Fish-Wars Revisited: 
A Stochastic Incomplete-Information Harvesting Game.

Robert McKelvey1, Kathleen Miller2, and Peter Golubtsov3

1) Department of Mathematical Sciences, University of Montana, Missoula, MT 59801, USA
2) Environmental and Societal Impacts Group, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307, USA
3) Physics Department, Moscow State Lomonosov University, Moscow, 119899, Russia

Abstract

This study employs a spatially distributed stochastic extension of the classical “fish-war” harvesting game. The model addresses the bioeconomic impact of exploiting a trans-boundary fish stock in a stochastic marine environment subject to natural fluctuations and long-term regime changes. Our goal is to study the evolution of the fishery, either with cooperative or non-cooperative harvesting, when the harvesting fleets possess only limited, possibly asymmetric, information of environmental changes. More specifically, we shall investigate how such information limitations and asymmetries will influence harvesting strategies and thus the outcome of the game. In particular we shall compare game versions that incorporate alternative information structures to determine the effect, on the evolution of the fish stock and the payoffs to the fleets, of an increase of available information (or a reduction in its degree of asymmetry). It will often be the case that, with competitive harvesting, information enrichment will be destructive both to the biological resource and to the welfare of the competing harvesters. This circumstance casts light on the design of cooperative institutional arrangements that will be stable in the presence of imperfectly predictable environmental stochasticity.

As an illustration we examine, in light of the model, the history of the long-running dispute between the United States and Canada over management of their bi-national Pacific salmon fishery. The Stochastic Split Stream model, developed here, is based loosely on Canadian-U.S. harvest competition over Canada’s Fraser River sockeye salmon stock. Fraser sockeye stocks vary considerable over time both in biological productivity and in their return migration route around Vancouver Island and, thus, their accessibility to the two national fleets. In addition, the model sheds light on other aspects of the dispute. Our analysis focuses on the effects of a pronounced warming in coastal ocean conditions that began the mid-1970s and continued for two decades. This climatic regime shift contributed to dramatic increases in Alaskan salmon abundance, declining ocean survival rates for southern salmon populations and changes in the migration behavior of Fraser River sockeye that favored the Canadian fleet. These unanticipated changes destabilized cooperation under the terms of the 1985 Pacific Salmon Treaty. The positions taken by Alaska, Canada and the southern U.S. jurisdictions during the subsequent period of turmoil and renegotiation are consistent with our model results.

Keywords: fisheries, games, information, asymmetry
Introduction

Many of the World’s marine fisheries are shared between the fleets of two or more nations. Efforts to cooperatively manage harvests are complicated by uncertainties caused by large natural variations in the abundance or migratory behavior of shared fish stocks. Cooperation may collapse if natural variations are unanticipated, misunderstood, have asymmetrical effects on the availability of fish to the different fleets, or if the parties have different views as to appropriate management responses.

In this context, one might imagine that reducing uncertainty would invariably be a good thing to do, but is that necessarily the case? Are there circumstances in which more information could be harmful? Would improved scientific information make it easier to achieve a stable cooperative fishery agreement? What difference would it make if one party had information that the other did not? What type of information is likely to be most valuable or strategically most important? Here, we attempt to explore such questions.

This study employs a spatially distributed stochastic extension of the classical “fish-war” harvesting game model to study the instabilities inherent in cooperative management of real-world trans-boundary fisheries. The focus here is on instabilities due to oceanic environmental change and climatic regime shifts. This situation is illustrated by an examination, in light of the model, of the history of the long-running dispute between the United States and Canada over management of their bi-national Pacific salmon fishery. The mathematical structure and numerical analysis of the model is described in detail in [McKelvey and Golubtsov, 2002].

Specifically, we here simulate the evolution of a bi-national marine fishery where the fleet managers possess only incomplete information about the stochastically evolving oceanic environment. Thereby we can explore the ways in which imperfect and asymmetric understanding of the changing environment can influence the strategic positions of competing harvesters, and hence disrupt their settled arrangements for achieving stable coordinated management. In particular, we shall compare cooperative and non-cooperative game versions that incorporate a range of information structures. The central theme addressed is how an increase of available information (or a reduction in its degree of asymmetry) can affect, in often unexpected ways, the outcome of the dynamic harvesting game.

