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Perspectives

Climate and Cooperation: A New Perspective on the Management of Shared Fish Stocks

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Abstract *Climate regime shifts occur at irregular intervals and have profound and persistent impacts on ocean temperature and circulation patterns and on the dynamics of marine fish populations. Despite a growing scientific literature and some attention to the implications of such regime shifts for domestic fisheries, the issue has received little attention in the context of international fishery management. This paper presents evidence for the significance of climatic regime shifts, and draws upon the recent history of conflict between Canada and the United States over Pacific salmon management to illustrate the dangers that unpredicted, unanticipated environmental regime shifts pose for efforts to maintain international cooperation. This suggests a need for greater attention to this issue. Fishery agreements can be made more resilient to the impacts of such environmental changes by explicitly building in flexibility — for example, by allowing the use of side payments. In addition, pre-agreements on procedures to be followed in the event of sustained changes in fish stock productivity or migration patterns, and cooperation on developing common scientific understandings, can help to prevent destructive conflicts. Finally, the literature employing game theoretic shared-fishery models could be further developed to focus on providing practical guidance for maintaining cooperation in the presence of unpredictable and persistent environmental changes.*

Key words Climate regimes, shared fisheries, potential conflicts, uncertainty.

JEL Classification Codes Q22, Q21.

Introduction

Over the past two decades, there has been growing recognition of the importance of uncertainty in the management of capture fisheries. Year-to-year variations in catch, price fluctuations, and the uncertain long-term impacts of competition from aquaculture are familiar sources of uncertainty. The predictability of such phenomena varies

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along a continuum. At one extreme, there may be cases in which modest investments in data collection and modeling can yield reliable predictions. At the other extreme, complex dynamics or unobservable components of the system may make accurate predictions virtually impossible. Even in the latter case, however, one can anticipate the possibility of significant change.[1]

A particularly large and important source of uncertainty, only recently recognized, consists of unpredictable, or imperfectly predictable, climate regime shifts. These shifts lead to uncertainty of a profound nature, in that the consequences are both far reaching and long lasting.

Work that has been done on the implications of climate regime shifts for fisheries management has largely been confined to domestic fisheries; *i.e.* fisheries confined within the Exclusive Economic Zone (EEZ) of a single coastal state. In this paper, we explore the consequences of unpredictable climate regime shifts for the management of international fishery resources, defined simply as fishery resources exploited by more than one state/entity. The consequences of climate regime shifts for the management of these international resources are raised to a higher level. Along with all the consequences experienced in domestic fisheries, one also must consider the impact of climate regime shifts upon the stability of cooperative resource management arrangements. It is now widely recognized that, with few exceptions, international fisheries will not be effectively managed unless stable cooperative resource management arrangements are in place (Munro 2003). In the absence of such cooperation, competing national fleets tend to fish aggressively, leading to resource depletion and low economic returns. We argue that, even if a cooperative management arrangement is ostensibly binding in nature, the impact of climate regime shifts can easily be great enough to undermine the arrangement.

In this paper, we first discuss the nature of climate regimes shifts and evidence of their importance to fisheries worldwide. Next, we set the stage and provide an analytical framework by briefly reviewing the existing economics of the management of international fisheries. We then draw upon a case study of Pacific salmon to illustrate the consequences of climate regime shifts for international fisheries management. Pacific salmon, shared by the US and Canada, are among the most important shared fishery resources in the world. These developed coastal nations pride themselves on the quality of their fisheries management capabilities. In spite of these joint resource management capabilities, the US-Canada cooperative management arrangement came close to disintegration because of the unforeseen effects of climate regime shifts. Finally, we discuss possible means by which the impact of climate regime shifts can be mitigated in the management of international fisheries.

Climate, Uncertainty, and Fisheries Management

Climatic variability affects fishery populations in a variety of ways and on many different temporal and spatial scales. Fisheries biologists have devoted considerable effort to understanding the linkages between physical changes in the ocean environment and changes in biological processes that ultimately affect the recruitment of harvestable fish. There is evidence that these processes can be quite complex, sometimes involving a chain of predator-prey relationships or subtle physical changes with large impacts on survival and growth at critical life stages. While understand-

[1] We are drawing a distinction between the terms "prediction" and "anticipation." Prediction implies foretelling an event with some level of detail and precision. Anticipation, on the other hand, suggests expecting the possibility of an event at some unspecified time in the future.

ing of year-to-year variability in fish abundance is gradually improving, such variability remains difficult to predict.

In addition, there has been growing recognition of the fact that variability in marine populations rarely takes the form of simple "white noise." Rather, occasional dramatically good or bad recruitment years may drive the dynamics of commercially important fish populations. In addition, abrupt and persistent changes in patterns of recruitment or migratory behavior occur at unpredictable intervals.

Bakun (1996, 1998) presents evidence for the significance of regime shifts, citing a pattern of global synchrony in several dramatic declines and expansions of marine fisheries with mirror image fluctuations in widely separated marine fish stocks. Although rapid fleet redeployment from declining to expanding fisheries could account for some of this apparent synchrony (Ueber and MacCall 1992), many researchers have noted that this pattern of large, roughly synchronous shifts in fish abundance often occurs in the absence of any evidence of fleet movements between the fisheries (Alheit and Hagen 2001). In addition, paleo-ecological evidence demonstrates that fish populations experienced significant long-term fluctuations long before harvesting pressure could have played a role (Baumgartner, Soutar, and Ferreira-Bartrina 1992; Finney, Gregory-Eaves, and Smol 2002).[2]

Recent research suggests that such biological "regime shifts" may be linked to large-scale, persistent changes in atmospheric circulation (Stenseth *et al.* 2002). While there is some hope that improved understanding of such linkages could lead to improved predictions of stock abundance (Bakun 1998), many observers caution that predictability may be inherently limited by chaotic dynamic behavior and by limits on our ability to observe important variables in the system (Ludwig, Hilborn, and Walters 1993). Francis and Shotten (1997), in developing a typology of uncertainties affecting fisheries management, draw a distinction between "reducible" and "irreducible" uncertainty. Given the complexity of the linkages between fishery population dynamics and changes in ocean-atmosphere circulation, the uncertainties associated with regime shifts may be destined to remain largely in the "irreducible" category.

The Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) provide striking examples of modes of atmospheric circulation having substantial, long-term impacts on a variety of fish populations. With regards to the PDO, many observers have noted an abrupt climatic and biological shift in the North Pacific, commencing in 1977. Ebbesmeyer *et al.* (1991), for example, catalogue a series of abrupt environmental changes in the mid-1970s, many related to marine fish stocks. Other researchers note strong, persistent changes in zooplankton biomass (Roemmich and McGowan 1995)[3] and a 1977 step change in recruitment of salmon, flatfish, rockfish, and mackerel (Beamish 1995; Mantua *et al.* 1997; Hare and Mantua 2000; Hollowed, Hare, and Wooster 2001).

The 1977 regime shift appears to have been only one of many such long-term fluctuations in the North Pacific, where climate has been characterized by recurring shifts in mean levels of sea level pressure and sea surface temperatures that have lasted for several decades (Zhang, Wallace, and Iwasaka 1996; Latif and Barnett

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[2] Dramatic swings in abundance over a roughly 2,000-year time horizon have been reconstructed for Alaskan salmon (Finney, Gregory-Eaves, and Smol 2002) and for California sardine and anchovy stocks (Baumgartner, Soutar, Ferreira-Bartrina 1992). The latter study found inverse fluctuations in sardine and anchovy abundance.

