Cooperation and Conflict in the Management of Transboundary Fishery Resources

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Paper prepared for the
Second World Congress of the
American and European Associations
of Environmental and Resource Economics
Monterey, California
June 2002

I Introduction

World fisheries are classified broadly into aquaculture and capture (wild) fisheries. Transboundary management issues are of negligible significance in aquaculture, while being of great importance in capture fisheries. This paper will, therefore, devote itself exclusively to capture fisheries, and more precisely to marine capture fisheries.[1]

The management of transboundary marine capture fishery resources, as an issue of prominence in world fisheries, traces its origins back to the United Nations Third Conference on the Law of the Sea, 1973–1982 and the resulting UN Convention on the Law of the Sea (LOSC, hereafter) (UN, 1982).[2] The LOSC, which achieved the status of international treaty law in 1994, is now to be seen as laying down the fundamental "rules of the game" for international fisheries management.

Prior to 1973, coastal states[3] had, with minor exceptions, recognized jurisdiction over marine fishery resources out to no more than 12 miles from shore (McRae and Munro, 1989). The vast bulk of such resources were high seas, international common property, subject to ineffective management and overexploitation. The LOSC revolutionized world capture fisheries by enabling coastal states to establish, and to claim jurisdiction over fishery resources within, 200 nautical mile Exclusive Economic Zones (EEZs), off their shores.

It was hoped and expected that the new EEZ regime would lead to improved resource management. Given the mobility of most capture fishery resources, however, many of the fishery resources encompassed by the newly established EEZs proved, to be transboundary in nature, crossing EEZ boundaries into neighbouring EEZs, or into the adjacent high seas, or both. The drafters of the LOSC anticipated that the management of transboundary fishery resources could become a significant resource management problem under the EEZ regime. These anticipations were more than fully realized.

Indeed, since the close of the 1973–1982 Conference, this resource management issue, has grown steadily in scope and importance, resulting, among other things, in the UN being compelled to hold a follow up conference, referred to as the UN Fish Stocks Conference,[4] 1993–1995. The Conference did, in turn, bring forth an agreement, popularly referred to as the UN Fish Stocks Agreement (UN, 1995), designed to buttress and supplement the earlier UN Convention on the Law of the Sea. The Agreement recently came into force (December 2001).

Partly in response to the coming into force of the Agreement, the FAO of the UN is now planning an Expert Consultation on the management of transboundary fishery resources, to be held in late 2002, which will subsequently report to the FAO's Committee on Fisheries. The management of such resources, the FAO contends, remains as one of the great challenges on the way towards achieving long-term sustainable fisheries (FAO, 2002).

Transboundary fishery resources can be divided, as we have implied, into two broad, non-mutually exclusive, categories:

A. Fishery resources, which cross the EEZ boundary into neighbouring EEZ(s), referred to by many legal experts as "shared" fishery resources (Hedley, 2000).
B. Fishery resources, which cross the EEZ boundary into the adjacent high seas. The UN, for certain historical reasons into which we shall not delve, subdivides these resources into highly migratory fish stocks (tuna, to all intents and purposes), and straddling fish stocks (all others) (UN, 1982; 1995).

The authors have been forced to the conclusion that they cannot, within the confines of this single paper, address adequately the management of both categories of resources. They have, therefore, decided to focus on the management of the larger of the two categories, Category A – "shared" fish stocks.[5] John Caddy, recently retired from the FAO, has estimated that there may be as many as 1500 "shared" stocks worldwide, and notes that only a few are subject to effective cooperative management (Caddy, 1997). Thus the resource management problem, as seen from a world perspective, remains a formidable one.

In addressing the issue, we shall commence with a review of the basic economics of "shared" fish stock management. We shall then go on to examine a specific real world case, using the aforementioned basic economics to provide the necessary analytical framework.

The case to be considered is that of the management of Pacific salmon, shared by Canada and the United States. Wild salmon does, during the course of its life cycle, move beyond coastal state EEZs into the adjacent high seas. As a consequence, however, of a concerted effort by Canada and the United States, during the UN Third Conference on the Law of the Sea, there is a specific article in the LOSC (Article 66), which has led to customary international law deeming the directed high seas fishing of salmon to be illegal (Burke, 1991; UN, 1982). For management purposes, salmon is properly considered to be a Category A ("shared") fishery resource.

The management of Pacific salmon has proven to be a particularly complex and difficult undertaking in joint fishery resource management, with multiple jurisdictions harvesting a set of biologically distinct, but intermingled stocks. Geography, and the behavior of the stocks as they return to spawn, create distinct asymmetries among the competing fleets. Furthermore, the abundance of these stocks and the details of their migratory behavior can change abruptly over time, and such shocks have contributed to significant international disputes over harvest management.

The joint resource management problems encountered in Pacific salmon are in no sense unique. A senior official of the FAO, concerned with the joint management of subtropical shared fishery resources in the western and central Atlantic, has informed the authors that the experience with the management of Pacific salmon is highly relevant to the management problems confronting him and his colleagues in the Atlantic (Kevern Cochrane, Fisheries Department, FAO, personal communication). As a final comment, Pacific salmon will constitute one of the case studies to be examined in detail at the aforementioned FAO Expert Consultation on the management of transboundary fishery resources.

II The Basic Economics of the Management of Transboundary Fishery Resources: A Review

We turn now to the review of the basic economics of "shared" fish stock management, which will then be used in examining the real world case of Pacific salmon. In our review, we shall commence by providing the "bare bones" of an analytical model of "shared" fish stock management, a model, one can note in passing, which has moved beyond the realm of academia, and is now to be found, for example, in OECD and World Bank publications (e.g., OECD, 1997; Agüero and Gonzalez, 1996).

Analytical models can take us only so far, however, in dealing with real world complexities. The discussion of analytical models will, therefore, be followed by a brief discussion of current attempts to extend the economic analysis by employing numerical models.

The basic economics of the management of shared fishery resources is a blend of the economist's dynamic model of a fishery resource confined to the waters of a single coastal state EEZ, and game theory. Prior to examining the "bare bones" of an analytical model, a few comments on the nature of the capture fishery management problem, and on the nature of the shared fishery resource management game, are in order.

With respect to the economics of the management of capture fisheries resources in general, the resources have one salient feature, which is comparable to that of many environmental resources, namely their "common property," or "common pool," nature, which exists, it should be stressed, within the EEZs, as well as without. The "tragedy of the commons," in this instance, manifests itself primarily through overexploitation of the resource from society's point of view.[6] The management of capture fisheries through time has been, and is, largely about, countering the effects of the "common pool" nature of the resources (Bjørndal and Munro, 1998).

One of the pioneers of modern fisheries economics, H. Scott Gordon, developed the concept of Bionomic Equilibrium, which represents the equilibrium that the fishery, and the resource, would achieve, under conditions of pure open access (Gordon, 1954). In certain fisheries there is no Bionomic Equilibrium, this side of extinction of the resource. In any event, Bionomic Equilibrium serves as a benchmark of undesirability in the management of capture fisheries from an economic perspective, a benchmark that proves to be of direct relevance to the management of all transboundary fishery resources.

Next, with respect to the nature of the "shared" fish stock "game," the following general points need to be borne in mind:

I. The number of players in a typical "game" is relatively small, often no more than two. Numbers over ten are occasionally encountered, but a number comparable to the number of countries signing the Montreal Protocol on Substances that Deplete the Ozone Layer (80, as of 1994, Barrett, 1994), is all but inconceivable.

II. The legal framework surrounding cooperative fisheries management regimes has strength. Daniel Owen, in a legal study undertaken for the FAO and the Nansen Institute, scoured the world for fisheries agreements relevant to cooperative management of fisheries resources in general

(Owen, 2001). Of the total of 39 agreements, which his search revealed, only three did not satisfy the lawyer's definition of a treaty (Owen, 2001). As Owen observes, a treaty is perforce binding upon signatories. Of course treaties can be violated, and/or undermined, but the point remains. The typical cooperative fisheries arrangement is not a loose, voluntary arrangement. Indeed, the economics of cooperative fisheries management is so closely interwoven with international law, that it would be more accurate to talk of the analysis as an exercise in law and economics, rather than as an exercise in economics alone.