Finally, we apply the predictions of the model to an understanding of the historical difficulties of the United States and Canada in attempting to craft stable arrangements for joint management of their important binational Pacific salmon fishery.

The Model

In the model, the fleets of two sovereign countries (denoted $\alpha$ and $\beta$) fish-down each successive generation of a marine fish population. Specifically, the migratory fish-stock, after leaving its nursery ground and maturing, constitutes the initial
“recruitment” biomass of the fishery. This recruitment stock is distributed fractionally into sub-stocks $R_\alpha$ and $R_\beta$, which are resident, during the harvesting season, in the home waters of country $\alpha$ and $\beta$ respectively. Thus

$$R = R_\alpha + R_\beta,$$

where

$$R_\alpha = \theta_\alpha R, \quad R_\beta = \theta_\beta R,$$

with $\theta_\alpha + \theta_\beta = 1$.

During the harvesting season, each country’s fishing fleet reduces its home waters’ sub-stock to a residual “escapement” level, denoted $S_\alpha$ or $S_\beta$ respectively. Following this harvest, the separate escapements migrate back to the nursery ground, where they combine to form the brood-stock

$$S = S_\alpha + S_\beta$$

for the next generation. Then, following the spawn, the brood stock dies.

Following the hatch, the young offspring generation eventually matures, to form the next harvest season’s “recruitment” $R^+$, and thereby the stock life cycle is completed. The biomass $R^+$ is determined by the size of its spawning stock $S$ through a so-called “stock-recruitment relation”

$$R^+ = F(S, a^+).$$

Here $a$ is a parameter, the “compensation factor”, which determines the size and shape characteristics of the recruitment. For each $a$, $F(S,a)$ is monotone increasing in $S$, with a single positive fixed-point $K(a)$, the no-harvest “carrying-capacity” at which $F[K(a), a]=K(a)$. Schematically,

$$R_\alpha = \theta_\alpha R \rightarrow S_\alpha$$

$$S^+ \rightarrow R$$

$\uparrow$ $a^-$

$R_\beta = \theta_\beta R \rightarrow S_\beta$

$$S \rightarrow R^+$$

$\uparrow$

This cyclic pattern then repeats. In the present application, only the stock split sequence $\{\theta(t)\}$ will be random, typically assumed to be i.i.d. (The full model is much more general; see McElveen and Golubtsov, 2002).

Depending on the value of $a$ (denoted CompFactor in figures 2-12 below), the stock-recruitment relation may be “compensatory”, that is concave from below, or convex in its lower range and concave in the higher ranges. (See figure 1.) In the convex “depensatory” range, the recruitment gain over the spawning stock will be small or even negative (then termed “critical depensation”). A centrally managed monopolistic fleet (or a cooperating pair of fleets) would usually avoid driving the escapement into the depensatory region; a competitive harvest may likely do so.
Figure 1. Cubic growth function ($b = 0$): “critical depensation” $A = 0.6$ (left), “non-critical depensation” $A = 1$ (middle), “compensation” $A = 3$ (right). Circle shows critical escapement $S_{crit}$ and cross indicates point of inflexion.

The immediate payoff from the seasonal harvest to the $\nu$-fleet (where $\nu = \alpha$ or $\beta$) is

$$\Omega_\nu(R, S) = \int_0^R [p_\nu - C_\nu(x)] dx.$$  

Here $p_\nu$ is the constant unit landings price for harvested biomass, and $C_\nu(x)$ is the unit harvest cost, which is monotone non-increasing as a function of the within-season stock level $x$. Note that, when $C_\nu(x)$ is decreasing, the marginal cost of harvesting increases as the stock is drawn down. This gives the fleets an immediate incentive to maintain high stock levels, with optimal current harvests and target stock levels depending on the value of the cost parameter relative to price. In a competitive fishery, each fleet will ignore the impacts of its harvests on the other fleet’s harvesting costs and payoffs. Thus, the competitive-fishery stock levels typically will be lower than those prevailing when the fleets cooperate.

