we regret to say, been the source of endless trouble and confusion, right up to the present day. As we have attempted to demonstrate many times, but with limited success, this simple theory of investment rule is valid, only under very special and very restrictive conditions. Once again, more on this later.

Prior to dealing with the limitations identified with respect to Eqs. (1) and (2), let us address the fundamental question of whether all of this really matters for policy purposes. With the benefit of hindsight, the mid-1960s can be seen as the high water mark of the static economic model of capture fisheries. During that period, Ralph Turvey published a widely cited article on the economics of fishery regulations in the *American Economic Review* (Turvey, 1964). In the article, Turvey comments on the capital theoretic aspects of fisheries management. In so doing, he states that "---all of this complicates matters, but introduces no interesting new principles" (Turvey, 1964, p.75). The capital theoretic aspects are difficult, as Gordon had said, and are really not worth the trouble of confronting.

While the mid-1960s may have been the high water mark of the static economic model of the fishery, the model has not lost its great appeal. How do we answer all of this?

We would hope that the answer would now be seen as self-evident. To begin, we are, as we noted earlier, faced with a major world capture fisheries policy problem, namely the rebuilding of capture fishery resources, which had been overexploited in the past. Restoration of some of the slower growing fishery resources could, under the best of circumstances take decades (Costello, et al., 2016). What is this large rebuilding of fishery resources program, other than an investment program in a particular form of natural capital? The program presents us with a problem that is dynamic, by definition; the economics of which is, once again by definition, an application of the theories of capital and investment.

The returns on such investment will appear only in the future, the uncertain future. From this it follows that application of dynamic analysis forces us to face up to the problem of uncertainty, and forces us to address the question of how best to mitigate the consequences of uncertainty. Uncertainty in fisheries management has now gained official recognition in policy circles, to the extent that it has become embedded in international treaty law, in the form of the Precautionary Approach to fisheries management (see, for example, the UN Fish Stocks Agreement; UN, 1995, Article 6).

The focus on resource investment does in turn give us a clearer idea of the nature of the ideal domestic (intra-EEZ) fisheries management scheme. It is one that will do more than to cause the fishers to act in an economically efficient manner in a static sense. It will, as well, give them an incentive to invest positively in the fishery resources.

There are many other benefits that arise from a dynamic approach to fisheries economics. Let us take but two examples, with the first being increasingly popular ecosystem approach to fisheries management. An ecosystem approach, in its narrowest form, recognizes the limitations of the single species approach to fisheries management; recognizes that species are linked by the nature of the fishery and/or through natural species interaction, e.g. predator-prey relationships (National Research Council, 1999). The dynamic economic model can deal with these ecosystem interrelationships, conceptually at least, with some ease, in a way that the static model simply cannot. In taking the dynamic approach, we envisage the social resource manager as a manger of assets. Very few, if any, asset managers are managers of single assets. Rather they are portfolio managers. The social manager taking an ecosystem approach to fisheries management is to be seen as a portfolio manager. Like any sensible portfolio manager, he/she will be concerned with the net economic return over time, not on individual fishery assets, but rather on the portfolio as a whole.

Attempts to model the ecosystem can, it is true, run into overwhelming complexities very rapidly. Our point remains, nonetheless. Note our use of the term *conceptually.* Furthermore, economic modelling of fisheries in an ecosystem setting, with ecosystem narrowly defined, goes back 40 years (Clark, 1976); modelling, which did, in turn, lead to numerous empirical applications (e.g., Flaaten, 1988; Eide and Flaaten ,1998).

The second takes the form of forcing us to face up to various manifestations of the time consistency problem in fisheries management. In the management of international fishery resources, we have learned painfully that cooperative fishery management arrangements must be time consistent, in the sense that cooperative fishery management arrangements, which are stable today, will not be tomorrow, unless they have sufficient resilience to withstand unpredictable shocks, be these shocks environmental, economic or political (Miller et al., 2013) In domestic fisheries management, time consistency problems can arise, if future policy changes of the resource managers can be predicted by the fishers/vessel owners. Buyback (decommissioning) schemes constitute a classic case in point (Clark, et al., 2005).

Now let us turn back to the two equations. The first limitation of Equation (1), the theory of capital equation, which we identified, is its complexity. The basic idea behind the equation, in determining the optimal stock level, x*, can, in fact. be demonstrated in a particular simple and straightforward manner as follows:

The complexity of Eq. (1) arises from the fact the Clark-Munro model, in its simplest form is dynamic version of the H. Scott Gordon model ,which in turn rests upon the famous biological model of M.B. Schaefer. From the Schaefer model, we have the following harvest production function:

$$h = qx^{\alpha}E^{\beta} \qquad (3)$$

where x is the biomass ,as before, E denotes fishing effort, and α and β are constants. By assumption in the Schaefer model, $\alpha = \beta = 1$. The consequence of this assumption is that harvesting costs become a function of the biomass, x. The larger is the biomass, the lower are harvesting costs. The LHS of Eq. (1) reflects the impact of a marginal investment in x upon harvesting costs, and is thus complex.