[3] Even when the effects of strong El Niños in 1958–59 and 1983–84 are specifically excluded, Roemmich and McGowan (1995) document an 80% decline in zooplankton biomass off the coast of southern California between the periods 1951–57 and 1987–93. They link the decline to a 1.5ºC warming of sea surface temperatures, increased stratification, and less effective upwelling.

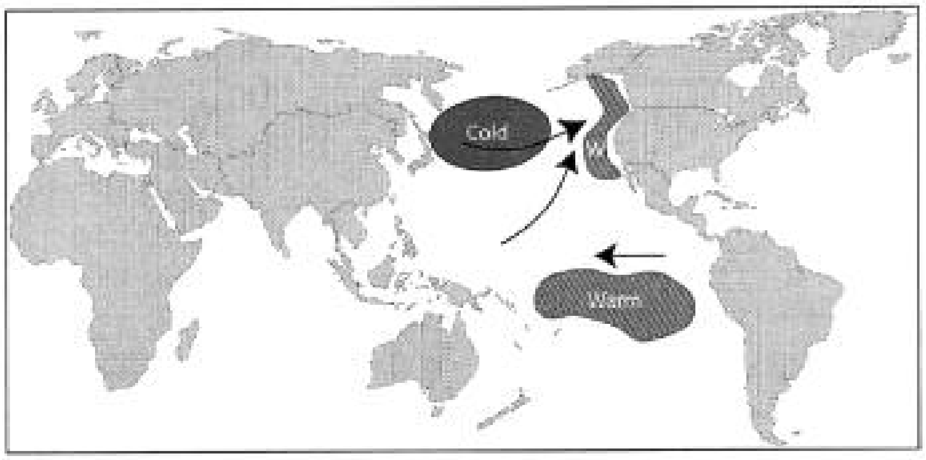
1996). While several competing atmosphere-ocean indices have been examined for their relationships to large-scale fluctuations in biological time series (Hare and Mantua 2000; McFarlane, King, and Beamish 2000; Hollowed, Hare, and Wooster 2001), all analyses point to changes in the intensity and position of the wintertime Aleutian Low as playing a central role in the dynamics of the North Pacific's regime shifts. Changes in the Aleutian Low are, in turn, closely linked to changes in coastal and offshore sea surface temperatures across the northeastern Pacific. The PDO index captures these linkages between temperature and pressure anomalies (Mantua *et al.* 1997) (figure 1). When the PDO is in its coastal warm phase, sea-surface temperatures along the west coast of North America are unusually warm, westerly wind stress is stronger than normal, and there is a large area of unusually cool sea surface temperatures in the western and central North Pacific. In the coastal cool phase, the signs of these anomalies are reversed (Mantua *et al.* 1997).[4] The PDO was in the warm phase during the early 20th century. There was a shift to the coastal cool pattern from the mid-1940s through 1976, then an abrupt return to the warm PDO pattern in 1977, lasting through at least the mid-1990s (Francis *et al.* 1998). The coastal warm phase is associated with an intensification of the Aleutian Low and increased winter storminess in the Gulf of Alaska.

Major changes in Pacific salmon stocks have been linked to changes in the PDO, with Alaskan salmon stocks generally thriving during the coastal warm period, while many stocks spawning in rivers along the US west coast experienced extremely poor survival and growth. During coastal cool periods, opposite changes in stock abundance occurred, with southern stocks faring well, and Alaskan stocks being relatively unproductive (Hare, Mantua, and Francis 1999). Although interpretation of the climate signal for Pacific salmon is admittedly complicated by the significant impacts of dams, degradation of spawning habitat, and changing hatchery practices in the US Pacific Northwest (Anderson 2000), a recent rebound of many of the southern stocks following a brief return to cool coastal sea surface temperatures from mid-1998 through 2001 strongly supports the view that ocean variability plays a significant role (Meloy and Drouin 2002).

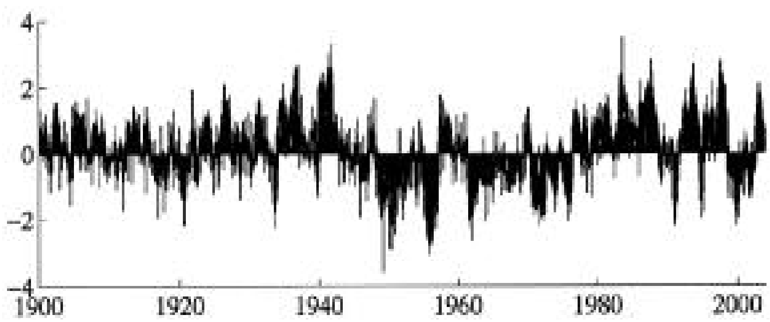
The link between the PDO and apparent biological system regime shifts is not simple or linear. Pointing to recruitment estimates for a number of British Columbia's fish stocks, including several groundfish species and Pacific salmon stocks, McFarlane, King, and Beamish (2000) argue for the existence of two distinct regime shifts in recent years, one in 1977 and another in 1989. The latter shift, they argue, was not a return to pre-1977 conditions, but rather marked the beginning of a period of extreme low productivity for a number of these stocks. Hare and Mantua (2000) also examine the evidence for two distinct regime shifts by comparing a large number of environmental, biological, and climatic time series. Their analysis supports the finding that many biological records show a clear further shift in 1989, but they note that most indices of north Pacific climate do not show a similar clear break in 1989. On the other hand, the fact that the retreat of glaciers in southeastern Alaska accelerated rapidly after 1989 suggests that some sort of climatic shift occurred at that time (Trabant, March, and Kennedy 1998).

The PDO may be related to changes in the behavior of the better-known El Niño — Southern Oscillation phenomenon (ENSO), in that the recent PDO warm period may have been supported and sustained by an unusual closely spaced sequence of El Niño events (Trenberth and Hoar 1996). However, the effects of PDO regime shifts on biological systems are much longer term than the impacts of individual El Niño (warm) or La Niña (cool) events and are more notable in the northern Pacific than in

[4] Information about the Pacific Decadal Oscillation is available at: http://tao.atmos.washington.edu/pdo/



A. Sea surface temperature and wind stress anomalies, coastal warm phase (positive values)



B. Monthly values - PDO Index

Figure 1. Pacific Decadal Oscillation
Source: Mantua 2004.

the tropics, where ENSO is the dominant mode of variability (Hare and Mantua 2000). ENSO has long been recognized as affecting the abundance and availability of a broad array of fishery resources (Wooster and Fluharty 1985; Caviedes and Fik 1992; Agüero and Gonzalez 1996; Bakun 1996; MacCall 1996; Lehodey *et al.* 1997; Lluch-Cota, Hernández, and Lluch-Cota 1997; Hollowed, Hare, and Wooster 2001;Yañez *et al*. 2001; Pontecorvo 2001; Lehodey, Chai, and Hampton 2003). However, it is now clear that the irregular seesaw between El Niño and La Niña conditions is only one type of biologically significant variability in the Pacific Ocean climate system.