Each individual fleet is centrally managed, and chooses its current harvest escapement $S_\nu$ in each harvest cycle to maximize the a priori expectation of its long-term objective function (the discounted sum of annual returns). The expectation is conditional on what the fleet currently knows of the future stochastic evolution of the fishery, and on what it can logically infer of its competitor’s strategy.

Typically we shall assume that, at the beginning of each harvest season, each fleet has full knowledge of the current state of the fishery, and in particular knows $R$ and $b$. But a fleet’s knowledge of $\theta_v$, and therefore of its own accessible sub-stock recruitment $R_v = \theta_v R$ may be incomplete: At minimum each fleet will possess only a common-knowledge a priori probability distribution of $\theta_v$. Or one fleet (perhaps both) may possess enhanced prior knowledge (a refined probability distribution) of $\theta_v$. Such enhanced knowledge is achieved through an imperfect observation $\theta_v$, and knowledge of the conditional probability distribution $p(\theta_v | \theta_v)$. In a polar case, a fleet, prior to harvest, may even know $\theta_v$ exactly.

On the other hand, posteriori, by the end of the harvest season, both fleets always will have learned the exact value $\theta_v$. (See the discussion, below, of the implementation of the control rule.)
We assume here risk-neutral $\alpha$ and $\beta$-fleets. More precisely, each fleet’s objective function is the (normalized) expected discounted-sum of its future payoffs, out to the infinite time horizon. (For a model with risk-averse fleets, see [McKelvey and Cripe, 2001]). In terms of the discount factor $\gamma$, and with

$$\kappa_i = (1 - \gamma) \gamma^i, \text{ so that } \sum_{i=0}^{\infty} \kappa_i = 1,$$

then

$$V_v[R(0)] = \max_{\{S_v(t)\}} E \left[ \sum_{t=0}^{\infty} \kappa_t \Omega_v[R_v(t), S_v(t)] \right]$$

where

$$R_v(t+1) = F[S_v(t), b],$$

for $t \geq 0$.

Thus $V[R(0)]$ is a weighted arithmetic mean of the fleet’s seasonal payoffs. The expectation is taken over the unknown future random evolution of the fishery denoted $\{S_v(t)\}$. It is conditioned on what the $V$-fleets knows, at time $t=0$, of the present and future states of the fishery, and on its beliefs concerning its competitor’s policy.

The escapement policy of the $V$-fleets is expressed through a specification of the fraction $f_v$ of the sub-stock recruitment $R_v$ that will be left unharvested. That is,

$$S_v = f_v R_v.$$

Here $f_v$ depends on the $V$-fleet’s knowledge of the current state of the fishery.

Specifically, if the $V$-fleets knows $(R, b, \tilde{\theta}_v)$ prior to the harvest, but does not know $\theta_v$, until the end of the harvest, then its optimal policy is of the form

$$S_v(R, b, \tilde{\theta}_v) = f_v(R, b, \tilde{\theta}_v) R_v.$$

But since in this case the fleet does not know $\theta_v$ a priori, therefore neither does it know $R_v = \theta_v R$, until the end of the harvest. Hence this harvest rule can be implemented only if an additional model refinement is made: e.g. that during the harvest season the migrating stock passes through the fishing ground over an extended period of time. As it does so, the fleet can control the fraction of cumulative stock that is harvested.

**Simulations**

The simulations shown here demonstrate that the payoffs to the harvesting fleets and the consequences for the resource itself are highly sensitive, not only to the biological and environmental characteristics of the natural resource system and to the technological and economic characteristics of the fleets, but also to the nature and timeliness of the information that the fleet managers possess when they make their harvesting decisions. It is well known that the value of information is always positive.

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when the players cooperate. A major finding of these studies is that the impact of enhanced information may well be negative, both for fleets and resource, when the fleets are competing. Here, we have organized our discussion of several of the most striking simulation results around a set of questions—questions relevant both to Pacific salmon and to other naturally fluctuating fishery resources.

In each simulation, \( \theta(t) = \theta_\alpha(t) \) denotes the proportion of the run available to the \( \alpha \) – fleet during the harvest period \( t=0, 1, \ldots \) The sequence \( \{\theta(t)\} \) consists of independent and identically distributed (IID) random variables, each taking on one of two possible values \( \theta_1 \) and \( \theta_2 \) with known fixed probabilities. A player’s knowledge of the current value of \( \theta \) can range from full knowledge (denoted “Cur”) to only minimal knowledge (“Min”) of the prior probability distribution function (PDF) of \( \theta \). Intermediate to these extremes are a range of levels of partial knowledge (through enhanced PDFs, obtained through imperfect current measurement (“Meas”), of \( \theta \).