It is well known that there are many fishery resources for which the Schaefer assumption does not hold. In particular, there are fisheries for which it will be found that $\alpha \ll 1$. Take the extreme case in which $\alpha = 0$. In this case, harvesting costs are independent of the size of the biomass (so long as the biomass is positive). Given our linearity assumptions, unit harvesting costs can be expressed simply as c. The net value of a unit of harvested fish is thus equal simply to: p-c. The complexities of Eq. (1) disappear.

Suppose now that the current biomass level is x, and consider the net economic benefits from a marginal change from x to x-1. This will give an immediate net economic return equal to (p-c)1. There will be a cost, however, in that the future stream of sustainable resource rent will be reduced. Express sustainable resource rent at any point in time as: R= (p-c)F(x). The present value of the reduced, lost, stream of sustainable resource rent can be expressed as:

$\frac{dR/dx}{\delta} = \frac{(p-c)F'(x)}{\delta}$, where, as before, δ is the social rate of discount[1].

Our resource investment decision rule now becomes invest (or disinvest) up (down) to the point that:

$$(p-c) = \frac{(p-c)F'(x^*)}{\delta} \quad (4)$$

or :

$$\frac{(p-c)F'(x^*)}{(p-c)} = \delta, \quad (5a)$$

where the LHS is now the simple “own rate of interest” on the marginal investment in the resource.

Eq.(5a) does, of course, reduce to:

$$F'(x^*) = \delta, \quad (5b)$$

which will be familiar from elementary theory of capital, to all students of Economics.

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[1] Economists will recognize the expression as a Keynesian type marginal user cost.

By the way, Eq.(5b) implies that, if $\delta > 0$, $x^* < x_{MSY}$. The model of H. Scott Gordon, however, implies that we will ALWAYS have: $x^* > x_{MSY}$ (unless fishing effort costs are equal to 0, which they never are) –an apparent complete contradiction.

The contradiction can be resolved by returning to Eq.(1). With the Gordon model, resting as it does upon the Schaefer biological model, we find on the LHS that: $-\frac{c'(x^*)F(x)}{p-c(x^*)}$,

which reflects the impact of the marginal investment in x on harvesting costs and is referred to as the Marginal Stock Effect (MSE), is positive. It has been demonstrated that the Gordon model implies that $\delta = 0$ (Clark, 1976). Given that the MSE >0 and that $\delta = 0$, Eq.(1) can hold, if and only if $F'(x^*) < 0$, which implies that $x^* > x_{MSY}$.

The second limitation of the Equation (1) is that it conceals the intrinsic (i.e. maximum) growth rate of the resource, a parameter, which is used by marine biologists to gauge whether a fishery resource is slow growing, fast growing or in between. Thus, for example, we can contrast bigeye scad, having an intrinsic annual growth rate of 0.75, with orange roughy, having an intrinsic annual growth rate of 0.025 (Froese and Pauly, 2009).

Equation (1), it will be recalled, rests upon the Schaefer biological model. From that model we have:

$F(x) = rx(1-x/G)$ and $F'(x) = r(1-2x/G)$,

where **r** is the intrinsic growth rate, and G is the carrying capacity. Now on the LHS of Eq. (1), substitute for $F'(x)$ and $F(x)$. We end up with an exceptionally cumbersome (gauche) equation, but it becomes immediately apparent that on the LHS of the equation we can factor out **r**. We could re-write the equation simply as:

$$r\left(\theta\left(x^*\right)\right) = \delta \qquad (6)$$

(where the nature of θ (x) will be obvious to the reader).

The implication is that the “own rate of interest” is *proportional* to **r.** Consider just what this means.

Take two fishery resources, appropriately modeled by the Schaefer model. The fishery resources are identical in all respects, except that in the case of the first resource, r = 0.60, while in the second case, r = 0.03. Assume that the prices of harvested fish in the two fisheries based upon the resources are constant and identical; assume that unit fishing effort costs in the two fisheries are constant and identical.

Now let it be supposed that in the case of the first resource the “own rate of interest” of the resource evaluated at $x = x_{MSY}$ is: 0.50 ,i.e. 50%. The “own rate of interest” of the second fishery resource $x = x_{MSY}$ will prove to be 0.025, i.e. 2.5%. Low intrinsic growth rates do not just mean that it takes such resources a long to time to rebuild. Low intrinsic growth rates mean miserable returns on investments in the resources. All of this serves to re-emphasize the economic vulnerability of fishery resource with low intrinsic growth rates, e. g. orange roughy.

We shall, at a later point, discuss the possibilities of co-management, in which the fishing industry, given the right incentive structure, may be in a position to influence the management of the resource, now and in the future. As stressed by the OECD (2012), complications could arise, if the private discount rate differs significantly from the social rate of discount. In particular, we could find that: $\delta_p >> \delta_s$. It can be shown that the magnitude of the complications will vary with the size of **r.** If the fishery resource is a fast growing one, the differences in the rates of discount may not matter all that much. If the fishery resource is a slow growing one, the differences in the rates of discount will matter, and matter a great deal.

Let us illustrate with an elementary example. Suppose that all of our linearity assumptions hold and suppose that harvesting costs are independent of the size of the biomass. From Eq.(5b), we an express our investment decision rule as:

$r\left(1-\frac{2x^*}{G}\right)=\delta$, which allows us to calculate x* with ease.