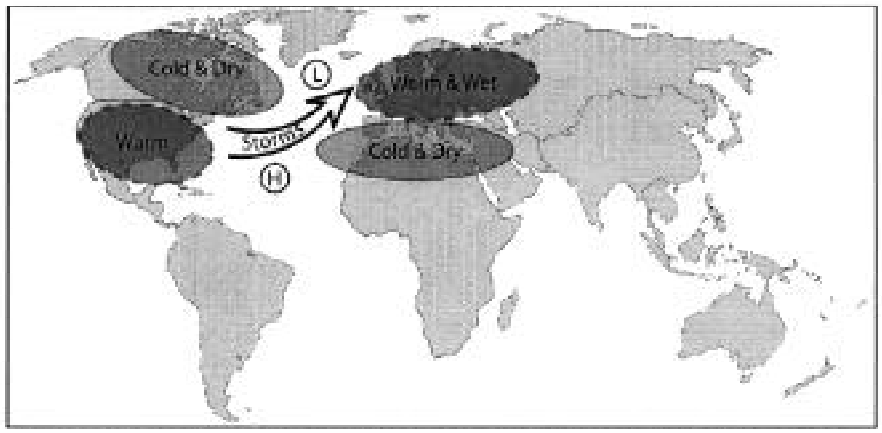
Similar long-term climatic and biological regime shifts are evident in the North Atlantic. The NAO has been well-documented as a significant source of climatic variability over Europe, Western Asia, and North Africa (Van Loon and Rogers

1978; Hurrell and Dickson 2003). It is also a major determinant of changes in oceanographic conditions with impacts on ecosystems and fishery resources in the North Atlantic and adjacent northern seas (Parsons and Lear 2001; Alheit and Hagen 1997, 2001; Ottersen and Stenseth 2001). The NAO is defined as being in a positive phase when the winter pressure difference between the low pressure cell centered over Iceland and the high pressure cell centered over the Azores is larger than normal. This pattern drives strong, westerly winds over northern Europe, bringing warm stormy winter weather, while southern Europe, the Mediterranean, and Western Asia experience unusually cool and dry conditions. Also in the positive phase, cold winter temperatures prevail over Greenland, the Labrador Sea, and northeastern Canada, and sea ice in the western Atlantic extends farther southward than usual. In the negative phase, the pressure differential is smaller than average, and winter conditions are unusually cold over northern Europe and milder than normal over Greenland, northeastern Canada, and the Northwest Atlantic (Hurrell and Dickson 2003). While the NAO does not show any consistent pattern of variability, there have been long periods during which it has tended to be either unusually low or high. In particular, it was generally low throughout the 1950s and 1960s. It then abruptly switched to an extreme positive state for most of the period from 1970 to the present, except for a sharp drop in the winter of 1996 (Parsons and Lear 2001) (figure 2).

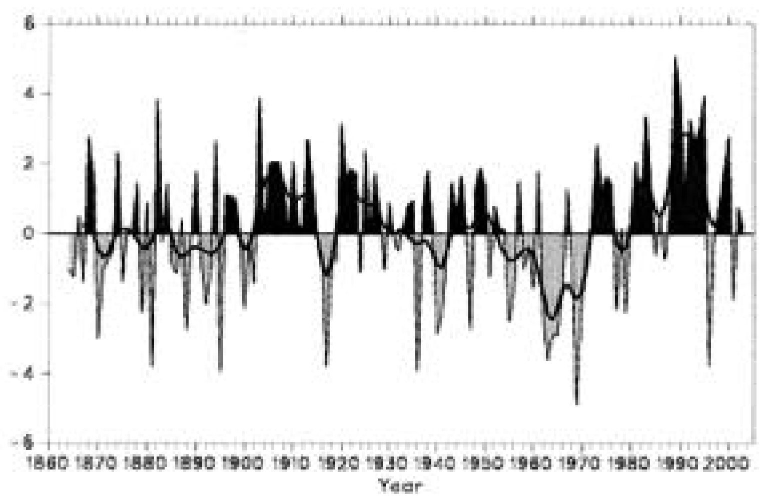
As for the apparent impacts of NAO variability on marine ecosystem dynamics and fishery resources, Parsons and Lear (2001) argue that the unusually cold winter conditions in the Northwest Atlantic during recent decades may have contributed to the collapse of Canadian Atlantic groundfish, West Greenland cod, and northern cod stocks, although overfishing also clearly played a significant role. Furthermore, they point to the extreme positive NAO as contributing to increased abundance of shrimp, crab, and lobster in the waters off northeastern Canada in the 1980s and 1990s. In the North Sea, they link a period of high abundance for gadoid stocks (cod, haddock, whiting, and saithe) to cold conditions associated with extreme negative values of the NAO Index in the 1960s, and subsequent poor recruitment of those stocks to the shift to strong positive NAO conditions.

Other analysts have noted that warm conditions in the Norwegian Sea (associated with positive NAO conditions) increase the likelihood of good recruitment years for Atlanto-Scandian (Norwegian spring spawning) herring (Krovnin and Rodionov 1992; Alheit and Hagen 1997, 2001). In addition, this stock has displayed major long-term shifts in migratory behavior that appear to be linked to changes in stock size and environmental conditions. When the stock is small, it remains close to the spawning grounds along the Norwegian coast. When abundant, the herring migrate more broadly through the international waters of the “Herring loophole” and through the EEZs of Iceland, the Faroe Islands, and the European Union (Alheit and Hagen 1997; Arnason, Magnusson, and Agnarsson 2001).

Within the broad patterns driven by the PDO, NAO, or other indices of large-scale climate variability, the details of changes in fish abundance are often better explained by smaller-scale processes. In the case of Pacific salmon, near-shore temperature anomalies during the critical period when salmon smolts first enter the ocean are a better predictor of subsequent recruitment than the PDO index (Downton and Miller 1998; Meuter, Ware, and Peterman 2002). Furthermore, the large-scale changes in atmosphere-ocean circulation patterns are, at present, unpredictable and poorly understood. So, while large-scale climate indices may be useful in explaining broad patterns of change in stock abundance and location, they will not, by themselves, provide the magic key to unlocking the mysteries of fluctuating fishery resources. The timing, location, and magnitude of significant changes in fish population dynamics will likely remain unpredictable. It must be emphasized that



A. Temperature and precipitation anomalies — positive phase



B. Dec.-Mar. values — NAO Index

Figure 2. North Atlantic Oscillation
Source: Hurrell 2004.

although such changes cannot be predicted, they can be anticipated. In other words, we now have a rapidly accumulating body of evidence suggesting that large and persistent natural changes in the oceans' biological resources can and do occur.

That understanding should allow us to anticipate the risk of regime shifts and undertake planning to manage the risk of climate regime shift. In the case of domestic fisheries management, the possibility of significant, imperfectly predictable regime shifts highlights the need for management systems that can minimize the cost and disruption of potentially large and long-term adjustments in effort and allowable harvests. Hilborn, Maguire, and Parma (2001) have addressed this issue.

Here, we are concerned with the management of shared international fisheries and the question of how the large, mostly irreducible uncertainties associated with regime shifts will affect efforts to cooperatively manage such fisheries. There is an urgent need for the marine resource economics community to address the question of how to make international fishery management regimes robust to this type of risk.