III. Cooperative fisheries arrangements are about the management of fishery resources through time. Thus flow models are inappropriate. Stock models are mandatory, and the appropriate "game" is a differential one.

IV. While "shared" fish stock games involving symmetric players are not unknown, asymmetry between and among players, and resultant asymmetry in perceived management goals of the players, is the rule, not the exception. Indeed, a key issue addressed in the economics of cooperative fisheries management arrangements is the search for an optimal compromise management program, when the "players" have different resource management goals.

V. Cooperative fisheries arrangements can be subject to unpredictable shocks, particularly of an environmental nature. In spite of the typical strong legal framework surrounding cooperative fisheries arrangements, emphasis is now being given to the necessity of enhancing the robustness of cooperative fisheries arrangements, through time.

With these comments in mind, let us begin with a simplified analytical model that allows us to focus on the value of cooperation and the consequences of failure to cooperate. Consider first a fishery confined to the waters of a single coastal state. An economic model of the fishery, to have any value, must have a properly specified biological model as its foundation. For expositional purposes, we shall suppose that the well known biological model of M.B. Schaefer (1954) is appropriate (see as well: Clark, 1990; Bjørndal and Munro, 1998).

The growth function of the resource is given by

(1) $$\frac{dx}{dt} = F(x), \quad x(0) = x_0$$

where x denotes the biomass (fishery resource measured in terms of weight). Let K denote the natural equilibrium level, or upper bound of the resource, often referred to as the carrying capacity of the resource. This is the equilibrium that the resource would achieve, in the absence of harvesting. It is assumed that $F(x)$ is concave in x, such that $F(0) = F(K) = 0$, $K > 0$, and that $F(x) > 0$ for $0 < x < K$ (Clark, 1990)[7].

The harvest production function is given by:

(2) $$h(t) = qEx(t)$$

where E denotes fishing effort, the flow of labor and capital services devoted to harvesting, and q is the so-called "catchability coefficient." From here on in, we shall assume, for the sake of convenience, that $q = 1$.

Given the existence of harvesting, the net growth of the resource is:

(3) $$dx/dt = F(x) - h(t)$$

Assume now that both the demand for harvested fish and the supply of labor and capital services are perfectly elastic, and let p be the price of harvested fish and c the unit cost of fishing effort.

At any point in time, the net revenue from the fishery, or resource rent, is given by:

(4) $$\pi = (p - c(x))h$$

where c(x) denotes unit harvest costs, $c(x) = c/x$.

It is assumed that the objective is to maximize, from society's point of view, the present value of resource rent from the fishery. Society's objective functional is thus:

(5) $$J(x_0, h) = \int_0^{\infty} e^{-\delta t}\pi(t)dt$$

subject to Eq. (3), and subject to a further assumption that there are upper and lower bounds on harvesting: $0 \le h(t) \le h_{max}$, and where δ denotes the social rate of discount.

We are thus presented an optimal control (linear) problem, with $x(t)$ as the state variable, and $h(t)$ as the control variable. We could just as easily have formulated the problem in such a way that $E(t)$ is the control variable, and shall do just that where it proves to be convenient. Be that as it may, it can be shown that there exists an unique optimal solution, and an optimal steady state biomass, x^*, given by the following equation (see: Clark, 1990; Bjørndal and Munro, 1998):

(6) $$F'(x^*) + \left.\frac{\partial\pi(t)/\partial x}{\partial\pi(t)/\partial h}\right|_{h=F(x^*)} = \delta$$

Equation (6) can be interpreted as a resource investment decision rule. It states, in effect, that one should invest in the resource up to the point that the yield on the marginal investment in the resource (LHS of Eq. (6)) is equal to the social rate of discount. Next, if the vessel capital employed in harvesting the resource is perfectly malleable, the optimal approach path to x^* is the most rapid one.[8]

It can be shown that, if the fishery is an open access, common pool, one, the resource will be driven down to the Bionomic Equilibrium level, x^∞, given by the equation:

(7) $$p - c(x^\infty) = 0$$

It can be further shown (Clark, 1990) that we shall have $x^\infty = x^*$, if and only if, $\delta = \infty$. Since we can safely assume that, except under the most extreme circumstances, $\delta << \infty$, Bionomic Equilibrium implies overexploitation of the resource from society's point of view.

Now suppose that the resource is transboundary in nature, in that it is shared by two neighbouring coastal states, 1 and 2. Assume, to begin with, that the two coastal states, while having adequate powers to control their own domestic fleets, choose not to cooperate. Each coastal state will go its own way and manage its segment of the resource as best it can. What then are the consequences?

In a few cases, the consequences will be negligible. There are examples of transboundary fishery resources, in which exploitation of the resource by one country or entity, will have little or no impact upon harvesting opportunities available to other countries, or entities, sharing the resource. In such instances, cooperation will matter little (Munro, 1987). These examples are, however, the exception. In the more usual case, in which the exploitation activities of one country/entity sharing the resource does have a significant impact upon exploitation opportunities available to others sharing the resource, the consequences of non-cooperation can be severe. The resultant non-cooperative game is a variant of the "Prisoner's Dilemma."

There are two widely cited analyses of the non-cooperative fisheries game, both of which appeared in the same year, namely Clark (1980), Levhari and Mirman (1980). The two analyses come to the same conclusions. We shall, for the sake of convenience, select Clark's model, which is summarized in a succinct and lucid manner, in the second edition of his book, *Mathematical Bioeconomics* (Clark, 1990).

Clark commences with the same linear control model that we have used to describe a fishery confined to the waters of a single state. He finds it convenient to let fishing effort, *E(t)*, serve as the control variable.

Clark, in developing his model, assumes that there are only two players, 1 and 2, but notes that the model can, with ease, be extended to $N > 2$ players. He further allows for the two players to differ in terms of fishing effort costs.[9] His model is, as follows:

(8) $$dx/dt = F(x) - h_1(t) - h_2(t), \quad x(0) = x_0$$

(9) $$h_i(t) = qE_i(t)x(t)$$

We shall assume, as before, that $q = 1$

(10) $$\pi_i(x, E_i) = (px - c_i)E$$

(11) $$J_i(E_1, E_2) = \int_0^\infty e^{-\delta t}\pi_i(x, E_i)dt$$

(12) $$0 \le E_i(t) \le E_i^{\max}$$

A closed-loop Nash solution to the non-cooperative game (see: Nash, 1951) is to be defined as a pair of feedback control strategies, $E_i^N(x)$, such that

(13) $$\begin{cases} J_1(E_1^N, E_2^N) \ge J_1(E_1, E_2^N) \text{ for all } E_1 \\ J_2(E_1^N, E_2^N) \ge J_2(E_1^N, E_2) \text{ for all } E_2 \end{cases}$$

Denote the biomass level that player 1 would deem to be optimal, if the resource was confined solely to its waters, as x_1^*. Let the Bionomic Equilibrium level of *x*, as perceived by player 1, be denoted by x_1^∞. Similarly for player 2, we have x_2^*, and x_2^∞, respectively.

Suppose that $c_1 < c_2$, i.e. player 1 has lower fishing effort costs than does player 2. It can then be easily shown that:

$$x_1^* < x_2^* \ ; \quad x_1^\infty < x_2^\infty$$

Clark (1990) then proves, provided that $E_1^{\max}$ and $E_2^{\max}$ are sufficiently large, that the solution to the Nash non-cooperative game is given by:

$$(14) \qquad E_1^N(x) = \begin{cases} E_1^{\max} & \text{if } x > \min(x_1^*, x_2^\infty) \\ F(x)/x & \text{if x} = \min(x_1^*, x_2^\infty) \\ 0 & \text{if } x < x_1^*, x_2^\infty) \end{cases}$$

$$(15) \qquad E_2^N(x) = \begin{cases} E_2^{\max} & \text{if } x > x_2^\infty \\ 0 & \text{if } x \le x_2^\infty \end{cases}$$

If it should be the case that $x_1^* < x_2^\infty$, there are no negative consequences to non-cooperation. The high cost player 2 will be hounded out of the fishery, and player 1 will mange the fishery, as if it controlled the fishery outright.