The simulated game outcomes are displayed for a range of distinct circumstances: A competitive (or “non-cooperative”) fishery with a symmetric information structure, i.e. where the fleets possess identical information about \( \theta \), will be designated “Cur”, “Meas” or “Min” respectively. If instead the game is cooperative, this designation will be preceded by the notation “Coop”. If the game is competitive but the information structure is asymmetric, then the designation is “cur-min” or “meas-min”, and the \( \alpha \) – fleet is understood to possess the superior level of information.

In our simulations, the stock-recruitment parameter \( a \) remains constant over time. It therefore becomes convenient to normalize the unit of biomass so that carrying capacity \( K \), where \( F(K, a) = K \), is always set at \( K = 1 \). Depending on the parameter \( a \), the stock-recruitment relation may be “compensatory”, that is concave from below, or “decompensatory”, that is convex in its lower range and concave in higher ranges (see fig. 1). In the convex decompensatory range, the recruitment gain over the spawning stock will be small or even negative (denoted “critically decompensatory”).

Unit market price \( p \) is taken to be constant, and the unit harvest cost functions are assumed to increase, according to \( C_r(x) = c_r / x \), as the stock biomass \( x \) is depleted. If the game is competitive, then the harvest strategy rules, and hence the resulting steady-state stock levels, will depend on price and costs only through the ratio of the cost and price parameters \( c_r / p \).

More general versions of stochastic incomplete-information fish-war models have been constructed and analyzed, with simulations carried out for a range of information structures (as reported in R. McKelvey and G. Cripe, [2001]; and in R. McKelvey and P.V. Golubtsov, [2002]). The simulations shown in the present report were all generated using the McKelvey-Golubtsov model, with both fleets assumed to be risk neutral.

We now turn to a summary of simulated model behavior, with results organized through a series of questions.
• How does the nature of the stochastic stock-recruitment relationship affect the outcome of an incomplete-information harvesting game?

As noted above, if the stock-recruitment relation is characterized by depensation, then there is a range over which stock size exhibits stagnant growth. It is known from deterministic fish-war models that a common property stock externality will lead to over-harvesting, and it is evident that this effect is exacerbated by depensation. This is especially true when the common parameter ratio (c/p) is low (and hence there is a relatively small harvest revenue penalty for depleting the stock). This effect carries over to a stochastic world, as is demonstrated in Figures 2-5. In these figures, the stochastic θ has its distribution symmetric around its mean of .5, so that nature treats the two fleets equitably. In addition, the unit harvesting cost function is held fixed while unit price varies.

Figure 2. Harvesting with Compensatory growth: CompFactor = 3

Figure 3. Harvesting with CompFactor= 1.5
In figure 2, where stock-recruitment is compensatory, one sees a relatively benign outcome of competitive harvest, as p increases for fixed c=0.1. In this figure, the net harvest payoffs, while lower with competition than with cooperation, increase monotonically with market price p, and also with the quality of available information about current $\theta$. However, when stock-recruitment displays depensation, competitive-fishery payoff curves are dome-shaped, so that payoffs actually drop as market price increases (figs.4a and 5a). It is clear from figure 5b that high market prices, and correspondingly high common-pool stock externalities, will depress stock levels into the depensatory low-productivity range, and may even result in extinction of the resource.

- **What is the impact of symmetrically enhanced information in a competitive fish war?**

The new feature displayed in these same figures is the interplay of the common property externality with the information structure of each model variant. First,
consider model variants where the two fleets have identical information. Full current information permits a fleet to fine-tune its escapements to maintain a near constant escapement across its “good” and “bad” years. But the escapement of a fleet with minimal information can be tuned with less precision, and will in fact be substantially lower in “bad” years than in “good”.