The following section provides an overview of the existing theoretical framework available to address this issue. The case study then illustrates what the theory can contribute to our understanding of the problems that can arise when a shared fishery resource is affected by a natural regime shift. We conclude that further development of the theory is needed to explicitly address the effects of such regime shifts.

A Brief Review of the Economics of International Fishery Resources Management

In this section, we review the relevant existing theory of the management of international fishery resources, which will, in turn, provide a framework, albeit less than perfect, for the examination of the case study to come. First, however, we need to define international fishery resources with somewhat greater precision.

International fishery resources, as noted in the introduction, are understood to mean resources that are exploited by more than one state/entity. We adopt the categorization of these resources currently used by the FAO (FAO 2002). The FAO defines international fishery resources as shared fishery resources, and subdivides them into four non-mutually exclusive categories, as follows: (A) Transboundary fishery resources — fish stocks that move between and among neighboring EEZs; (B) Highly migratory fish stocks — fish stocks, defined as such by the United Nations (UN 1982, Annex 1) which, because of their highly migratory nature, cross EEZ boundaries into the adjacent high seas; (C) Straddling fish stocks — all other fish stocks (excluding anadromous and catadromous stocks) which cross EEZ boundaries into the adjacent high seas; and (D) Fish stocks that are found exclusively in the high seas.[5]

In the discussion and case study to follow, we confine our attention largely to Category A, transboundary fishery resources.[6] In part, this is deliberate. Fishery resources found in Category A are, generally speaking, easier to manage than are those found in Categories B, C, or D (Munro 2003). It is our desire to make the point that, even in the case of those international fishery resources, which are relatively easy to manage, unpredictable climate regime shifts can have potentially damaging consequences.

A few characteristics and features of transboundary fishery resources are worth noting. While exceptions can be found, the number of state/entities typically in-

[5] With regards to definitions of classes of international fishery resources, there is a second school of thought, in addition to that of the FAO. This second school of thought accepts the FAO definitions of highly migratory and straddling stocks. It, however, uses "transboundary" as the generic term for international fishery resources, and uses the term "shared" to denote Category A stocks. The school of thought that one chooses to accept is a matter of taste and convenience.

[6] Since it is our intention to focus primarily on transboundary fishery resources, and since the major case study will be Pacific salmon, a seeming inconsistency needs to be resolved. Salmon, being a wide-ranging anadromous species, cross EEZ boundaries into the adjacent high seas. The resolution lies within the UN Convention on the Law of the Sea (UN 1982). Article 66 of the Convention (included because of joint US — Canadian pressure) effectively bans directed high-seas fishing of salmon, with the consequence that Pacific salmon is, to all intents and purposes, a transboundary fishery resource.

volved in the exploitation of a transboundary fishery resource is small. Two is not uncommon; ten would be considered very large (Miller and Munro 2002). This stands in contrast to the typical straddling, or highly migratory, stock. Secondly, the legal framework surrounding the cooperative management of these resources is usually strong, with the norm being a legal framework in the form of a treaty, which is perforce binding upon the signatories (Owen 2001). Thirdly, if we define symmetry among the states/entities exploiting the resource to mean that they are identical in all respects, then we can say, with confidence, that asymmetry appears to be the rule (Miller and Munro 2002). Finally, we can be assured that Category A resources are indeed of genuine significance in terms of world fisheries. John Caddy, formerly with the FAO, estimates conservatively that there could easily be 1,500 such resources worldwide (Caddy 1997).

Since the discussion will be confined largely to Category A resources, there is no need for the review of the economic theory of international fishery resources management to be other than brief, since much of the theory will be familiar to the reader (for example, Munro 1990). To commence, in order for a transboundary fishery resource to be worthy of concern as a distinctive resource management problem, the harvesting activities of at least one state/entity exploiting the resource must have a significant impact on the harvesting opportunities of other states/entities exploiting the resource. Given that this condition is met, strategic interaction between/among those exploiting the resource becomes inescapable. Consequently, the economic theory brought to bear in analyzing the management of these resources is a blend of the dynamic economic theory of the management of domestic fishery resources and the theory of strategic behaviour, more popularly known as the theory of games.

The first question to be asked is what the consequences would be if states/entities sharing a transboundary resource did not cooperate in its management. Each state/entity would be expected to manage its share of the resource as best it could. The answer is that we should expect the consequences to be destructive, with the non-cooperative game having a Prisoner's Dilemma type of outcome, leading to overexploitation of the resource and dissipation of the rents that it could have generated. Clark (1980), for example, demonstrates that if the players in the non-cooperative game are symmetric, the outcome will be the equivalent of Bionomic Equilibrium in a domestic fishery — even if the number of players is only two. Thus, if a climate regime shift succeeds in disrupting an otherwise successful cooperative resource management arrangement, we can predict, with some assurance, that the result will be almost certain overexploitation of the resource.

Thus, cooperation matters. The question then becomes, what conditions must prevail for a cooperative management arrangement to be stable over the long run? Since we are dealing with transboundary resources, we can limit the following discussion to two-player cooperative games and assume that the cooperative resource arrangement is legally binding, and that outright cheating is not a problem. In keeping with our assertion that asymmetry among the players in the fisheries game is the rule, not the exception, we assume that the players have different management goals.

Finally, we initially assume that side payments are not considered. We shall define a fisheries game without side payments to be one in which the economic returns from the fishery to each player are determined solely by the harvests of that player's fleet, within the player's own waters.

The two well-known *minimum* conditions that must be met for the solution to the cooperative game to be stable are as follows: (*i*) the solution must be Pareto Optimal, (*ii*) the Individual Rationality Constraint must be satisfied, which is to say that the solution payoff to each player must be at least as great as the payoff which that player would enjoy under non-cooperation.

Consider figure 3 (also well known), which illustrates the two-player cooperative fisheries game. The payoffs, θ, γ, are the present value of the net economic returns to each of the two players arising from various resource management regimes. The payoffs, θ_0, γ_0, represent the payoffs to two players from non-cooperation, and thus constitute the Threat Point. The Threat Point payoffs are those existing at the beginning of the cooperative management program. At the beginning of the program, both players anticipate that the Threat Point payoffs will remain constant through time.

The segment of the Pareto Frontier marked by the dashed lines emanating from the Threat Point payoffs represents the "core" of the game. The "core" is non-empty, so that a solution to the cooperative game is achievable.

Now suppose that after the cooperative management regime has been in place for some time, there is an unanticipated, unpredicted climate regime shift. One obvious consequence could be that there would be an equally unpredicted shift in the Threat Point payoffs. Consider figure 4, which allows us to illustrate the resulting problem in a particularly simple fashion. Ignore, for the moment, the 45 degree line.

In figure 4, we are presented with the original Threat Point payoffs and the post climate regime shift Threat Point payoffs, θ_0', γ_0'. The climate regime shift has benefited Player I, but has been detrimental to Player II. With the new Threat Point, the original solution to the cooperative game is no longer feasible. It is clear that Player I would be much better off not cooperating rather than continuing to accept the originally agreed upon cooperative management regime. Indeed, in the example presented, it is worse than that. In the absence of side payments, the new Threat Point is such that it would not be possible to satisfy the Individual Rationality Constraint, with the consequence that cooperation would break down.