In the more likely case, in which $x_1^* > x_2^\infty$, then non-cooperation will produce sub-optimal results. If it should be the case that the two players are identical, $c_1 = c_2$, the resource will be driven down to the common Bionomic Equilibrium level. The results will correspond to that of an open-access, unregulated fishery confined to the waters of a single state.

The history of Pacific salmon, includes both struggles to negotiate and maintain cooperation, and periods of intense competitive harvesting -- with the unfortunate consequences outlined above (Miller et al., 2001). This is but one example, however. There are many others. The theory has proven over time to have substantial predictive power (Kaitala and Munro, 1997; Munro, 1990).

In turning now to cooperative management of the resource, the issue, as we noted before, is not that simply of bargaining over the division of the returns from the resource. The resource has to be managed through time. As we have stressed, there is no necessary reason why the management objectives of the countries, or entities sharing the resource, should coincide. Thus, to return to the Clark model of non-cooperative fisheries management, if the two players decide to cooperate, and, if it is true that $c_1 < c_2$, the two players will be found not to have identical management objectives. Player 2 will be more conservationist than player 2, i.e. $x_2^* > x_1^*$.[10]

As a first step in resolving the compromise management problem, we consider a two player cooperative game, assuming that there are no side payments. Many cooperative fisheries arrangements continue to ignore the possibility of side payments.

We shall continue to assume that the linear control model used in the non-cooperative case applies. Let the players be 1 and 2, as before, and assume that $c_1 < c_2$.

The first question to be addressed is whether harvest shares are determined before, or during negotiations over the resource management program. It is often the case that countries/entities sharing a resource will have prior agreement for sharing the harvest on the basis of some sort of formula.[11] Let us commence by assuming fixed harvest shares, and then ask what are the consequences of allowing harvest shares to vary through time. Thus, to begin with, we have at any point in time:

(16) $$h = h_1 + h_2$$

where $h_1 = \alpha h$; $h_2 = (1-\alpha)h_1$ and where α is a constant $0 \leq \alpha \leq 1$.

We use the Nash (1953) model of a cooperative game as a framework[12]. The well known two fundamental pre-requisites for a stable solution to the game are that the solution be Pareto Optimal and that the Individual Rationality Constraint be satisfied. That is to say that each player be assured a payoff at least as great as its Threat Point payoff, which can be assumed to be the payoff arising from the solution to a non-cooperative game (Munro, 1979).

A potential solution, satisfying the first pre-requisite, can be characterized as follows:

(17) $$J(x_0, h) = \beta J_1(x_0, h_1) + (1-\beta) J_2(x_0, h_2)$$

where β is a bargaining parameter, $0 \leq \beta \leq 1$, such that, if $\beta = 1$, the resource management preferences of 1 will be wholly dominant. The payoffs to players 1 and 2 are the present values of the streams of economic returns to the two players from the fishery, given a particular resource management policy. By maximizing $J(x_0,h)$ for every possible β, one traces out the Pareto frontier.

Given that the second pre-requisite is met, and thus that the core of the game is not empty, the solution to the Nash cooperative game can be determined by maximizing the following expression:

$$\max\ (\theta^* - \theta_0)(\gamma^* - \gamma_0)$$

where θ^* and θ_0 denote the solution and Threat Point payoffs respectively of 1, and γ^* and γ_0 denote the solution and Threat Point payoffs respectively of 2. Once we know θ^* and γ^*, we know the size of β as well (Munro, 1979). Suppose, for the sake of argument, that the β corresponding to θ^* and γ^* lies between 0 and 1, i.e. a true compromise must be achieved. An equilibrium equation determining the optimal compromise biomass, which we might denote as x_3^*, does exist. The equation essentially balances off the differential harvesting cost benefits arising from a larger, as opposed to a small, stock size. The equation is cumbersome, and will not be reported here (see: Munro, 1979).

If α is allowed to become a function of time, $\alpha(t)$, while the ban on side payments remains, a compromise resource management through time can be developed, but once again it is remarkably cumbersome (Munro, 1979).

Relaxing the ban on side payments makes all the difference in the world, and does so for obvious reasons. The optimal solution then calls, in our example, for setting $\beta = \alpha = 1$. Player 1 effectively buys out Player 2, although it must be noted that the total buy out is a consequence of the linearity of the model. The division of the benefits from the fishery also is very straightforward. Following Bjørndal and colleagues (2000), let $\omega(x(o))$ denote the present value of the net economic returns from the fishery, when the management preferences of 1 prevail. We thus have:
$\omega(x(0)) = \omega_1(x(0)) + \omega_2(x(0))$, where $\omega_1(x(0))$, $\omega_2(x(0)$ represent player 1 and 2's shares respectively. The cooperative surplus $C(x)$ can then be expressed as follows:

(18) $$C(x_0) = \omega(x(0)) - [J_1(E_1^N, E_2^N) + J_2(E_1^N, E_2^N)]$$

and it can be shown that:

(19) $$\begin{cases} \omega_1(x(0)) = J_1(E_1^N, E_2^N) + \frac{1}{2}C(x_0) \\ \omega_2(x(0)) = J_2(E_1^N, E_2^N) + \frac{1}{2}C(x_0) \end{cases}$$

(Bjørndal et al., 2000).

Munro (1987) has made the argument that, where differences in management goals exist, it is almost invariably the case that one player places a higher value on the resource than the other. The optimal outcome is then one in which the management preferences of that player placing the highest value on the resource are allowed to hold sway in untrammeled form. It then becomes incumbent upon that player to compensate (bribe, some might say) the other players.

While the use of side payments in real world fisheries is still limited, there are examples of where, what we might term the *compensation principle*, has been put into effect. One of the most dramatic involved the North Pacific Fur Seal Fishery, in the days when it was respectable to harvest seals. The cooperative game involved four countries, Canada, Japan, Russia and the United States. The cooperative game commenced in 1911, and lasted, on and off, for almost three quarters of a century. Prior to 1911, a non-cooperative game had played itself out, which gave rise to fear's that the resource would be driven to extinction.

The four players broke into two sub-coalitions, a low harvesting cost coalition and a high cost one. The United States and Russia harvested the seals on land (Pribilof Islands); Canada and Japan harvested the seals at sea. Harvesting at sea is a higher cost operation than harvesting on land. The solution to the cooperative game took the form of Canada and Japan agreeing to cease sealing outright. Each year, Canada and Japan received a certain percentage share of the harvested skins – a pure side payment. The cooperative arrangement was profitable for all four, and proved to have strong conservationist benefits as well (Munro, 2000b).

The second example involves the Pacific Island Nations of the western and central Pacific. Collectively, the Pacific Islands have, as a consequence of the EEZ regime, jurisdiction over what is the world's largest set of tropical tuna resources. Being highly migratory, the resources are manifestly transboundary in nature.

The Pacific Island Nations cooperative fisheries management game commenced in 1979, as a seemingly intractable fourteen-player game. The tuna resources are not spread evenly throughout the region, however, tending to concentrate near the Equator, and becoming steadily thinner as one moves North or South of the Equator. The Pacific Islands were thus not equally endowed with tuna resources.

Two sub-coalitions of seven players each emerged, which could be termed the "have" and "have not" sub-coalitions. By definition, the "have" sub-coalition places a higher value on the resource than the "have not" coalition. There is clear evidence, both that the management preferences of the "have" sub-coalition are dominant, and that the "have" sub-coalition has been "buying" the support of the "have not" sub-coalition through side payments, explicitly and implicitly. The Pacific Island Nations cooperative fisheries management program has proven to be one of the most successful in the world at large, and can claim to be the single most successful in the developing world (Munro, 1991; David Doulman, FAO of the UN, personal communication, 2001).