Next, suppose that the private rate of discount is: δ_P= = 0.10; while the social rate of discount is: δ_S = 0.03, neither unreasonable. Suppose further that we have G, the carrying capacity (or natural equilibrium level) of the resource, being: G = 400.

Now consider two separate cases I and II. In Case I we have **r** = 0.60; while in Case II, we have **r** = 0.11

Denote x*, as perceived by the private sector and the social (public) sector, as: $x_P^*; x_S^*$ respectively .

Next calculate the two perceived optimal biomass levels in Case I – fast growing resource. We have:

$x_P^* = 167; x_S^* = 190$, where the private sector's perceived optimal biomass level is approximately **12** per cent below the social sector's perceived optimal biomass level.

In Case II –slow growing resource we have:

$x_P^* = 18; x_S^* = 146$, where the private sector's perceived optimal biomass level is approximately **88** per cent below the social sector's perceived optimal biomass level.

Finally, with respect to Eq. (1), let us attempt to sharpen up our definition of the "social rate of discount". To begin, we talk about a social, as opposed to a private, rate of discount because we, along with the World Bank and FAO (2009), see the capture fishery resources as public resources. In the case of the United Kingdom, for example, we would see the social rate of discount as being as the discount rate employed by the UK Treasury for public investments.

We put forward the proposition that the social rate of discount applied to investment in capture fishery resources is best seen as a measure of opportunity cost. Investment opportunities in fishery resources represent a very modest component of society's total investment opportunities, during any given period of time. Given that, during any period of time, society's savings are finite and scarce in relation to society's investment opportunities, it follows that any part of those savings devoted to investment in fishery resources will come at the expense of other investment opportunities open to society. IIFET Fellow Anthony Scott made this point forcefully, with respect to natural resources in general, over 60 years ago, in his book, *Natural Resources: The Economics of Conservation* (Scott, 1955a). We quote Scott as follows, recalling that he uses the expression “conservation of natural resources” to mean positive investment in these resources.

> Conservation of [natural] resources is not only analogous to investment in [produced] capital goods; it is also, in each planning period, an actual alternative to investment in –[such] goods---Society must continually choose how it will allocate resources among competing uses----. Conservation of [natural] resources is only one of many possible choices; one that implies sacrificing ----investment in produced means of production in favour of increased future supplies of a group of ‘natural’ resources. Given an aggregate amount of savings available for investment in each time period, increased conservation of [natural] resources must mean also a reduced endowment of buildings and equipment for posterity (Scott, 1955, pp. vi-vii).

How to deal with this savings allocation problem? Think of society having a vast portfolio of real capital assets, some of which take the form of “natural” capital. We have a problem of portfolio balance, or equilibrium. We then invoke the rule that portfolios are to be seen in equilibrium “when all assets in a given risk class earn the same rate of return-----. The common rate of return is the interest [discount] rate for that risk class” (Solow, 1974, p.2)[2]. If the allocation of society savings to various investment opportunities (enhancing the size of the portfolio) leads to this rule being violated, then we conclude that the savings have been misallocated, from society’s point of view.

We think, rightly or wrongly, of the social rate of discount as representing that “common rate of return”, and do so with the following added argument. The World Bank and FAO

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[2] Solow puts forth this rule in a discussion of the economics of non-renewable natural resources. The rule applies with equal force to renewable natural resources.

(2009) do, as we have pointed out, regard capture fishery resources as public property, from which if follows that investment in these resources can be seen as a type of public investment. It seems not inappropriate to use the same rate of discount that is used for other public investments. Returning to the UK example, the social rate of discount historically has been in the order of 3.5 per cent (in real terms, for investment periods of up to 30 years) (U.K., HM Treasury, 2011).

Does all of this matter from a policy perspective? The answer is that it does, given the ongoing popularity of the static economic model of the fishery. To repeat, the H. Scott Gordon model – Gordon –Schaefer model – implicitly assumes that the social rate of discount, δ, is: $\delta = 0$ (Clark, 1976)[3].

Now suppose that, through great effort and sacrifice, we had all of the world's capture fishery resources built up to and stabilized at levels dictated by the Gordon-Schaefer model. Then surely, in so doing, we would be doing the very best possible for future generations, would we not? Actually, we would not, because such a policy would lead to a misallocation of world saving available for investment purposes, to the detriment of future generations. The misallocation would be particularly egregious, as we can now surmise, in the case of the application of the Gordon –Schaefer type policy to capture fishery resources with low intrinsic growth rates.

Next let us turn to Eq. (2), the theory of investment equation. The investment program prescribed by the equation in the case of fishery resources that are to be rebuilt is draconian. An outright harvest moratorium is to be declared and maintained until the goal, x^*, is achieved, even if this takes decades. The fate of fishing industries and communities dependent upon these resources is of no concern on economic grounds, or so it would seem. If concessions are made to this draconian policy, it would have to be on social and political grounds.

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[3] Gordon was unaware of this implicit assumption. One of the authors (Clark) met Gordon in the late 1970s, and in so doing convinced Gordon of the existence of the implicit assumption in his famous 1954 article. Gordon was appalled.