We assumed that the cooperative arrangement was binding. The two players

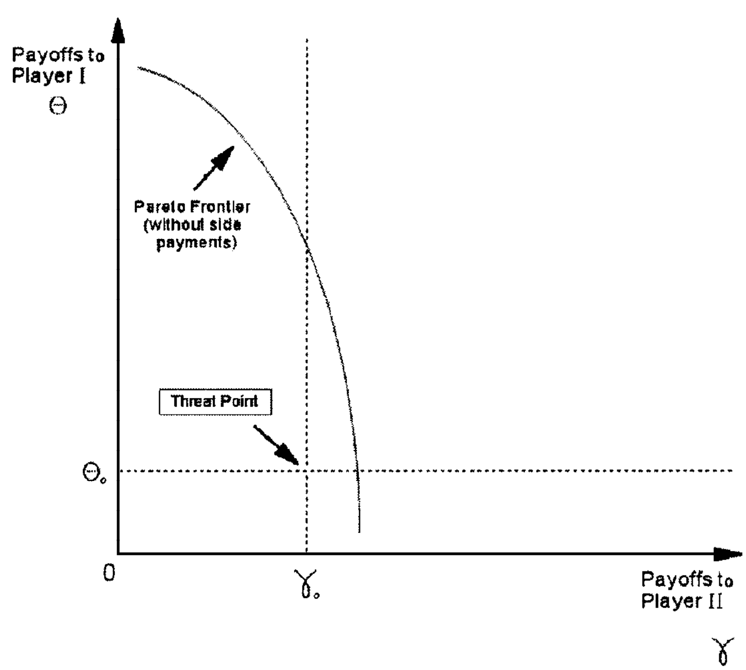


Figure 3. Two-player Game

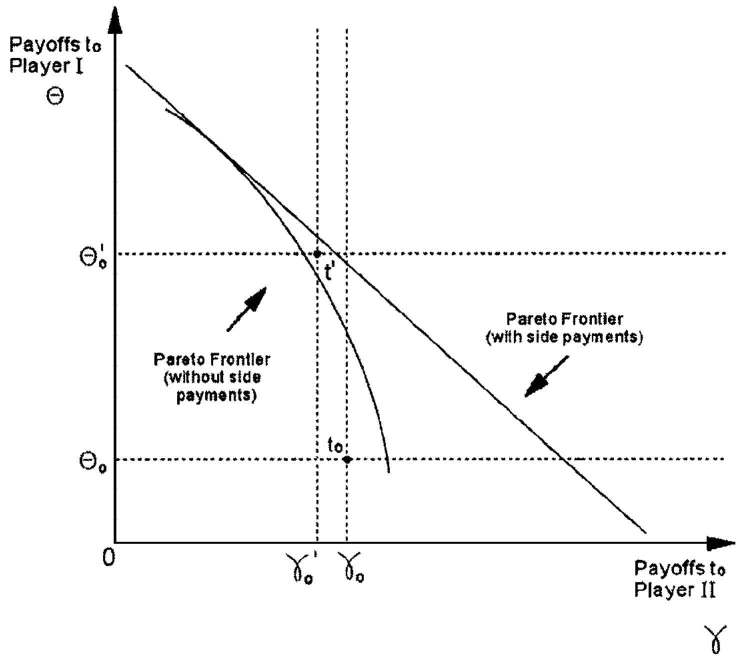


Figure 4. Game with Change in Climatic Regime

may, for example, have signed a treaty. One might suppose that this would be sufficient to prevent cooperation from collapsing. However, it would not. As history has demonstrated, and as the example of Pacific salmon will illustrate, it is not necessary for the dissatisfied player to denounce the arrangement (treaty) formally or to act in clear violation of the terms of the arrangement for difficulties to arise. There are innumerable ways in which the dissatisfied player can undermine the arrangement, "throw sand in the gears" as it were, with the consequence that the cooperative management arrangement seizes up and ceases to function.

In the context of a non-binding cooperative management arrangement, Kaitala and Pohjola (1988) demonstrated the need for cooperative management arrangements to have sufficient flexibility and resiliency to accommodate changing circumstances through time. If not, then what might have appeared to be a sound and equitable cooperative management arrangement at the beginning of the resource management program will cease to be so, and will ultimately collapse. What experience has taught us, often painfully, is that the need for flexibility and resiliency is not limited to non-binding cooperative arrangements. Legally binding arrangements must be so, as well. Thus, resiliency through time should be seen as a third condition to be met, if the solution to the cooperative game is to be stable over the long run.

The Kaitala-Pohjola model, we might note in passing, is deterministic. If the changes through time can be predicted with certainty, then it should not be particularly difficult to accommodate these changes when initially negotiating the cooperative arrangement, even if they are of large magnitude. It is quite another matter, needless to say, if one is dealing with changes subject to irreducible uncertainty.

Return now to figure 4. Up to this point, it was assumed that side payments have not been considered. If side payments are allowed, then the Pareto Frontier becomes a 45° line, the significance of which is that the sum of the payoffs at any one point on the Frontier is equal to the sum of the payoffs at any other point on the Frontier. The objective of the two players becomes that of maximizing the global net economic returns from the fishery, through time, and then bargaining over the division of these returns.

The point has been made many times in the past that when there are differences in management goals, it is invariably the case that one player places a higher value on the resource than does the other player(s) (for example, Munro 1987). In our example, it is assumed that Player I places the highest value on the resource. Consequently, maximizing the global net economic benefits from the resources involves ensuring that the management preferences of Player I are dominant.

In our example, the introduction of side payments would make it feasible for cooperation to continue after the shift leading to the new Threat Point. Allowing for side payments can lead to greater efficiencies, as is certainly the case in figure 4. We can also think of side payments as broadening the scope for bargaining. Clearly, anything that enhances the scope for bargaining will improve the flexibility and resiliency of the arrangement. The case study to follow on Pacific salmon will reveal that the detailed, carefully negotiated treaty between the two players almost foundered because the scope for bargaining proved, in retrospect, to be too narrow.

Side payments, which we have defined broadly, are one means of enhancing the scope for bargaining. We make no claim that they are the only means. Be that as it may, the significance of side payments in the management of international fisheries, which has become increasingly recognized in the academic literature over the past several years, is now beginning to be recognized by policymakers (for example, Arnason, Magnusson and Agnarsson 2001; Agüero and Gonzalez 1996). Thus, the Report of the recently held Norway-FAO Expert Consultation on the Management of Shared Fish Stocks (FAO 2002) puts forth a list of General Issues pertaining to the management of international fisheries, which the Expert Consultation believed to be both important and inadequately understood. Heading the list is side payments (which some in the Consultation preferred to label "negotiation facilitators"). The Report states that "—these devices [side payments] will serve to enhance the long term flexibility and resilience of the cooperative arrangement, once the arrangement has been concluded" (FAO 2002, p. 8).