Side payments, as well as serving to resolve possible conflicts over resource management goals, have been seen generally as broadening the scope for bargaining. A cooperative fisheries arrangement without side payments is one in which any one player's benefits from the fishery are determined by the harvests of that player's fleet. To economists, what is being shared are the economic returns from the resource. Sharing the physical harvest is only one of many ways in which the economic returns can be shared. It makes no economic sense for countries in a cooperative management regime to restrict themselves to their own means of sharing the returns from the fishery. In any event, the advantages of side payments are so widely accepted among economists that few current analytical models of transboundary fishery resource management even bother to consider cases in which side payments are absent

The model described has been applied in empirical studies. Let two examples suffice. Claire Armstrong and Ola Flaaten (Armstrong and Flaaten, 1991) fitted the model to the Arctic-Norwegian Cod Stock, concentrated largely in the Barents Sea, which has been successfully co-managed by Norway and the Soviet Union/Russia, since the mid-1970s. Max Agüero and Exequiel Gonzalez undertook an empirical study, on behalf of the World Bank, of the potential gains from the co-operative management of the substantial small pelagic fishery resources (e.g., anchovies and pilchards) shared by Peru and Chile (Agüero and Gonzalez, 1996). The aforementioned model provided the framework of the empirical analysis.

<u>A Commentary on Further Developments of the Analytical Model</u>

The model described to this point is a two-player game, and carries with it the implicit assumption that the arrangement is binding in nature. Viejo Kaitala and Mati Pohjola (1988), and Rögnvaldur Hannesson (1997), in particular, have addressed the consequences of agreements being less than fully binding, and the consequent need for the arrangement to be, in fact, self-enforcing . Kaitala (1985), and Hannesson (1997) discuss the problem of cheating, and the countering of such a problem by each partner developing a set of credible punishments, with results that are similar to analyses of International Environmental Agreements (IEAs) (see as well: McKelvey, 1999).

Kaitala and Pohjola (1988) address a complementary issue, which is of at least as great importance as cheating, namely that of “time consistency.” If the agreement is not fully binding, de facto if not de jure, then one must always be aware of the impact of changing conditions through time, which may serve to undermine what appeared, at the commencement of the cooperative resource management program, to have been entirely satisfactory to all players. One can think of this, in the first instance, in terms of the Threat Point shifting through time. This is an issue that is particularly relevant to the Pacific Salmon case, where changing environmental conditions radically altered the payoff structure of the game.

Kaitala and Pohjola (1988) take as their example, the case discussed of two players sharing a fishery resource and differing only in terms of their fishing effort costs. The low cost harvester buys out the high cost harvester, but since the agreement is non-binding, the transfer payments must, of necessity, be spread over time. Kaitala and Pohjola develop the concept of an "agreeable transfer payments program," a transfer payments program, which will ensure the stability of the cooperative resource management arrangement over time in the face of changing underlying conditions. They demonstrate that neglecting to develop an "agreeable" program invite collapse of the cooperative management arrangement.

In practice, it is difficult to overestimate the importance of "time consistency", even if the cooperative arrangement appears, on the surface to be binding, as the case of Pacific salmon will exemplify, yet again. The optimal means of enhancing the flexibility and robustness of cooperative fisheries management regimes through time remains an issue that has yet to be fully explored.

The basic model has been further extended to allow for $N > 2$ players. The work of Veijo Kaitala and Marko Lindroos has been most significant in this regard (Kaitala and Lindroos, 1998). The approach taken might best be described as a characteristic function game – Shapley value approach. In the solution to the cooperative game, the cooperative surplus is not evenly divided among players, as in a Nash model, but is rather divided according to the relative contributions at the margin, which each player can make to all possible coalitions. This approach has now been extensively used in empirical models of $N > 2$ player cooperative fisheries arrangements (e.g., Arnason et al., 2000; Pintassiglio and Duarte, 2000).

A Commentary on Numerical Models

The analytical models, described to this point, can be criticized on the grounds that they slide over much of the true dynamics, and on the grounds that they are largely deterministic. The criticisms have merit, but the shortcomings of the analytical models reflect the limits beyond which one cannot reasonably expect to extend such models. There are now an increasing number of numerical models, which do attempt to go beyond the limits of the analytical models, and to capture both the full dynamics and uncertainty. Several of these have already been referred to in passing, such as Arnason et al. (2000), Lindroos and Kaitala (2000) and Pintassiglio and Duarte (2000). Particular reference should be made to the work of McKelvey and Golubtsov (2002), McKelvey

(2001) and McKelvey and Cripe (2001), all of which are of direct relevance to the case of Pacific salmon, to be discussed in the following section. These three papers, as well as attempting to capture the full dynamics, address the difficult issues of uncertainty and the consequences of the existence of asymmetric information among the players.

The McKelvey and Golubtsov (2002) paper is of particular interest because it examines the consequences of uncertainty being reduced through increased availability of information. Under cooperation, the benefits are always positive, as one would expect. Under conditions of non-cooperation, however, increased information can, given the right circumstances, make a bad situation worse. The increased information will cause the players to harvest more aggressively, as yet another manifestation of the Prisoner's Dilemma. When information is asymmetric, under competitive conditions, the information advantaged players will usually do better than their competitors, and have an incentive to maintain that advantage – but not always. In some cases, it will be to the benefit of the information advantaged players to share their information with their less fortunate colleagues (McKelvey and Golubtsov, 2002).

The McKelvey and Golubtsov (2002) simulation results also suggest that the potential cooperative surplus is far from constant. Rather, it varies with the quality of forecast information, the value of harvested fish, and the extent to which the resource is resilient or susceptible to extinction risks. In particular, the potential gains from cooperation (or penalty for failure to cooperate) will tend to be largest when:

i. the environment is highly variable, but forecast information is high quality
ii. the stock production function displays depensation or critical depensation at low stock levels (i.e. recovery from over-harvesting will be slow, or extinction is possible)
iii. the net value of harvested fish is high.

These results may provide a basis for predicting the sorts of situations in which the parties will have sufficient incentive to undertake the negotiating costs needed to develop and implement a binding cooperative agreement. Specifically, when there is more to lose by failing to cooperate, we might predict that the parties will be more likely to make efforts to maintain cooperation.

With the review of the basic economics of transboundary fisheries management now complete, we turn to the promised specific case study, Pacific salmon. To repeat, the joint management of Pacific salmon by Canada and the United States constitutes one of most complex examples of transboundary fisheries management in existence, and serves well to illustrate some of the key points raised in this section. The discussion to follow draws heavily upon the recently published work of Miller and colleagues (2001).

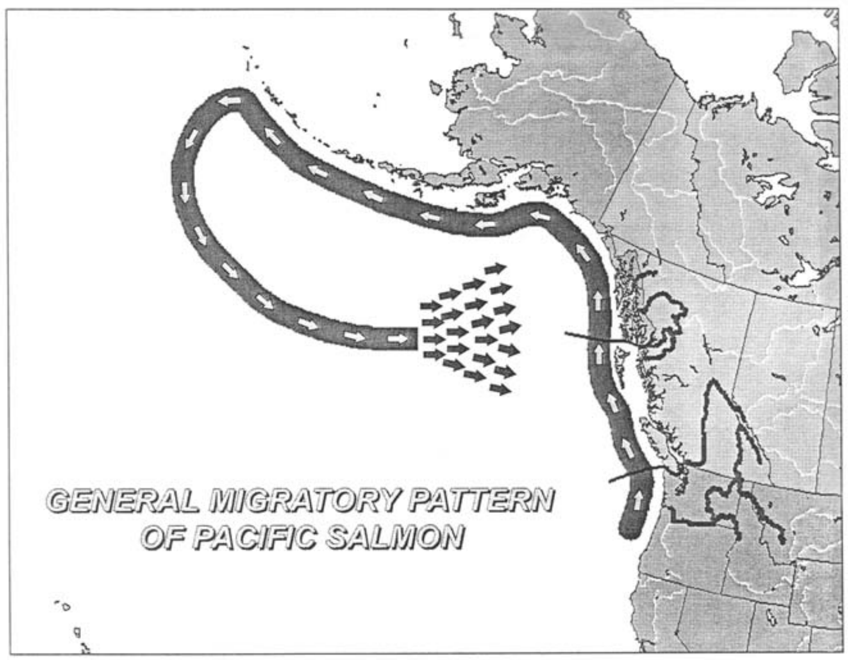
III. The Case of Pacific Salmon

As has been pointed out, Article 66 of the LOSC largely eliminated high seas harvesting of North American salmon, leaving Canada and the United States free to manage these stocks jointly. However, it has proved difficult for the two nations to maintain cooperation, and the sources of conflict did not disappear along with competing harvests on the high seas. The difficulties encountered in the Pacific salmon case illustrate many of points raised in the analysis above. In particular, environmental shocks have played a major role in destabilizing efforts to cooperatively manage these fisheries. Whenever cooperation has broken down, aggressive competitive harvesting has tended to deplete stocks and reduce the rents derived from the shared resources.