With cooperative management, additional information provided to the fleets necessarily will enhance their mean payoffs. This positive value of information can be present in a competitive fishery as well, provided that prices are sufficiently low, or the resource is sufficiently resilient (e.g. compare figures 2 and 5). While full current information can enhance a fleet’s immediate harvest payoff, in a competitive fishery it will also exacerbate the effect of the common-stock externality. In some cases, even symmetrically enhanced information may actually damage future stock levels and both fleets’ mean long-run payoffs. These externality effects are strongest in the presence of dispensatory growth (in figures 4 and 5) and high prices.

- What difference does it make if one party has more information than the other?

Consider next, model variants involving asymmetric information. Because cooperation requires full sharing of information, asymmetric information implies competitive harvesting. In all cases, the player possessing superior information gains at the expense of the less fortunate player. Over the lower portion of the price range, the fleet possessing superior information can even reap payoffs exceeding those resulting from full cooperation. This effect becomes more pronounced as the compensation factor (CompFactor) declines and thus the growth function becomes more dispensatory. In this range, the player with an informational advantage would never voluntarily share its private information with its competitor, unless the latter party provides a side payment to buy both information and cooperation.

As price increases (while the harvesting cost function is held constant), there is a point beyond which the player possessing the superior information can gain by voluntarily sharing its private information in exchange for securing a cooperative agreement. The more fragile the resource (i.e. the lower the value of CompFactor), the lower will be the price at which this crossover occurs. In figure 2, for example, at prices above about 0.6 party 1 could gain slightly by sharing information. The incentive to share private information when prices are high is much stronger in figure 5, and the crossover occurs at a price below 0.4. In that case, critical dispensation causes competitive harvesting to become extremely damaging to both parties’ interests as prices increase.

These simulations demonstrate a general principle, namely that if competition rather than cooperation prevails, enhanced information can be harmful. How harmful, depends importantly on the characteristics of the resource itself. If the shape of the stock-recruitment function makes it difficult for the resource to recover from episodes of heavy fishing pressure or entails the possibility of the stock declining to the point of extinction (dispensation or even critical dispensation), then information that is of high quality is likely to lead to falling payoffs and stock decline – or even to stock extinction.
• *How does the level of stochastic variability affect the game outcome?*

![Graph showing the effect of increasing environmental variability; CompFactor = 0.6](image)

Figure 6. Effect of increasing environmental variability; CompFactor = 0.6

In figure 6, the distribution of $\Theta$ is uniform around its mean value of 0.5, so that the fleets are treated symmetrically by nature. Maximum standard deviation is $\sigma_{\text{max}} = 0.5$, and the measurement of “variability” on the horizontal axis is $\sigma / \sigma_{\text{max}}$.

In the complete-information cooperative model version, the mean payoff is high, and actually increases with variability. The explanation is that cooperative management permits concentrating the seasonal harvest in that area where the stock is currently concentrated, thereby minimizing harvest costs. Cooperative management, with only minimal knowledge, cannot target harvest in this optimal way and instead will simply divide the harvest equally between the fleets. The constancy of payoff results from the particularly simple distribution function assumed in this simulation.

When the game is competitive, complete contemporary knowledge allows each fleet manager to increase effort in those seasons when a large fraction of the stock is accessible within its stream. When the variability is large, this strategy will not be adequate to overcome the negative impact of the common property externality. As usual, this effect is most prominent when recruitment is dispensatory.

• *What are the effects of changing the quality of information, or the degree of asymmetry?*

Figures 7-9 show the same interplay between information structure, dispensation, and cost-price ratio as before, but now one holds the latter two fixed, while permitting the knowledge level of one or both of the fleets to range continuously across the gradations of measurement accuracy, from minimum to full. Furthermore, competitive situations are contrasted with fully cooperative ones.
Figure 7. Harvesting with information of varying quality; CompFactor = 3

Figure 8. Harvesting with information of varying quality; CompFactor = 1

Figure 9. Harvesting with information of varying quality; CompFactor = 0.6
When the growth function is depensatory and competition prevails, increasing the quality of symmetrically-held information will eventually reduce payoffs and damage the resource (figures 8 and 9). Note that if the information is available only to party 1, that party may be able to benefit from the information and forestall a resource crash, even when the resource is quite fragile. However, payoffs would be higher with cooperation, in most instances.