This policy continues to attract. For example, the World Bank/FAO study, *The Sunken Billions* (World Bank, 2009) was accompanied by a number case studies, several of which addressed the question of rebuilding hitherto overexploited fish stocks. These studies maintain that the resource investment program, which would maximize the present value of the stream of future net economic returns from the resources, is that set out by Eq. (2). The studies go on to state that political and social pressures may force the implementation of a "reasonable" resource restoration program, in which there is not an outright harvest moratorium (Munro, 2010). "---- the implication is that the economist's prescription for an economically sound resource stock rebuilding program, *pur et dur*, will likely have to be modified (most regrettably) in the face of the social/political pressures" (Munro, 2010, p.107). Larkin, et al. in their study on the application of bioeconomic modeling to the rebuilding of fisheries, undertaken for the OECD, cite several policy papers, which insist on the necessity of the *pur et dur* rebuilding program (Larkin, et al., 2011 ,pp. 18-20).

We have attempted, apparently with no more than limited success, to point out that the aforementioned draconian resource investment program is valid on *economic* grounds only under very special conditions. It behooves us to try yet again. The first condition to be satisfied is that the both the demand for harvested fish and the supply of fishing effort are perfectly elastic. If non-linearities creep in, if, for example, the demand for harvested fish has finite price elasticity, the draconian resource investment policy is no longer optimal on economic grounds, i.e. it will not lead to a maximization of the present value of future net economic returns from the fishery. This was pointed out by us in 1975 (Clark and Munro, 1975).

The second condition, which must be met, is that both the produced capital and the human capital employed in the fishery are perfectly malleable. By the term "perfectly malleable" produced/human capital in a given fishery we mean the following. The produced/human capital can be moved with ease and without significant cost into or out of the fishery. The concept is analogous to that of highly liquid assets in the world of finance.

The whole point of the 1979 Clark, Clarke and Munro article is to examine the consequences of this second condition not being met. The article restricts itself to the consequences of less than perfectly malleable produced capital in the fishery (while assuming implicitly that the human capital employed is perfectly malleable). The article comes forth with two conclusions. The first is, if the produced capital is less than perfectly malleable, it is non-optimal on *economic* grounds to declare an outright harvest moratorium for fishery resources to be rebuilt, except in cases of extreme overexploitation, and then only for a limited period (Clark, Clarke and Munro, 1979)[4]. The second conclusion is that the pre-1979 dynamic economic models of the fishery (e.g. Clark and Munro, 1975) implicitly assume that both produced and human capital employed in the fishery are perfectly malleable.

We would assert the following, without fear of contradiction. Fisheries characterized by perfect malleability of both produced and of human capital are the exception, not the rule. We would also note in passing the observation of the OECD that, while the significance of non-malleability of capital for fisheries rebuilding programs has been given short shrift by many academic economists[5], it has not at all been ignored by policy makers, by those in the real world (OECD, 2012, p.33).

III Areas of Future Research 1.

[4] The rationale can be seen most easily in the case of so called quasi-malleable vessel capital, in which the vessels upon being purchased have a re-sale value of zero, but have a positive rate of depreciation. Suppose that a fishery, in which such vessel capital is employed, has hitherto been open access, but now comes under the control of a resource manager. The resource manager concludes that the fishery resource should be rebuilt. To the resource manager, the cost of acquiring the vessels is a bygone, with the only relevant vessels costs being operating costs. Hence, the vessel capital is “cheap”. But this “cheap” vessel capital is temporary, since the vessels are depreciating. If a harvest moratorium were to be declared and enforced, until the resource was rebuilt, the economic benefits of the temporary “cheap” vessel capital would be lost. Not a wise move in the economic management of the fishery (see: Munro, 2010).

[5] A significant counter example, however, is to be found in the study by Larkin, et al., which provides a powerful empirical case against *pur et dur* fishery resource re-building programs (Larkin, et al., 2011).

We wish to put forward two suggestions for future research, with the first following directly from our discussion of Eq. (2). This pertains to investment programs in the natural capital we call capture fishery resources. There have been, as we have noted, calls for extensive rebuilding of capture fishery resources. *The Sunken Billions* study referred to so many times does by implication call for a doubling of capture fishery stocks (World Bank, 2009). A more recent and much more detailed study, “Global Fishery prospects under contrasting management regimes” (Costello et al., 2016), also calls for a very extensive program of rebuilding of capture fishery resources. The OECD did, of course, recently complete a project on rebuilding fisheries ,and in so doing stated that: “rebuilding fisheries is an urgent task which is high on the international policy agenda” (OECD, 2012 ,p. 9).

The OECD, in its project, did indeed sponsor considerable research on the issue, commissioning, for example some 23 case studies. The OECD makes no claim, however, that the research on the issue is complete. On the contrary, it admonishes the research community to do more, much more. To quote the OECD:

“More work is needed on clarifying issues ----regarding the economic theory of rebuilding fisheries the most important being; the design of optimal harvesting rules for rebuilding fisheries, taking into account the time aspect; the non-malleability of human and physical capital; and how uncertainty and lack of information should be taken into account” (OECD, 2012, p. 33).

Our call then, is a call to respond to the OECD admonition. First, however, a warning.