The coordination problem for North American Pacific Salmon involves at least 4 major players with divergent management objectives: Canada, Alaska, Washington/Oregon and 24 Treaty tribes located in Washington, Oregon and Idaho. In addition, there are many asymmetries affecting this problem – in valuations, in physical access to the shared resources, and in information about the state of the resources. Efforts to find cooperative solutions have been severely hampered by the fact that until recently, side-payments were never on the bargaining table. In other words, bargaining had focused solely on defining commercial harvest shares, with the benefits accruing to each jurisdiction coming only from its own harvests. In addition, the parties often tended to ignore the reality of one another's individual rationality positions and differing management objectives. Furthermore, this set of fisheries is strongly affected by environmental variability. Long-term changes in ocean conditions have had profound impacts on the productivity and migratory behavior of several important stocks. These natural changes, together with changes in the resource caused by human activities, have altered the parties' bargaining objectives and expected payoffs from cooperation. Much of the recent turmoil in U.S. / Canadian relations over Pacific salmon management can be best understood as the consequence of such changing circumstances.

Pacific salmon are not a single resource harvested in an undifferentiated common pool, but rather a collective term applied to five species consisting of possibly hundreds of distinct stocks. Each stock hatches in a particular river or stream, migrates to the ocean to feed and mature, and then returns to its natal stream to spawn and die (see Figure 1). Salmon migrate across international boundaries during their ocean phase, and most of the commercial harvest of salmon occurs in coastal waters where several species and stocks may be intermingled. Given this situation, it is inevitable that harvesters from each jurisdiction will "intercept" some of the salmon heading to spawn in the rivers of other jurisdictions.

Figure 1

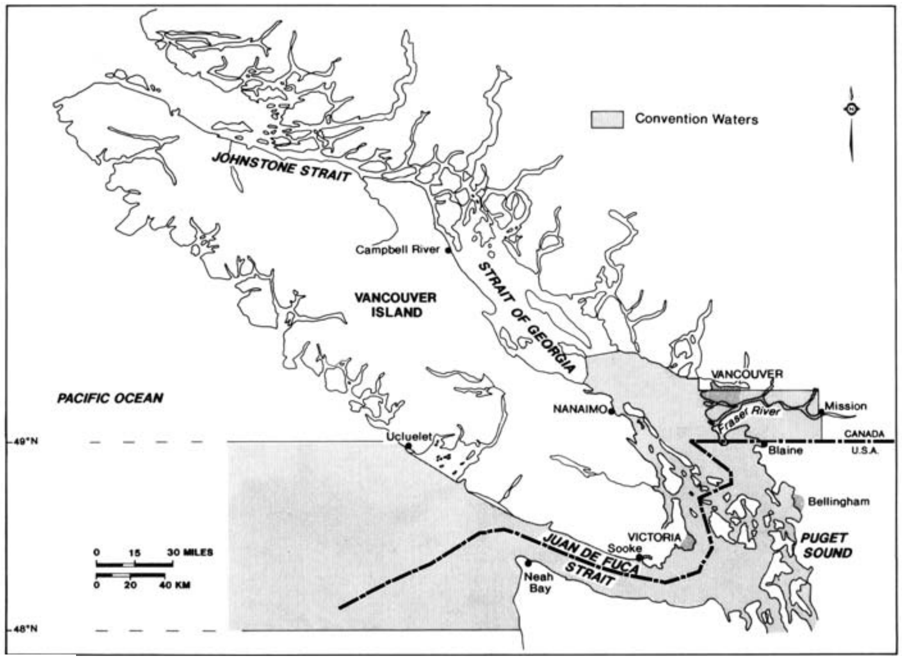


Source: Canada (1997), Department of Fisheries and Oceans, *Pacific Salmon Treaty: Moving Towards Equity and Conservation,* paper prepared by Bud Graham, Director of Fisheries Management, Department of Fisheries and Oceans, Pacific Region.

The Fraser River Convention, ratified in 1937,[13] divided the harvest of Fraser River sockeye and pink salmon as well as management and restoration costs equally between the two nations (Munro and Stokes, 1989). Under the Convention, the International Pacific Salmon Fishery Commission (IPSFC) regulated harvests of the Fraser River stocks within an area designated as "the Convention Waters" which encompassed the traditional fishing grounds for those stocks (Figure 2). Although the Fraser River lies entirely in Canada, a large portion of the salmon spawning in that drainage typically approach the river through the Strait of Juan de Fuca where, historically, they had been harvested by Washington State fishing vessels.

Figure 2

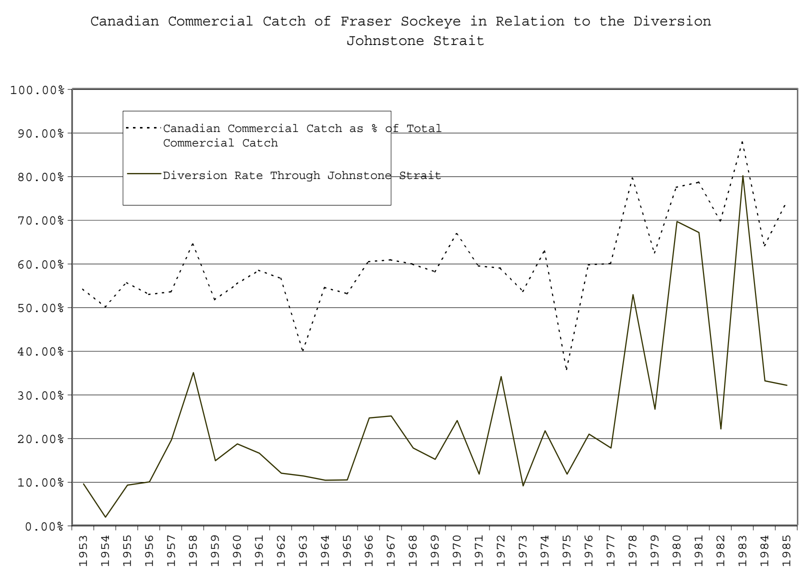
Convention waters fishing area under 1937 Convention



Support for the Fraser River Convention began to evaporate during the 1960s, when the Canadians grew increasingly unhappy with their agreement to share one-half of the Fraser River salmon. Canadian harvesters also had discovered that they could circumvent the IPSFC regulations by fishing for Fraser sockeye in Georgia Strait, outside of the Convention waters. This was made increasingly possible and profitable by a change in the migratory habits of the returning Fraser sockeye.

As the Fraser sockeye return southward to spawn, the run splits as it rounds Canada's Vancouver Island. The (normally larger) fraction, that passes seaward of the island, must pass through the Strait of Juan de Fuca, between the U.S. and Canada. There it is accessible to harvest by both countries' fleets. The remaining fraction of the stock, returning by way of Johnstone Strait, stays shoreward of the island, entirely within Canadian waters, and accessible to the Canadian fleet outside of Convention waters. Toward the end of the Convention period, when negotiations were well underway for the subsequent Pacific Salmon Treaty (1985), a sudden shift in ocean conditions contributed to a marked increase in the average Johnstone Strait diversion rate. In the period 1953–1976, the diversion rate averaged 16.4%. From 1977 through 1985, the average diversion rate jumped to 46%.[14] This shift surely strengthened Canada's hand in the negotiations leading to the 1985 Treaty. In fact, Canada clearly took advantage of unusually high diversion rates in 1978, 1980, 1981, and 1983 to concentrate harvesting efforts outside of Convention Waters, and thus increase its overall share of the harvest (Figure 3). In addition, Canadian harvesting effort intensified off the west coast of Vancouver Island, leading to increased interceptions of U.S. origin coho and chinook salmon heading south to spawn in the Columbia River system and other west coast streams.