Note also that, with asymmetric information, party 2 generally has more to gain by moving to cooperation than does party 1, and might agree to make a side-payment to the better-informed party to secure cooperation. In general, the effects of asymmetry in access to information are rather complex, and appear to depend upon the type of information that is privately held, the players’ harvesting costs and the shape of the stock-recruitment function. In some competitive harvesting cases, a better-informed player can gain by keeping private information secret. In other cases, the better-informed party will gain by sharing information with its competitor.

- **How does the quality of available information promote cooperation?**

These models do not explicitly address the negotiation or maintenance of cooperative agreements but, as noted above, the simulation results suggest circumstances in which cooperation would be most likely to arise and the importance of information in this context. In the simulations, cooperative payoffs invariably exceed those that could be attained by equally-informed competing harvesters. This cooperative surplus is far from constant, though it is often greatest when information levels are high. In some cases, the potential gains from cooperation are modest – as, for example, when harvesting costs are high (or the value of harvested fish is low) and the resource is characterized by compensatory growth. In other cases, competition would result in extremely low payoffs, while substantial benefits would be possible with cooperation. For example, in figures 8 and 9 above, the potential cooperative surplus for equally-informed parties is large, and increases dramatically as the quality of information improves. If it is costly to negotiate and maintain agreements, it might not be worth the trouble when the resource is both resilient and lightly targeted. However, we might suppose that the parties would be more likely to undertake the cost of working out an agreement when they have more to lose by failing to cooperate. If the folk wisdom that “it takes a crisis to force an agreement” is correct, then we might expect to see cooperative agreements arising in those cases in which competitive harvesting threatens to deplete a relatively fragile resource. Improved measurements and forecasts could play a positive role, here, by increasing the potential gains from cooperation.

- **What might be the effect of a climatic regime shift, altering mean $\theta$?**

One possible effect of a climatic regime shift is that the mean of the “stock-split” PDF may change, so that the migration pattern becomes more favorable, on average, to one or the other of the players. As the mean value $\bar{\theta} = E\theta$ becomes more unbalanced, payoffs increase or decrease, always favoring the environmentally advantaged party. This holds both for cooperative and competitive harvesting. Figure 10 shows this
phenomenon when there is full symmetric knowledge of $\theta$; figure 11 assumes minimal knowledge, and fig 12 examines only competition but with knowledge asymmetries.

Figure 10. Effect of change in mean of $\theta$ – CompFactor = 1; full information

An interesting point to note in figure 10 is that the greater a party’s natural advantage, the more it has to gain from cooperation. Examine, for example, the region in which the mean of $\theta$ exceeds 0.7. There, with full information, party 2 would be better off behaving competitively, while party 1, who is favored by nature, has a great deal to gain from cooperation. This situation suggests that it may be up to the advantaged party to buy the cooperation of its less-favored neighbor.

Figure 11. Natural asymmetry with minimal information; CompFactor = 1

When there is minimal information, the ability of the naturally advantaged player to gain from cooperation diminishes as the mean of theta becomes extremely favorable, because the disadvantaged fleet no longer plays a significant role.
Figure 12. Natural asymmetry and asymmetric information; CompFactor = 1

Note, here, that a party that is favored by nature and also possesses superior information will have a strong incentive to maintain the privacy of its privileged information.

Application to Pacific Salmon

A recent period of conflict between Canada and the United States over their Pacific salmon harvests illustrates how unanticipated and poorly understood climate-related changes in stock abundance and migratory behavior can contribute to the breakdown of a cooperative harvesting agreement (Miller et al., 2001). In that case, the negotiators of the 1985 Pacific Salmon Treaty had neither recognized nor anticipated the impacts of an extended period of warmer coastal waters, both on the productivity of the stocks covered by the Treaty and their altered availability to the competing fleets. The shift to a warmer climatic regime contributed to dramatic increases in northern salmon stocks, declines in southern stocks, and a change in the migratory behavior of Fraser River sockeye that strongly favored the Canadian fleet. These changes altered the balance of power among the Treaty participants, and made it increasingly difficult to balance the multiple objectives expressed in the language of the Treaty. A new Pacific Salmon Agreement was signed in 1999 (U.S. Department of State, 1999), which both nations hope will prove more resilient to such stresses (Miller et al., 2001). This history provides background for our model, and allows us to examine the consistency of model predictions with real-world experience.