In so analyzing the rebuilding of fisheries and the benefits to be obtained thereby, the temptation to let the static model, or the spirit of the static model, come in through the back door should be resisted. We take as examples two otherwise excellent studies, one by Costello et al. (2016), and the other the now very well known World Bank/FAO study, *The Sunken Billions* (World Bank, 2009).

Both studies provide estimates of the economic gains to be had by a rebuilding of world capture fisheries. The Costello et al. base case, however, explicitly assumes that the social rate of discount is equal to zero (Costello et al., 2016, p.5). *The Sunken Billions* model does by implication also assume that the social rate of discount is equal to zero. Recall the key implicit assumption of the static model.

Assuming that $\delta = 0$, brings with it the risk of making it too easy, too tempting, to downplay, if not ignore, the costs and difficulties of the resource investment program. To illustrate, we return to the linear, autonomous version of the Clark- Munro 1975 model, and take an alternative version of Eq. (1) and ask, in terms of this model, just what the consequences are of assuming that the social rate of discount is equal to zero. We have:

$$\delta\left(p-c\left(x^*\right)\right)=\left[\frac{d}{dx^*}\left\{\left(p-\left(x^*\right)\right)F\left(x^*\right)\right\}\right] \qquad (7)$$

The RHS of Eq. (7) can be seen as a measure of the marginal sustainable resource rent arising from the marginal investment in the resource. The (p-c(x*)) on the LHS of the equation is a measure of the foregone current resource rent resulting from the marginal resource investment. If the social rate of discount, δ, is: $\delta = 0$, then the implication is that the cost of the resource investment counts for nothing. It can, furthermore, be demonstrated, in terms of the 1979 Clark, Clarke and Munro model, that, if $\delta = 0$, the optimal rate of investment in a hitherto overexploited resource stock is always the maximum. The demonstration can be safely left to the reader.

Furthermore, return to Eq. (6). It can be seen that whether the resource is fast growing or slow growing is of no interest whatsoever, if $\delta = 0$. Letting $\delta = 0$, makes it too tempting for us to deal with the economic costs and problems of resource investment through the economist's time honoured practice of assuming them away, with these problems being safely relegated to political and social realms.

It is when the assumption that $\delta = 0$ is relaxed, and the spirit of the static economic model banished, that there is no choice but to meet the economics of the fisheries investment program head on. The economics, let it be conceded from the outset, is daunting, because sweeping generalizations become highly suspect. Just consider the consequences of non-malleable produced capital alone. The degree of non-malleability of produced capital is almost certain to vary significantly from fishery to fishery. The OECD in its project commissioned a set of case studies. In a sense, the development of the economics of rebuilding fisheries must expand beyond this to a case, by case, by case analysis

As promoters of the importance of non-malleable capital in fisheries, there is one specific area of research, which we like to urge be undertaken, this being on the consequences of non-malleable **human** capital – an issue of particular importance, we would suggest, to developing coastal states. At the end of their 1979 article, Clark, Clarke and Munro assert that the implications of non-malleable human capital would be similar to those of non-malleable produced capital (Clark, et al., 1979, p. 47).

This assertion may prove to be valid. On the other hand, it may not. Human capital is not produced capital. If significant research has been done to date on the economic implications for resource investment of non-malleable human capital, we are unaware of it. If our perceptions are correct, then this represents a glaring omission in our profession's research accomplishments.

IV Areas of Future Research 2

The second area of research, involves the intra-EEZ management of fisheries and the application of game theory. This is a theme that one of the authors (Munro) has been pressing for some time (see, for example: Munro, et al., 2013). The basic argument is that there are an increasing number of cases of fishers engaging in what amounts to cooperative resource management. From what has been said up to this point, the goal of intra-EEZ fisheries management is not just to encourage fishers to seek static efficiency, but rather to come to regard fishery resources as assets in which it is in their selfish interest to invest. Such cooperative resource management will enhance the achievement of this two part goal, for reasons that should be obvious.

This second area of research is directly linked to the first. The OECD report, *Rebuilding Fisheries,* devotes considerable space to a discussion of fisheries management methods and techniques (OECD, 2012). The reasons for this are straightforward. If positive investment in capture fishery resource “natural” capital takes place, but the fisheries management regime is such that it leads to the generation of resource rent being no more than temporary, e.g. through the build up of excess fleet capacity, then the investment, in economic terms, has an excellent chance of turning out to be a bad one. The net present value (NPV) of the investment could well prove to be negative. Secondly, if the fisheries management scheme is such that the fishers have an incentive to invest positively in the resource(s), then obviously this will greatly enhance the prospects for success of rebuilding programs. These conclusions are supported by empirical research – see, for example, Costello et al., 2016.

In any event, in order to analyse the development of fisher cooperative resource management effectively, it is argued further, we need to bring to bear to a greater extent than we have done in the past the theory of strategic interaction, better known as the theory of games. Consider the following from the press release announcing the joint award of the 2005 Nobel Prize in Economics to economists and game theorists Robert Aumann and Thomas Schelling:

“Why do some groups of individuals, organizations and countries succeed in promoting cooperation, while others suffer from conflict? The work of Robert Aumann and Thomas Schelling has established game theory- or interactive decision theory- as the dominant approach to this age-old question” (http://www.Nobelprize.org.2005). This “age-old question” is precisely the one to be addressed in the context of intra-EEZ fisheries management. Having said this, the drive to make more extensive use of game theory in the analysis of intra-EEZ fisheries management has been met with considerable resistance.