Figure 3



While these pressure tactics made the affected interests in Washington and Oregon eager for a settlement, Alaskans saw little potential benefit from entering into the proposed Treaty. Given a general north-to-south migration pattern for returning salmon stocks, Alaskan fisheries are in a natural position to intercept many Canadian and some southern U.S. chinook stocks, while few Alaskan stocks are vulnerable to Canadian interception. Alaska yielded only when the U.S. Treaty tribes involved in the negotiations promised that as long as the Treaty remained in force, they would not sue to extend the landmark Boldt decision[15] to restrict commercial salmon harvests in Alaskan waters[16] (Yanagida, 1987; Munro et al., 1998).

The Treaty created the Pacific Salmon Commission whose primary task was to develop and recommend fishing regimes intended to govern the overall harvest and allocation of the salmon stocks jointly exploited by the U.S. and Canada. The body of the Treaty lays out a set of principles to guide the Commission in this task. Of central importance are the conservation and equity objectives or principles, which the Treaty expresses as follows:

...each Party shall conduct its fisheries and its salmon enhancement programs so as to:

a) prevent overfishing and provide for optimum production; and

b) provide for each Party to receive benefits equivalent to the production of salmon originating in its waters (Pacific Salmon Treaty, Article III).[17]

The Treaty then advises the Parties to consider the following factors in the application of these objectives or principles: the desirability of reducing interceptions, the desirability of avoiding disruption of existing fisheries, and annual variations in abundances of the stocks. The Treaty attempted to establish a balance among competing objectives and interests, but it failed to resolve major tensions between individual rationality and strongly held perceptions of equity.

The bargaining framework implemented in 1985 called for frequent renegotiation of the fishing regimes. Negotiations were to follow a consensus rule in that the Canadian and American delegations were to agree on new regimes. Pursuant to the U.S. legislation implementing the 1985 Treaty, the American delegation was composed of three voting Commissioners representing Alaska, Washington/Oregon and the Treaty Indian Nations, and a fourth non-voting Commissioner from the U.S. federal government (U.S. Senate, 1985; Yanagida, 1987; Schmidt, 1996). In most circumstances, this arrangement gave each of the three voting U.S. Commissioners an effective veto over the work of the Pacific Salmon Commission in developing new regimes.

From the beginning, there were fundamental differences of opinion regarding the meaning of the so-called equity clause (Article III (1) (b)) and whether or not it should take precedence over other objectives and factors expressed in the language of the Treaty. (Shepard and Argue, 1998; McDorman, 1998a; Yanagida, 1987; Strangway and Ruckelshaus, 1998).

One major difficulty is that it is not an easy task to quantify the interceptions balance. Commercial harvest value is only one possible measure of the value of a salmon – and it is certainly not the most important measure in cases where individual stocks are threatened with extinction, support highly valued sports fisheries, or have significant cultural value to native communities that have relied on those stocks since time immemorial. Thus, while all interests recognized that the equity principle was meant to reflect economic values and did not amount to a simple fish-for-fish balancing rule, they could legitimately disagree on how the balance was to be measured. In order to reach agreement in 1985, the Parties chose to finesse the equity point by putting off any decision on measurement.[18] Their failure to firmly establish the content and role of the equity clause allowed it to become a major bone of contention when incentives to continue cooperation changed.

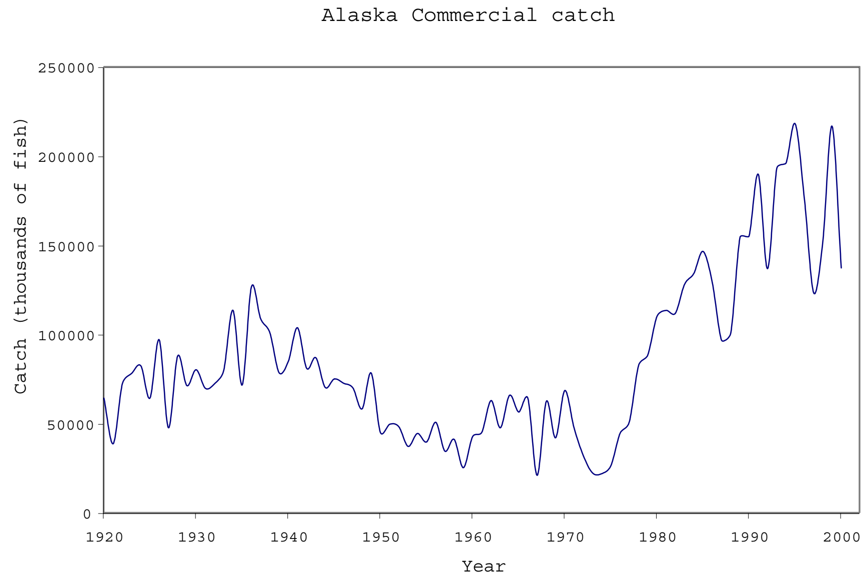
For the first few years, the Commission could ignore the equity issue because Canada remained satisfied that interceptions were roughly in balance. Attention focused, instead, on designing regimes that would encourage enhancement and conservation efforts by guaranteeing that the party making the investment would be able to reap the rewards from the *expected* subsequent increase in production. The regimes established by the Commission relied heavily on the use of "ceilings." For example, the initial agreement specified a cap of 7 million fish over each of two successive 4- year periods for Washington State harvest of Fraser sockeye (Pacific Salmon Treaty, Annex IV, Chapter 4). This approach was based on the notion that capping harvests in the intercepting fishery would allow any increase in run strength to primarily benefit the nation of origin – whose hatchery or habitat restoration investments had presumably caused the increase.

However, while enhancement and restoration efforts certainly can increase the number of salmon available for harvest, the effects of such actions easily can be dwarfed by the impacts of natural environmental fluctuations. Negotiators on both sides underestimated the power of such natural changes, and the optimistic assumptions on which they relied proved grossly incorrect.

During the negotiation period leading to the 1985 Treaty, changes were already apparent in the ocean environment that would contribute to the Treaty's later difficulties. In the mid-1970s, ocean conditions in the North Pacific changed dramatically. Significant warming of coastal waters was reinforced and sustained by a sequence of closely spaced ENSO (El Niño-Southern Oscillation) warm events from 1977 to 1998. Associated changes in patterns of upwelling, nutrient transport and related physical and biological processes led to favorable survival and growth conditions for salmon in the Gulf of Alaska, while survival rates plummeted for stocks that enter the marine environment along the U.S. west coast.

These climate-related changes contributed to a nearly ten-fold increase in Alaskan salmon harvests, with harvests rising from fewer than 22 million salmon (of all species) in 1974 to three successive record highs in 1993, 1994, and 1995 (Figure 4). At the 1995 peak, Alaska harvested close to 218 million salmon. Another high was attained in 1999 when Alaska harvested almost 217 million salmon.

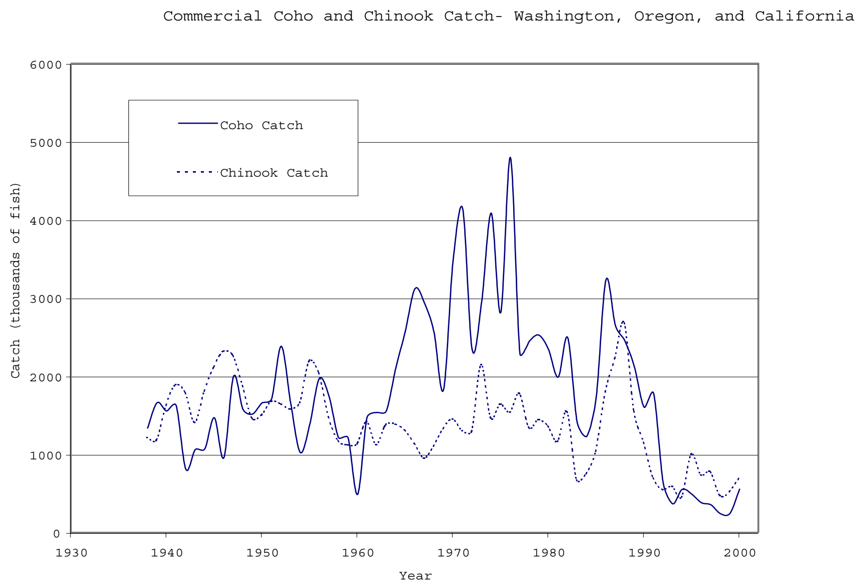
Figure 4



Harvests of most salmon species in northern British Columbia fared well through the mid-1990s. However, by the late 1990s it had become apparent that many of British Columbia’s southern and interior coho stocks were severely depleted (Pacific Fisheries Resource Conservation Council, 1999). In addition, British Columbia’s chinook harvests have declined steadily (Hare et al., 1999; PSC Joint Chinook Technical Committee, 1999),

Southward, commercial chinook and coho catches in California, Oregon, and Washington dropped abruptly in the late 1970s, hitting El Niño-related lows in 1983 and 1984. A dramatic but brief recovery in 1986 and 1987 then gave way to a precipitous decline to record low harvests in recent years (Figure 5). Abundance has declined to the point that some stocks are on the verge of extinction. The natural sources of low salmon survival and stock productivity in the south were compounded by other stresses, including habitat degradation, mortality at dams, water diversions, and questionable hatchery practices. By 1998 to early 1999, the cumulative effects of all of these stresses led the U.S. National Marine Fisheries Service to list a number of these stocks as "threatened" under the Endangered Species Act (U.S. Federal Register, 2000).