To this point, our review of the theory as it pertains to the impact of unpredictable climate regime shifts, has not really gone much beyond comparative statics. It behooves us, therefore, to ask what attempts have been made to incorporate dynamics and uncertainty into the formal analysis of fisheries games. The answer is that most of the literature pertaining to the effects of environmental variability focuses on optimization models, rather than game models. The small existing body of literature on game models incorporating environmental variability is rather abstract and limited in its practical applicability. That literature treats environmental variability in ways that are not fully comparable to the effects of an unanticipated climatic regime shift. While it is certainly possible to specify a stochastic recruitment function that would mimic the abrupt, infrequent, and unpredictable changes associated with climatic regime shifts, much of the literature focuses on more routine inter-annual variability. Many papers model environmental variability simply as an add-on disturbance to an otherwise deterministic recruitment function. For example, in continuous time stochastic models, randomness is usually introduced as an add-on function of a Weiner process. While in other treatments, the environment may be characterized as transitioning fairly regularly (perhaps annually) between alternate states (Sobel 1982; Sandler and Sterbenz 1990; Kaitala 1993; Jørgensen and Yeung 1996). Realism would require treating the randomness in other, non-additive ways, which would be mathematically difficult. Finally, most game models, even stochastic models, assume complete information. That approach limits their relevance, because uncertainty and misperception are central to the difficulties of maintaining cooperation in the real world.

More recent contributions include McKelvey (1997), which considers a sequential harvesting game in which the intercepting (α) fleet's harvesting cost function varies stochastically between "good" and "bad" years, while the home (β) fleet, as the second harvester, controls the size of the spawning stock. Furthermore, the β fleet may not be able to observe whether the α fleet is currently experiencing a "good" or "bad" year. Despite this highly asymmetric situation, the author finds that it may be possible to structure the bargaining process to secure both cooperation and honest revelation of the year type. However, in some cases, external side payments would be needed to maintain mutually beneficial cooperation.

A recent paper by Laukkanen (2003) models another sequential harvesting game applied to Northern Baltic salmon, in which unobservable environmental shocks make it difficult for the intercepting nation to detect cheating on the part of the nation in whose waters the salmon spawn. In that situation, the author concludes that greater environmental variability can make it more difficult to maintain cooperation.

McKelvey, Miller, and Golubtsov (2003) explore the implications of imperfect and/or asymmetric information in the special case of a "split-stream" fishery. The "stochastic split-stream model" mimics the Fraser River sockeye salmon fishery, in that a single breeding stock splits into two sub-populations as it passes through the fishing grounds. Each sub-population is accessible to only one of the competing fleets, and the fraction of the stock available to each fleet varies stochastically. The paper simulates the effects of a climatic regime shift by positing a change in the mean "split," and uses model simulations to examine competitive and cooperative game outcomes under various assumptions regarding the quality of information available to the players and the degree of asymmetry in access to that information. Simulation results suggest that when there is a climatic regime shift that causes the average split to change to the advantage of one of the fleets, payoffs increase for the environmentally advantaged player and decrease for the disfavored player. The simulations also indicate that the environmentally advantaged player will be better off with cooperation than without. So it is in that player's interest to seek to maintain cooperation. That result arises because, as the stock becomes concentrated in one player's waters, the increased density reduces the per-fish cost of harvesting. Both players can gain by cooperating to concentrate harvesting effort in the area where the fish are most abundant.

For the particular model structure considered, the simulations demonstrate that improved information is always valuable if cooperation prevails. However, if the fleets are engaged in a non-cooperative harvesting game, improved information could merely contribute to a more intense race to the tragedy of the commons, with lower payoffs and declines in the biological health of the resource. The simulations suggest that competitive harvesting is likely to be most damaging when the resource is high priced, relatively easy to harvest, and fragile in the sense of being characterized by low recruitment rates and slow stock growth. It is in those cases that improved forecast information can do more harm than good. The difference between cooperative and competitive payoffs (the cooperative surplus) also tends to be largest in those cases, which suggests that better forecast information might serve as a stimulus for cooperation. That question requires further research, because the model does not explicitly address the process of moving from competition to cooperation.

While these efforts represent useful first steps, it is clear that they are not adequate to allow us to understand fully the implications of long-term climate regime shifts for international fisheries management. In particular, greater attention should be given to the question of how to maintain incentives to cooperate in the presence of possible persistent environmental changes occurring at unpredictable intervals.

With the brief review of the relevant existing economic theory of the management of international fishery resources being complete, our analytical framework is in place. We turn now to the illustrative case study.

Pacific Salmon: A Cautionary Tale

The history of conflict between Canada and the US 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; Miller and Munro 2002; Miller 2003). Both nations are committed to managing these resources wisely, and both have devoted considerable scientific and management resources to the task. Their fishery managers nevertheless failed to recognize, or anticipate, the impacts of the mid-1970s climate regime shift on their shared salmon resources until long after its effects contributed to the collapse of existing cooperative management arrangements.[7] Specifically, neither the 1985 Pacific Salmon Treaty nor the earlier Fraser River Convention[8] were designed to accommodate significant changes in the threat-point bargaining positions of the players. The shift to the coastal warm phase of the PDO in the mid-1970s caused the threat points to change so substantially that existing sharing arrangements were no longer mutually acceptable.

In many respects, Canada and the US are well situated to achieve cooperative management of these fisheries. During the UN Third Conference on the Law of the Sea, Canada and the US cooperated in insisting that the UN Convention on the Law of the Sea Article 66 be adopted, which effectively banned directed high-seas fishing for salmon (Burke 1991; United Nations 1982). This largely eliminated Russian and Japanese interceptions of North American salmon and left Canada and the US free to jointly manage their salmon stocks as “transboundary” fishery resources.

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 (figure 5).

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.

For most of the history of US/Canadian efforts to cooperate on Pacific salmon management, the Fraser River was the primary focus of attention. Although the Fraser River lies entirely in Canada, a large portion of the salmon spawning in that drainage typically approached the river through the Strait of Juan de Fuca where, historically, they had been harvested by Washington State fishing vessels (figure 6). The Fraser River Convention, ratified in 1937, divided the harvest of Fraser River sockeye and pink salmon equally between the two nations.[9] The International Pacific

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[7] Hare and Mantua (2000) argue that it took 10–15 years for the significance of the 1977 climatic regime shift to be fully recognized, despite the strength and scope of its impacts.
[8] 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.
[9] 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.

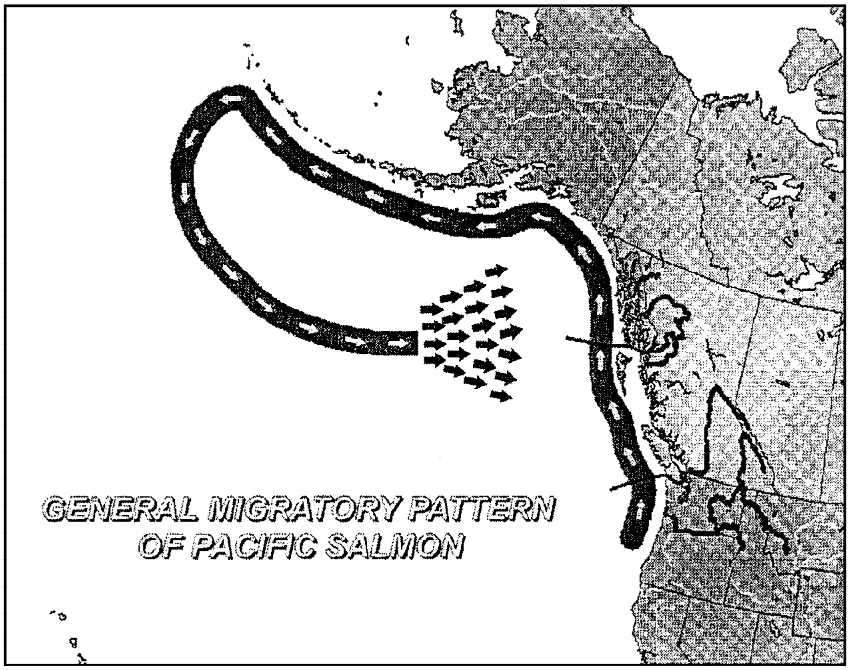

Figure 5. General Pacific Salmon Migration Pattern
Source: DFO 1997.