After spending its adult years in northern oceans, Canada’s Fraser Sockeye stock journeys southward to spawn. The run splits as it rounds Canada’s Vancouver Island. The (normally larger) fraction of the stock, 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 both countries’ fleets. The remaining fraction stays shoreward of the island, within Canadian waters and accessible only to Canadian harvesters. Following harvest these substreams rejoin at the river mouth and swim upstream to spawn.
Oceanic temperatures, coastal upwelling and related physical and biological processes in the Northern Pacific are constantly changing, driven by the El Niño-Southern Oscillation phenomenon and a longer-term pattern of variability known as the Pacific Decadal Oscillation. For the Fraser River sockeye, these environmental shifts contribute to year-to-year changes in the run-size and its fractional split, and these have been difficult to predict. Similarly unpredicted migratory and demographic shifts have characterized other jointly exploited North American Pacific salmon stocks. Historically, poorly recognized changes in such stock characteristics have contributed to serious miscalculations by the competing national fleets in setting their harvest levels. The result has been recurring “fish wars” between the two harvesting nations’ fleets. During periods of intense competition, individual stocks have sometimes been dangerously over-harvested.

Although real-world U.S./Canadian Pacific salmon management is far more complicated than our simple model, many of the events in the evolution of conflict and cooperation over Pacific salmon are broadly consistent with the predictions of the model. In the case of efforts to jointly manage Fraser sockeye harvests, two periods of intense competitive harvesting stand out. The first lasted for roughly a decade prior to the signing of the 1985 Pacific Salmon Treaty, and the second episodically during the 1993-1998 dispute.

Under the 1930 Fraser River Convention, the International Pacific Salmon Fishery Commission (IPSFC) regulated harvests of the Fraser River stocks within an area designated as “the Convention Waters.” Each nation was allocated half of the harvest (Convention, 1930). When the Canadians became unhappy with the agreement, they discovered that they could circumvent the IPSFC regulations by fishing for Fraser sockeye outside of the Convention waters. This was made increasingly possible and profitable by a change in the migratory habits of the returning Fraser sockeye. Beginning in 1977, a sudden and sustained shift in ocean conditions contributed to a marked increase in the proportion of the returning run via the northern all-Canadian route, through Johnstone Strait. In the period 1953–1976, the Johnstone Strait diversion rate averaged 16.4%. From 1977 through 1998, the diversion rate has averaged 48.2%.

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. Referring back to our simulation of the effect of a shift in natural advantage in a competitive game, we can see that a shift in payoffs in the direction of a change in the average split is just what the model would predict.

The most striking effects of the 1977 climatic regime shift were its impacts on the relative productivity of the various salmon stocks shared by Canada and the United States. 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. At the 1995 peak, Alaska harvested close to 218 million salmon. Another high was attained in 1999 when Alaska harvested almost 217 million salmon. In particular, pink salmon harvests increased dramatically in southeastern Alaska, where those stocks are intermingled with Canadian salmon.

In the southern border region, the effects of the climatic regime were profoundly different. There, poor survival conditions contributed to major declines in several salmon populations. The climate-related fragile condition of those stocks can be modeled as a shift in the shape of the stock recruitment function to a lower CompFactor.

Although those changes were already underway during the negotiation period for the 1985 Treaty, the linkages between climate, ocean conditions and salmon abundance were poorly understood and no one could predict how long the recent trends would last. Consequently, the negotiators of the 1985 Treaty simply ignored the potential impacts of sustained changes in salmon abundance and migratory behavior.

The 1985 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. Both equity and conservation objectives were expressed in the language of the Treaty, but the agreement only succeed in achieving a delicate balance among competing interests and objectives.

The bargaining framework implemented in 1985 required consensus, effectively giving each party a veto, and called for frequent renegotiation of the fishing regimes. 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.