Figure 5



The explosion in salmon abundance in northern waters led Alaskan harvesters to fish harder in areas where British Columbian salmon are intermingled with Alaskan fish. In particular, the dramatic increase in pink salmon abundance in southeastern Alaska led to increased interceptions of Canadian sockeye from the Skeena, Nass, and other northern British Columbia rivers. The Canadians proved unable to redress the growing interceptions imbalance because declining southern coho and chinook stocks prevented Canadian harvesters from reaching the agreed-upon ceilings for harvests of those stocks along the west coast of Vancouver Island. At the same time, fishing interests along the U.S. West Coast claimed that Canada's efforts to reach the ceilings resulted in overharvesting of those fragile stocks.

From Canada's perspective, there appeared to be a mounting interceptions imbalance in favor of the U.S., but little U.S. willingness to make concessions to redress the imbalance. From Alaska's perspective, the requested concessions promised to entail only uncompensated costs. While the southern U.S. jurisdictions demonstrated a willingness to make further concessions on their harvests of Fraser River salmon in exchange for reduced Canadian harvesting pressure on southward-bound coho and chinook, they really had few bargaining chips to bring to the table.

By 1993, the growing frustrations caused cooperation to collapse when the parties proved unable to agree on a full set of fishing regimes. While clearly binding in a legal sense, the treaty-based cooperative resource management regime had nonetheless foundered, because it had not met the test of “time consistency”.

The dispute festered for several years with occasional dramatic incidents, including Canada’s adoption of an “aggressive fishing strategy,” in 1994 (Fraser River Sockeye Public Review Board, 1995), and a three-day blockade of the Alaska Ferry by approximately 150 Canadian fishing vessels in the port of Prince Rupert in 1997. The two federal governments made several efforts to resolve the impasse, but it appears that they achieved a solution only after there was a significant shift in bargaining objectives coupled with a new-found willingness to try more flexible tools to achieve equity objectives.

Significant deterioration in the condition of Canada’s fall chinook and coho stocks over this period (Pacific Fisheries Resource Conservation Council, 1999; DFO, 1998a,b) appears to have triggered a shift in Canadian bargaining objectives with respect to bi-national harvest management. The Canadian focus shifted radically from insistence on an equitable interceptions balance to the need to tailor harvesting efforts to protect the stocks that had become severely depleted. The ESA listings in the Pacific Northwest most likely colored the positions of the southern U.S. participants in the negotiations as well. This shift in focus was instrumental in breaking the previous deadlock.

Throughout 1998 and early 1999, federal negotiators from both sides worked to hammer out the details of the 1999 Pacific Salmon Agreement that was adopted on June 30. The vigor with which the two governments pursued the negotiations suggests that both sides recognized that they had much to lose if they failed to resolve their differences. The depleted condition of Canadian and southern coho and chinook stocks had caused the value of the remaining fish to increase dramatically – not as harvested fish, but as brood stock and for their contribution to symbolic, cultural and aesthetic values. It appears that fishery officials had come to the realization that the unfavorable shift in ocean conditions had substantially depressed the productive potential of these stocks, so that previous harvesting rates simply could no longer be sustained. As noted above, such changes would cause the penalty for failure to cooperate to be larger than it would be if the stocks were believed to be relatively healthy and resilient. Thus, the heightened importance of reaching a settlement appears to have been sufficient to induce both Canada and the southern U.S. parties to make major concessions in the negotiations, while they allowed Alaska's harvests to remain relatively unchanged under the new arrangements.

The 1999 Agreement does not replace the 1985 Pacific Salmon Treaty, but rather places additional obligations on the Parties and replaces the expired short-term harvest management regimes, contained in an annex to the Treaty, with new longer-term arrangements. In reaching the Agreement, the two nations consented to temporarily set aside the dispute about equitable division of the harvest and to focus on implementing multi-year abundance-based harvesting regimes that would foster conservation and restoration of depressed salmon stocks. Rather than relying on short-lived, ceiling-based regimes whose frequent renegotiation provided ample opportunity for disagreement and brinkmanship, the new Agreement establishes a long-term commitment to define harvest shares as a function of the abundance of each salmon species in the areas covered by the Treaty. For example, for 12 years beginning in 1999, the U.S. share of Fraser River sockeye will be fixed at 16.5% of the TAC (total allowable catch). This represents a decrease from the post-1985 average U.S. share of 20.5%, but an increase relative to the share actually attained by the U.S. fleet during the 1992–1997 salmon war period (DFO, 1999; O'Neil, 1999).

Another major feature of the Agreement is its provision for two endowment funds. Initial funding is to be provided entirely by the U.S., but either Party may make additional contributions, and even third parties may contribute, with the agreement of the two states. The annual investment earnings on the Northern Boundary and Transboundary Rivers Restoration and Enhancement Fund (Northern Fund), and Southern Boundary Restoration and Enhancement Fund (Southern Fund) are to be used to support scientific research, habitat restoration and enhancement of wild stock production in their respective areas. The U.S. has agreed to contribute $75 million to the Northern Fund and $65 million to the Southern Fund over a four-year period. Canada also has made small contributions to the funds. Since the funds (at this stage) come overwhelmingly from the U.S., they can be viewed as implicit side payments from the U.S. to Canada. The Funds, together with new U.S. federally funded vessel buyback programs, also constitute side payments from U.S. taxpayers to U.S. salmon harvesters.

The 1999 Agreement represents a significant step forward. The shift in focus toward conservation represents a broadening in the scope for bargaining, while the abundance-based management formulas still accommodate Alaska's strong interest in the commercial harvesting sector. Abundance-based management is also better suited than the ceiling approach to maintaining appropriate levels of harvesting effort when there are large natural changes in salmon abundance. In addition, the experimental use of side payments in the form of the Endowment Funds opens the door for a more flexible approach to allocating the benefits of these fisheries.

While these developments are laudable, the new Agreement has not laid all sources of conflict to rest. A particular weakness is the fact that effective implementation of abundance-based management requires that the parties agree on the indices of abundance that will be used to set their harvest targets. Abundance, however, is very difficult to forecast in advance of the arrival of the runs. Forecasting models are imperfect, and data inadequacies and the uncertain and uneven impacts of variable marine and river conditions impair the accuracy of the forecasts. Precise estimates are likely to remain an elusive goal. The best that reasonably can be expected should be mutual willingness to accommodate uncertainty and to share the risks arising from imprecise abundance estimates. However, the new Agreement leaves the Commission's institutions for decision-making largely intact, and has not dealt directly with the problem of unstable incentives to cooperate. Thus, scientific uncertainties may loom larger than ever as a source of conflict (McDorman, 1998b). One of the most pressing needs will be to find a way around this problem.

Impartial scientific input might help. In the Barents Sea, Norway and Russia rely on stock assessments and recommendations regarding harvest levels and practices provided by ICES (the International Council for the Exploration of the Sea), through its Advisory Committee on Fishery Management. ICES is a broadly-based, independent scientific organization, that both nations view as credible and impartial.