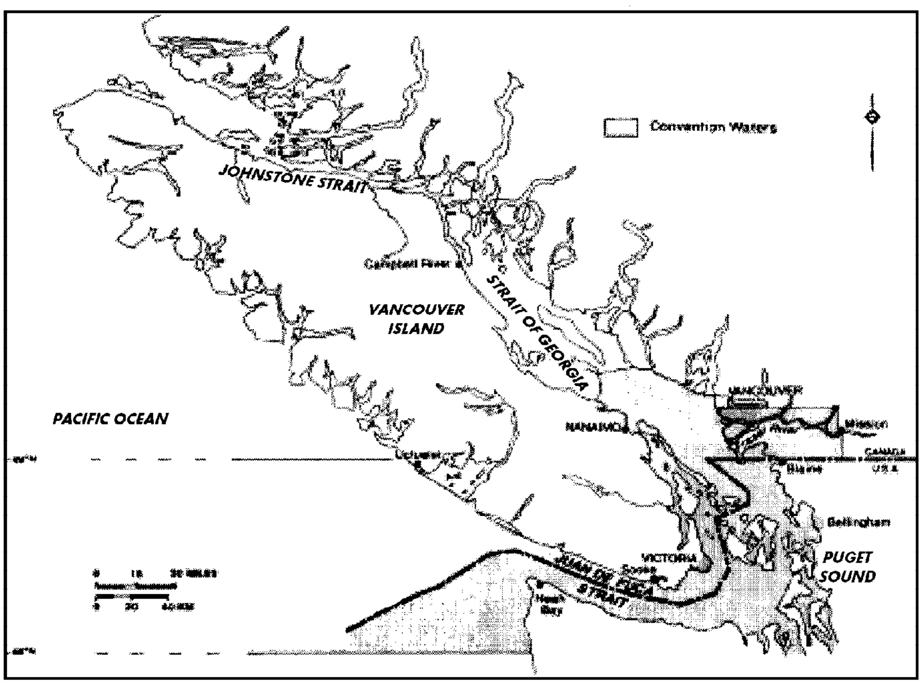

Figure 6. Convention Waters Fishing Area under 1937 Convention

Salmon Fishery Commission (IPSFC) regulated harvests within an area designated as “the Convention Waters,” and the two nations shared management and restoration costs (Roos 1996).

Negotiations began in the 1970s for a new treaty to extend cooperative management to all of the salmon stocks shared by the two countries (Yanagida 1987; Munro and Stokes 1989). The 1977 climatic regime shift affected the negotiation process by changing the migratory behavior of the Fraser sockeye to Canada’s advantage. Warm conditions after 1977 caused a significant increase in the proportion of the run taking the “all-Canadian” route around the north end of Vancouver Island through Johnstone Strait (Xie and Hsieh 1989).[10] The change allowed the Canadian fleet to circumvent the IPSFC regulations by fishing outside of Convention waters, and Canada clearly took advantage of unusually high diversion rates in 1978, 1980, 1981, and 1983 to increase its overall share of the harvest (figure 7). In addition, Canadian harvesting effort intensified off the west coast of Vancouver Island, leading to increased interceptions of US origin coho and chinook salmon heading south to spawn in the Columbia River system and other West Coast streams.

The 1985 Pacific Salmon Treaty reflected Canada’s strengthened bargaining position (a shift in the threat point) by changing the allocation agreement for the Fraser stocks and by linking Canadian consent to share the Fraser stocks to equivalent US consent to allow Canadian interceptions of US salmon stocks. Specifically, the Treaty created the Pacific Salmon Commission, whose primary task was to develop and recommend fishing regimes intended to govern the overall harvest and alloca-

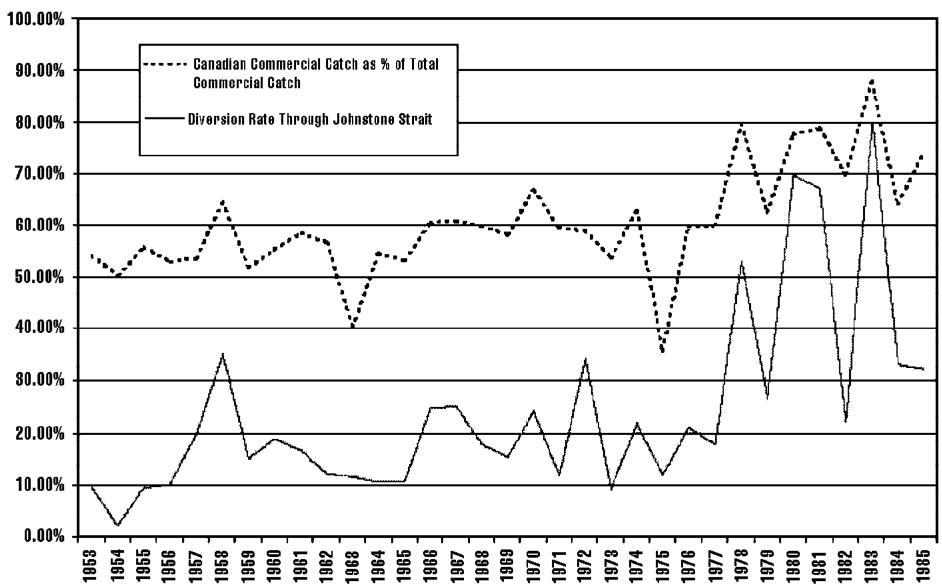

Figure 7. Johnstone Strait Diversion and Canadian Harvest Share

[10] Over the period 1953–76, the Johnstone Strait diversion rate averaged 16.4%. From 1977 through 1998, the diversion rate averaged 48.2%.

tion of the salmon stocks jointly exploited by the US 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).*[11]

When the Treaty went into effect, the two nations failed to agree on a specific formula to measure the equity balance, but both sides assumed that they would fulfill that objective by maintaining a rough balance between US interceptions of Fraser River salmon and Canadian interceptions of Washington and Oregon coho and chinook salmon.[12] Although the Treaty also covered harvests of salmon originating in southeastern Alaska and Northern British Columbia, those stocks were not at the center of attention. Rather, the focus remained riveted on the Fraser, because the Canadian Department of Fisheries and Oceans (DFO) maintained that US interceptions of Fraser River sockeye and pink salmon accounted for 80% of all US interceptions of Canadian produced salmon (DFO 1985).

The negotiators and early members of the Commission apparently did not contemplate the possibility that large, sustained changes in stock abundance could interfere with efforts to maintain the equity balance. In their view, the Commission's primary task was to design fishing 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." 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 (Huppert 1995).