The Treaty might have proved satisfactory if the shift to warmer ocean conditions had not continued. But the warming did continue and the payoffs that the Canadians and southern U.S. interests expected from the Treaty never materialized. Instead, Alaskan interceptions of Canadian salmon increased, and Canada returned to aggressive competitive tactics with respect to its harvests of Fraser sockeye and its interceptions of other salmon stocks migrating to spawn in Washington and Oregon rivers. The latter practice was particularly damaging because the climatic shift had depressed the productivity and resilience of those stocks—a shift to a more depensatory recruitment function. The 1999 Agreement accommodates the Canadian position by further decreasing the U.S. share of the Fraser sockeye harvest. In addition, the revised agreement provides implicit side-payments to Canada in the form of financing for
research and enhancement activities through two endowment funds, funded almost entirely by the United States. Most importantly, the new Agreement defines harvest shares on the basis of indices of abundance, thus limiting the parties’ ability to aggressively fish “up to the ceiling” when the resource is in a fragile state.

Pressure to resolve the Pacific salmon dispute was strongest in the south. Referring to the figures above, it can be seen that the fragile condition of those stocks meant that considerable damage could be done by continued competitive harvesting. The potential gains from cooperation were, thus, increased by the decline in the resilience of those stocks.

Alaska, on the other hand, remained unwilling to make concessions to secure cooperation. Given the fact that most salmon swim northwards as juveniles and follow a north-to-south route on their return migration, Alaska is in a good position to intercept Canadian and some southern U.S. salmon stocks, while few Alaskan salmon are vulnerable to interceptions. As figures 10-12 demonstrate, such a natural advantage would lead a party to expect to receive a large share of the benefits of the fishery. Our simulations also suggest that the robust condition of Alaska’s stocks would tend to reduce Alaska’s expected gains from cooperation. In the end, the 1999 Agreement accommodates Alaska’s position, in that Alaskan harvests will remain relatively unchanged under the new abundance-based rules. In addition, Alaska will benefit from new U.S. federal funding for research, enhancement and vessel buybacks.

As for the effects of information, or its absence, it is evident that when the provisions of the 1985 Treaty were negotiated, there was relatively little understanding of the potential for long-term climate-related changes in patterns of salmon production or migration. Uncertainty contributed to disagreements throughout the Treaty period. For example, the stated goal of balancing the value of each nation’s interceptions of the other’s salmon, was confounded by difficulties in calculating values and in tracking actual interceptions. Given the Treaty’s equity language and the bargaining framework that entailed frequent renegotiations, it is not surprising that the parties often differed in their estimates of interceptions, and that the differences frequently favored their own positions.

In recent years, there has been a rapid accumulation of scientific research that has led to a growing understanding and awareness of the role of large-scale climatic fluctuations in driving changes in abundance and migratory behavior (Xie and Hsieh, 1989; Mantua et al., 1997; Downton and Miller, 1998; Beamish et al., 1999a,b). It is interesting to note that a major provision of the 1999 Agreement calls for enhanced scientific cooperation and open sharing of information (U.S. Department of State, 1999). This suggests that the parties clearly recognize the potential value of good information in a cooperative regime. While there is little publicly-available information indicating that strategic withholding of data or analyses had been a common practice, the amount of attention given to the matter in the 1999 Agreement demonstrates that the parties are eager to avoid that danger.
References


Xie, L. and Hseih, W., 1989. “Predicting the return migration routes of the Fraser River sockeye salmon (Oncorhynchus nerka). Canadian Journal of Fisheries and Aquatic Sciences, 46, 1287-92.

NOTES:

i Peterman (1977) discusses environmental shifts in salmon recruitment functions in relation to depensatory mortality at low population levels. In that treatment, stochastic environmental factors shift the net recruitment function up or down, changing the critical threshold at which recruitment falls below replacement.

ii 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. agreed to contribute $75 million to the Northern Fund and $65 million to the Southern Fund over a four-year period. The first installments have been made, and balance of the commitment is to be remitted in fiscal year 2003. Canada also contributed $250,000 (CND) to each of the two funds in November 2000 (PSC, 2002). 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.

iii The Joint Interceptions Committee of the Pacific Salmon Commission was established to coordinate documentation of interceptions. Its few reports tended to document the wide range of uncertainty surrounding the estimates and the disparate views of the parties as to the magnitude and direction of interceptions imbalances (PSC-JIC, 1993). That committee ceased issuing reports when the dispute over equitable allocation escalated.