There is a similar scientific organization in the Pacific – PICES (the North Pacific Marine Science Organization). It is a much younger organization that has not yet assumed a prominent role in providing scientific advice to fishery managers, but it seems possible that PICES could grow into the role of an independent (and neutral) provider of timely management-oriented stock assessments, if the Parties to the Pacific Salmon Treaty were willing to encourage and finance that development. At the very least, the engagement of such an organization in the ongoing assessment efforts of the Commission and the relevant fishery agencies could serve to enhance transparency and to curtail unproductive disagreements about abundance indicators.

Other tools that have proved valuable elsewhere include more extensive use of side payments and cross-border access agreements. There seems to be room for additional side payments in the Pacific salmon case. For example, given the high cost of current efforts to restore ailing salmon populations in Puget Sound, along the Oregon coast and in the Columbia Basin, it might make sense to allow U.S. Pacific Northwest power, forestry, water-use, and development interests to compensate Canadian (and perhaps Alaskan) harvesters for taking further actions to reduce harvest pressures on sensitive stocks (Shaffer and Associates Ltd., 1998).

The efforts of the Iceland-based, and largely privately supported North Atlantic Salmon Fund (NASF) to reduce ocean harvesting of Atlantic salmon provides a model. Since 1991, NASF has been working to increase the number of Atlantic salmon returning to their natal streams by paying commercial Atlantic salmon fishermen in the Faroe Islands not to fish their allocated quota. Similarly, in both 1993 and 1994, the NASF reached a comparable agreement with the commercial salmon fishermen of Greenland.

The Russian/Norwegian Mutual Access Agreement (1976) governing their Barents Sea fisheries for Arcto-Norwegian cod – along with haddock and capelin, provides an example of the use of an access agreement to rationalize the management of a bi-national fishery. In that case, the cod migrating between the Russian and Norwegian zones spend their juvenile life stages in the former zone, and their adult life stages in the latter zone. It makes good sense for the cod to be harvested as adults, and the Agreement has allowed the Russians to take a substantial portion of their cod quota in the Norwegian zone (Stokke et al., 1999).

In the North American Pacific salmon case, a cross-border access agreement could be used to prevent accumulation of imbalances in harvests relative to the agreed-upon formulas. For example, if an imbalance in favor of the U.S. were to accumulate in a specific fishery, the U.S. national government could acquire existing transferable fishing licenses and rent them to Canadian fishing vessels. Those vessels could then use the licenses to fish in U.S. waters, with their harvests credited to the Canadian "account".

In summary, Canada and the U.S. have struggled to maintain cooperation in the context of divergent management goals and shifting incentives. Until recently, their efforts were severely hampered by a failure to consider side payments as a legitimate option, and by narrow definitions of the scope for bargaining. When cooperation broke down, the actions of each party tended to conform to game theoretic descriptions of competitive regimes.

The new cooperative regime represented by the 1999 Pacific Salmon Agreement seems to reflect some of the predicted features of a cooperative equilibrium. For example, it is clear that the U.S. values enhanced escapement of some of its severely depleted southern salmon stocks more highly than Canada values the commercial harvest of those same fish. Therefore, it is fitting that the agreement stringently restricts harvests of those stocks when abundance is low, and that the new rules are coupled with side payments flowing from the U.S. to Canada. The new Agreement also attempts to accommodate divergent management goals. In addition, the new practice of defining harvest shares on the basis of abundance provides flexibility in the face of changeable natural conditions.

Solutions to the problems that remain are also suggested by the theoretical literature. In particular, the literature suggests that cooperation can be promoted by broadening the range of tools for redistributing the benefits of the fishery, and that scientific advice from neutral third parties can forestall unproductive disputes and prevent destructive strategic use of asymmetrically held information.

IV Conclusions

As a consequence of the advent of U.N. Convention on the Law of the Sea (UN, 1982), and the EEZ regime to which it gave rise, transboundary fishery resources are now ubiquitous throughout the world. The management of these resources remains as one of the great challenges on the way towards achieving long-term sustainable fisheries worldwide. In this paper, we have focussed on the largest class of such resources, in the form of fishery resources shared between, and among, coastal states.

The economics of the management of such shared transboundary fishery resources is a blend of the economics of the management of fishery resources confined to the EEZ of a single coastal state, and the theory of differential games. The economic analysis predicts that in all, but a few cases, cooperation does indeed matter. The non-cooperative fisheries game proves to be but a variant of the “Prisoner’s Dilemma”, normally leading to overexploitation of the resources, sometimes to the point of extinction. The analysis has a high degree of predictive power.

The cooperative fisheries game is about the joint management of resource stocks through time, in which asymmetry between, and among, the players is the rule, not the exception. One of the problems, which remains far from being resolved in theory, let alone in practice, is that of achieving “time consistency” in cooperative fisheries management arrangements, in the face of high degrees of uncertainty.

The case study on Pacific salmon, shared by Canada and the United States serves to illustrate, both the consequences of non-cooperation, and the difficulties to be encountered in achieving stable cooperative resource management arrangements. Periods of non-cooperation led to conflict and threats of resource destruction. Attempts at cooperative management have been repeatedly faced with the problem of “time consistency”. Although the cooperative management arrangement appears to have been binding, having a detailed, formal treaty as its foundation, the arrangement almost foundered, because the arrangement’s flexibility and robustness proved to be inadequate in the face of unpredictable, and inescapable, environmental shocks through time.

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Notes

[1] There are also inland (fresh water) capture fisheries. Everything that we shall have to say about marine transboundary capture fisheries can be applied, with minor modifications, to inland capture fisheries

[2] The Convention acquired the status of international treaty law in December, 1994.

[3] A coastal state is defined by the United Nations as a state which has significant marine coast line, as opposed to land locked states (e.g. Austria), or geographically disadvantaged states (e.g. Singapore).

[4] The United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks.

[5] Those readers interested in the economics of the management of Category B transboundary fishery resources are referred to Kaitala and Munro, 1997; Munro, 2000a; and Pintassilgo and Duarte, 2000; Bjørndal and Munro, forthcoming.

[6] The meaning of the expression “overexploitation of the resource form society’s point of view” will become clearer as we review the economic theory of fisheries management.

[7] Note that other biological models may have a convex region at low stock levels, in some cases, with a critical population threshold below which recruitment would be too small to maintain the stock. Stock extinction is a distinct possibility for stocks characterized by such a biological production function.

[8] That is to say:

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

If the capital employed is not perfectly malleable, or if the appropriate optimal control model is non-linear (e.g. because the demand for fish exhibits finite elasticity), the most rapid approach path is no longer optimal.

[9] He assumes that they are identical in all other respects. They face the same price for harvested fish, and have the same social rate of discount.

[10] Return to Eq. (6). The second term on the LHS of the equation is referred to as the marginal stock effect. I reflects the marginal impact on returns from building p, "investing in," the resource through reduced harvest costs. It will be found that the marginal stock effect holds greater significance for high cost 2, than it does for low cost 1 (Munro, 1979).

[11] Thus, for example, in the past Norway and the EU used the estimated proportion of the relevant transboundary resources in one another's waters as a basis for allocating $h(t)$.

[12] We are certainly not restricted the Nash model, however. Other models of cooperative games have been employed in examining "shared" stock fisheries. See, for example, Armstrong, 1994.

[10] Convention for the Protection, Preservation and Extension of the Sockeye Salmon Fishery in the Fraser River System, May 26, 1930, U.S.-Can., 8 U.S.T. 1058.

[14] During the post-Treaty period, it has continued to be higher than the previous norm. The average diversion rate for 1977-1998 has been 48.2%.

[15] *United States v. Washington*, [W.D. Wash. 1974]. This court decision guaranteed to the Treaty tribes the right to harvest 50 percent of the salmon that would have ordinarily return to their traditional fishing grounds.

[16] Agreement between Alaska and the tribes in *Confederated Tribes and Bands v. Baldridge* (W.D. Wash. 1985).

[17] Pacific Salmon Treaty, March 18, 1985, U.S.-Can., 99 Stat. 7 [codified at 16 U.S.C. 3631-3644 (1997)].

[18] Memorandum of Understanding to the Pacific Salmon Treaty: Pacific Salmon Treaty, March 18, 1985, U.S.-Can., 99 Stat. 7 [codified at 16 U.S.C. 3631-3644 (1997)]