Earlier discussions of this issue (Munro, et al., 2013) focused on a particular case study. We shall return to this case study, which has gained increasing prominence over the past year, to make our points. The case study involves the groundfish trawl fishery of British Columbia, Canada. The fishery has been under an ITQ scheme, since 1997. Some preliminary comments on ITQ schemes and the scope for cooperation among ITQed fishers is in order.

In 2012, the *Review of Environmental Economics and Policy* published a symposium on rights-based fisheries management, covering ITQs, territorial use rights and harvester cooperatives (Arnason, 2012; Costello, 2012: Deacon, 2012; Wilen, Cancino and Uchida,2012). The symposium presents what can be seen as the received view of the prospects for cooperation among ITQ holders. There is general agreement that ITQ schemes greatly improve the efficiency of the management of intra-EEZ fisheries. There is also agreement, however, that, since, by definition, ITQs are granted to individual fishers (or vessel owners), the scope for cooperation among them, while not non-existent, is limited. One study maintains that experience has shown that such cooperation is very difficult to achieve, if the number of ITQ holders is not fewer than 15 (Townsend, 2010, p.526). Essentially, with larger numbers, free riding becomes an intractable problem.

Cooperation can be achieved, the argument continues, if ITQ holders are prepared to surrender some of their individual rights. Thus, in the aforementioned symposium, Deacon argues that an ITQ scheme can achieve the desired cooperation, if it is overlaid by a fisher cooperative. A cooperative is defined by Deacon, as a body in which some individual right are surrendered to a cooperative board or equivalent (Deacon, 2012). Some authors go further and maintain that what is required for effective fisher management is a full fledged fisher corporation (e.g., Townsend, *ibid*.).

The arguments sound eminently reasonable, indeed common sense. The problem is that the experience of the aforementioned ITQed British Columbia groundfish fishery stands as a powerful counter example. The fishery operates along the length and breadth of the British Columbia coastline of over 27,0000 km. (knowbc.com/knowbc/BC-Facts), and has a fleet of some 55 active vessels[6]. While the vessel ownerships are complex, it is estimated that there are not fewer than 30 independent “players” (agents) in the fishery (Munro et al., 2013). The groundfish industry does have, it is true, an association, the Canadian Groundfish Research and Conservation Society (CGRCS). The CGRCS is an association, however, and is no more than that. It is not a cooperative, as defined by

[6] There are actually a total of 142 licensed groundfish trawl vessels (Bruce Turris, personal communication).

Deacon, and has no power over individual ITQ holders (Bruce Turris, personal communication).

The groundfish industry, through its own initiative, negotiated a habitat by catch limitation scheme, which can be claimed to be a global first. It has, moreover on several occasions put pressure on the Canadian resource manager, the Canadian Department of Fisheries and Oceans (DFO, from hereon in), to reduce sharply several TACs on relevant species. Indeed, in one instance, the industry initiated a resource investment program (Munro ,et al., 2013). None of this would have occurred, if this ITQed industry had not been been acting as a cohesive whole.

Figure 1 here

When Munro et al. first discussed the case study in 2013, the aforementioned habitat by catch limitation scheme had completed only one year. It was easy for skeptics to dismiss the experience. The agreement has now completed four years. Furthermore, the agreement and its history have been fully documented, with the documentation taking the form of an article published in *Marine Policy*, in late 2015 (Wallace et al., 2015). Moreover, those involved in the agreement have been presented with a conservation award. More on this later.

How did this come about? The fishery is a very complex one, involving some 50 species (Wallace et al., ibid.). From 1980 until the mid-1990s the fishery was managed though a combinations of TACs, licence limitation, trip limits etc. The vessels granted access to the fishery competed among themselves. The fisher "game" was, by definition, competitive, indeed highly so, as was the "game" between the fishers and the resource managers. The management of the fishery was manifestly unsuccessful. In 1995, the Canadian Department of Fisheries and Oceans (DFO) felt compelled to close the fishery. The fishery was re-opened in stages in 1996 -1997, with, by 1997, a government imposed ITQ scheme, accompanied by mandatory onboard observers and mandatory dockside monitoring. The new management approach aroused considerable opposition within the industry. The government did not relent.

Move forward now to the mid-2000s. The bottom trawling component of the industry came under attack by environmental NGOs (ENGOs) for destruction of several sponge and coral species off the coast of British Columbia. The ENGOs were able to give economic teeth to their complaints by bringing these complaints to the attention of the Monterey Bay Aquarium, which does through its Seafood Watch program identify fisheries as sustainable or unsustainable. California is an important market for the British Columbia industry (Wallace et al., ibid.).

DFO was aware of the problem, but at the time lacked the legislative wherewithal to address the problem. DFO hoped to be able to address the problem in due course. The industry could not wait.

The industry, which in the mid-1990s had been characterized by a highly competitive game, was now characterized by a stable cooperative game. Through the vehicle of the CGRCS, the industry approached a consortium of ENGOs involved in the sponge/coral controversy to see, if an agreement could be negotiated. The ENGOs responded positively and negotiations commenced. Nothing would have happened, of course, without the approval and support of DFO. Both were readily forthcoming.

Several years of negotiations eventually led to an agreement, the British Columbia Groundfish Trawl Habitat Conservation Collaboration Agreement, in 2012 (Wallace, et al., 2015). Having been given the blessing of DFO, officially came into force in April of that year. The season for the fishery ends during the third week in February of each year. The fourth year of the Agreement concluded in February, 2016.

Without going into details, the industry is allowed a global annual quota of all identified species of sponge and coral of 4,500 kg. The hope is expressed that this quota can be reduced in time to just under 900 kg.

The 4,500 kg .quota is spread out like tiny ITQs among the 70 active vessels. Any vessel that exceeds its quota, and is unable to cover its overage through purchase or lease of quota, must cease fishing for the rest of the season (Wallace et al., 2015).

Over each of the four years, the actual industry harvest of sponge and coral has fallen below the long term goal, let alone 4,500 kg. The actual harvest over Year One was 500 kg. (Wallace et al., 2015). The actual harvest over Year Four was 280 kg. (Bruce Turris, personal communication).

As indicated at an earlier point, the Agreement, the negotiations leading up to it, and the results so far, were written up and published in *Marine Policy*. The article has six authors, with the lead author being Scott Wallace, Senior Scientist, David Suzuki Foundation and lead negotiator from the ENGO side. He is accompanied by two other ENGO authors; by Bruce Turris, Executive Manager, CGCRS, and lead negotiator from the industry side; Brian Mose, President, British Columbia Deep Sea Trawlers Association, and by an academic. A decade ago, Scott Wallace and Brian Mose were bitter opponents.

The Vancouver Aquarium and its associated scientific institute, the Coastal Ocean Research Institute, each year present a set of aquatic conservation awards, two of which are their key awards, named after the first President of the Vancouver Aquarium, Murray A. Newman. One of the "Murrays" is for research; the other for "conservation action". It was announced in January of this year that the 2016 Murray A. Newman Conservation Action Award was to be presented jointly to the six authors of the *Marine Policy* article.

To many marine biologists and ecologists, bottom trawlers are seen as the worst of the worst. In British Columbia, Brian Mose, of the B.C. Deep Sea Trawlers Association, can be seen as "Mr. Bottom Trawler". One of the authors (Munro) attended the Vancouver Aquarium/ Coastal Ocean Research Institute awards ceremony. He was impressed as he watched "Mr. Bottom Trawler" go on stage to receive from the marine biologist Director of the Coastal Ocean Research Institute a Murray A. Newman Conservation Action Award.

Two additional comments on the B.C. groundfish trawl case study are in order. First, it is conjectured (Munro, et al. 2013) that a key reason why the intra-industry cooperation has been successful is because of very effective DFO surveillance and enforcement. This is not a case of pure industry self –management. Combine this with the fact that industry has been able to influence resource management – pressing for reductions in

TACs in several instances[7], and one can say is that what has emerged is a type of co-management, in which the industry and the resource manager – DFO- are engaged in a cooperative game. The co-management, let it be emphasized, is de facto, not de jure, and is the result of evolution. The reasons for this development are not at all well understood.

Secondly, co-management, as the OECD has emphasized, and as have we discussed, can lead to conflicts that will need to be resolved (OECD, 2012). Differences between social and private rates of discount provide the obvious example. There are, however, positive aspects of co-management, which are not well understood. Data and information provide an example. Return to our quote from the OECD 2012 report, where inter-alia, the need to address uncertainty in rebuilding programs is stressed. The B.C. groundfish trawl case points to the unsurprising fact that the industry may well have data and information, not readily available to the resource manager. In the instances in which the industry pressed for TAC reductions, one could see the fleet providing what amounted to an early warning system. Once again, this is an under researched issue.

How then to explain all of this; how to determine the relevance, if any, of the British Columbia experience to the rest of the world? In terms of what we described as the received view of ITQs and fisher cooperation, what happened in British Columbia should have been impossible. We return to the Nobel Prize committee press release for Auman and Schelling, to the "age-old" question, and find that we are forced to turn, whether we like it or not, to the theory of strategic interaction (game theory). Game theory has been applied to intra-EEZ fisheries management questions, but only to a very limited degree. The *Marine Policy* article makes this point (Wallace et al., 2015)

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[7] By way of example, one the resources harvested by the industry is a Pacific Ocean Perch resources in the waters off the northern coast of British Columbia. The industry became about the state of the resource in the mid-2000s. As well as voicing its concern to DFO, the industry put a scientist under contract (at industry expense) to carry out, in collaboration with a DFO scientist, a stock assessment of the resource, an assessment, which proceeded over several years. As a result of the industry's initiative, the TAC on the resource was ultimately reduced by almost 40 per cent (Bruce Turris, personal communication).

As has been pointed out before, however, game theory has been employed extensively to the analysis of the management of international fisheries (Munro et al., 2013). It is impossible to believe that the many game theoretic tools so employed are without relevance to the analysis of the management of intra-EEZ fisheries. The opportunities for future research are, these authors would suggest, immense.

V Conclusions

In this paper, we commenced by reviewing our earlier attempts to bring the theories of capital and investment to the fore in fisheries economics. It is our hope that we have made a convincing argument that such seemingly esoteric analysis does, in fact, have strong policy relevance.

In the review, we pointed to some limitations in the earlier analysis, with the first being the complexity of the capital theory results. The second was the concealing of the intrinsic growth rates of the resources. It really does matter in the economic management of these resources whether a resource is fast or slow growing. The third was the fuzziness of our definition of the social rate of discount. We attempted to sharpen up that definition, and convinced ourselves that it is properly seen as a measure of investment opportunity cost. The fourth was our seeming inability to convince much of the world that, in rebuilding a fishery, the draconian investment policy of declaring an outright harvest moratorium is optimal in economics terms, only under very special and restrictive conditions. We tried, once again.

It has not been our intention, however, simply to review past endeavors. We have also put forward what we believe to be significant areas of future research, which we see as being interlinked. The first is to respond to the OECD's admonition to expand the research on the economics of the worldwide problem of rebuilding, of investing in, hitherto overexploited capture fishery resources. We made a specific recommendation in this regard to undertake research on the economic consequences for the rebuilding programs on non-malleable human capital in the relevant fisheries. Unless there is research of which we are unaware, this a much neglected area of research, of great importance to developing fishing states. While we did not discuss this earlier in the paper, it is research, which will of necessity be multi-disciplinary in nature.

The second area that we put forward was that of enhancing the application of the theory of strategic interaction (game theory) to the analysis of the economic management of intra-EEZ (intra-EU) capture fisheries. The increasing prospects of cooperative management of such fisheries, involving cooperation among fishers, and cooperation between fishers and resource managers makes the application of the theory of strategic interaction imperative. The first question to be addressed in this regard is the applicability of game theoretic tools developed in the analysis of international fisheries. The second question is what new, additional, game theoretic tools, if any, must be developed for the effective analysis of this management issue.

We see the opportunities for future research on the economics of fisheries as being immense, and predict with confidence that fisheries economists can look forward to long periods of full employment.

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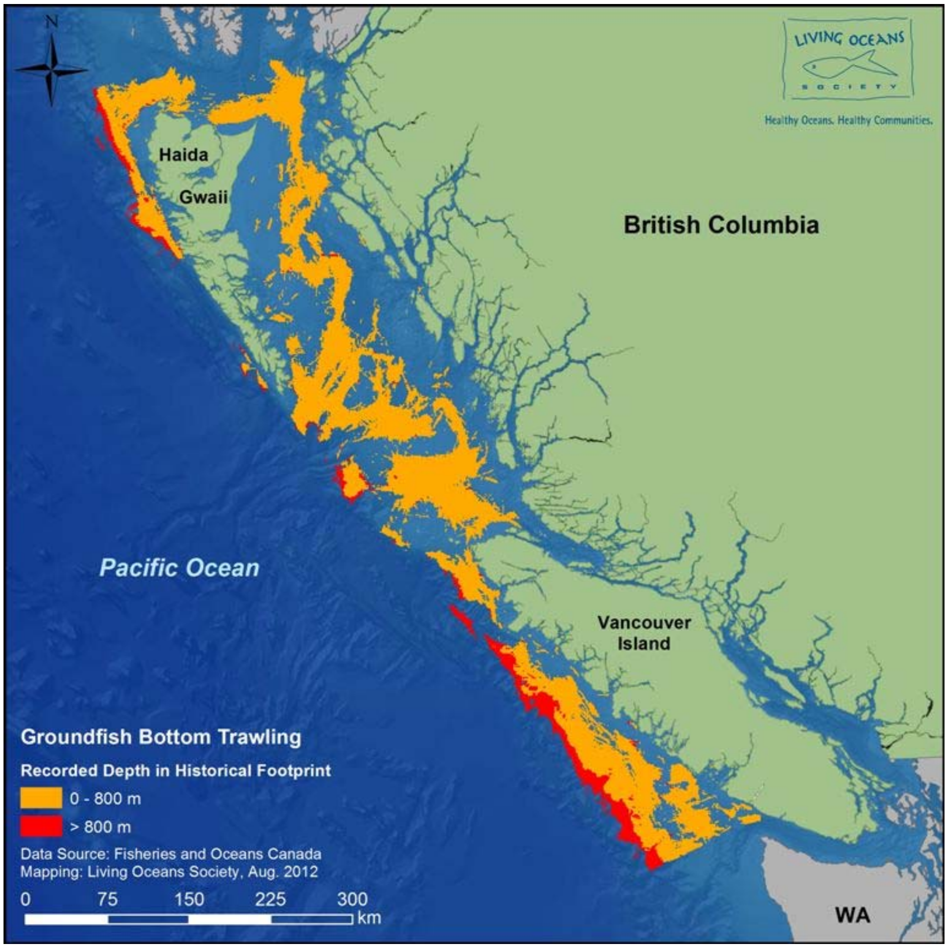
Figure 1. British Columbia Ground Fish Trawl Fishery: 1997-2011



Bottom Area Trawled between 1997-2011 (approximately 41,000km^2)

Source: Wallace et al., 2015