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. Furthermore, the optimistic assumptions upon which they relied proved to be grossly incorrect.

The bargaining framework implemented in 1985 called for frequent renegotiation of the fishing regimes and gave effective veto power to Canada, as well as to each of three voting US Commissioners representing Alaska, Washington/Oregon, and the Treaty Indian Nations (US Senate 1985; Yanagida 1987; Schmidt 1996). That arrangement proved to be destructive when incentives to continue cooperating changed over time. Another source of difficulty was the fact that some of the Commissioners and other senior policymakers adopted a narrow definition of what was being shared, and considered only a limited set of options for achieving equity — focusing on balancing "fish" as opposed to "benefits from the fishery." In fact, in the early 1990s, the Canadian Minister of Fisheries and Oceans described the equity

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

[12] 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)].

principle as giving each nation "the opportunity to harvest the fish produced in its rivers, or failing that, to harvest an equal amount of the other nation's fish" (quoted in Huppert 1995, p.12).

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 US. Significant warming of coastal waters, and 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 US 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 (figure 8). 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, 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 the mid-1990s (figure 9). Abundance declined to the point that some stocks faced a significant risk of extinction, prompting the US National Marine Fisheries Service to list a number of these stocks as "threatened" under the Endangered Species Act (ESA) (US Federal Register 2000).

The 1985 Treaty might have proved satisfactory if the shift to warmer ocean conditions had not persisted. But the warming did continue, and the payoffs that the

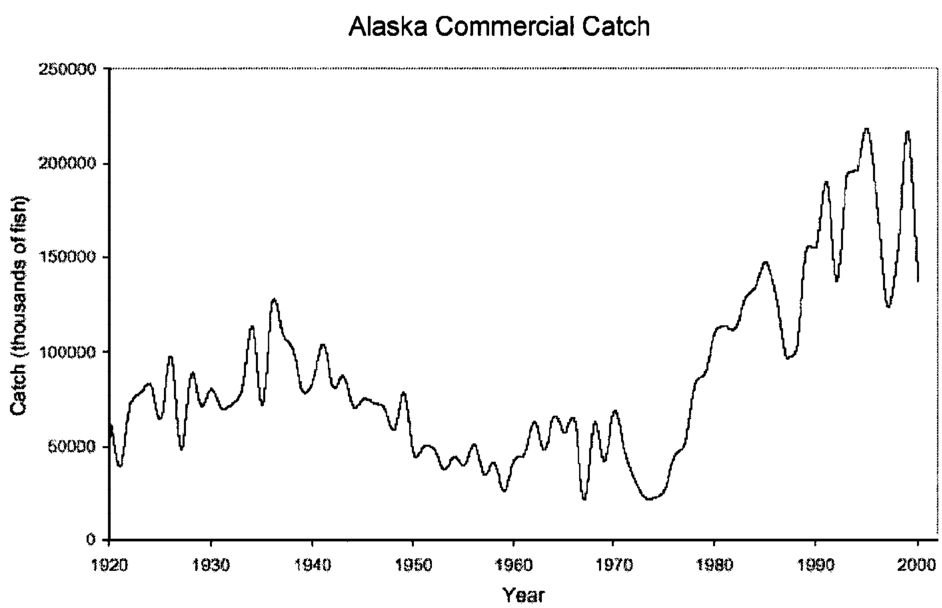

Figure 8. Alaskan Total Commercial Pacific Salmon Harvest

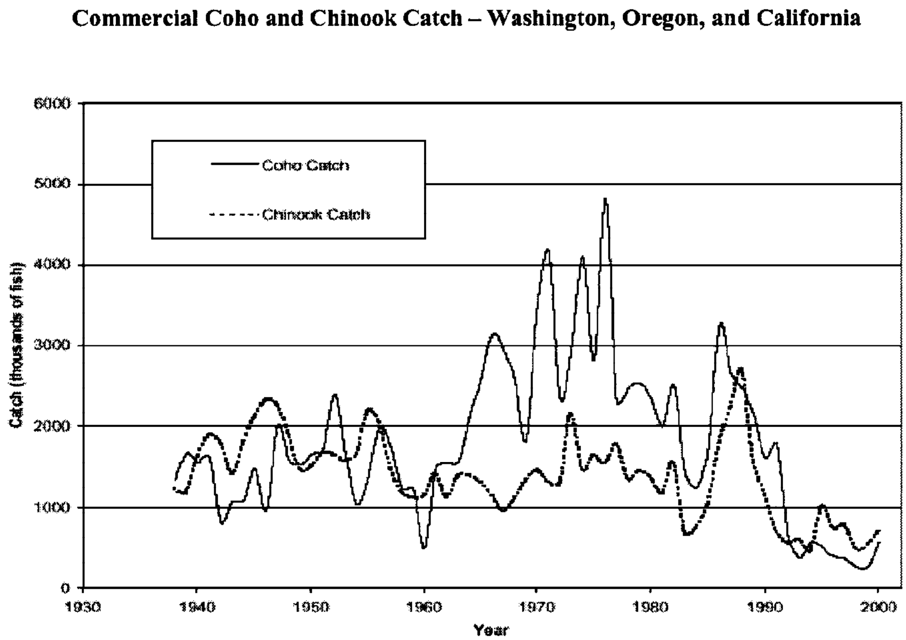

Figure 9. Southern Coho and Chinook Commercial Catch

Canadians and southern US interests expected from the Treaty never materialized. Instead, the dramatic increase in pink salmon abundance in southeastern Alaska led Alaskan harvesters to fish harder in that area, so that Alaskan interceptions of Canadian salmon increased. 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.

From Canada's perspective, there appeared to be a mounting interceptions imbalance in favor of the US, but little US willingness to make concessions to redress the imbalance. From Alaska's perspective, the requested concessions promised to entail only uncompensated costs. In frustration, 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. While the southern US 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, the southern US parties really had few bargaining chips to bring to the table. Although the Pacific Salmon Treaty game had always involved more than two players, the nature of the game clearly evolved over this period. In effect, a three-player game emerged, with the Treaty tribes and southern US jurisdictions acting as a coalition, and Alaska emerging as a very powerful player.

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 resiliency through time. The

Individual Rationality Constraint was no longer satisfied for at least one player, namely Alaska, which now found that it had little, or nothing, to gain from the treaty.

The dispute festered for several years, during which time 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 during the 1990s appears to have triggered a shift in Canadian bargaining objectives with respect to bi-national harvest management (DFO 1998a,b; Pacific Fisheries Resource Conservation Council 1999; McFarlane, King, and Beamish 2000). 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 US 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 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, with new longer-term arrangements in which harvest shares are to be defined on the basis of indices of abundance. This new approach will better protect the stocks that have been weakened by climatic regime changes or anthropogenic impacts by limiting the parties' ability to aggressively fish "up to the ceiling" when the resource is in a fragile state. The Agreement accommodates the Canadian position on the equity imbalance by further decreasing the US share of the Fraser sockeye harvest. It also 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 US federal funding for research, enhancement, and vessel buybacks.

Another major feature of the Agreement is its provision for two endowment funds, financed almost entirely by the US.[13] These funds provide an implicit side payment to Canada in the form of financing for research and enhancement activities.

The current management arrangements for Pacific salmon are not perfect, but the 1999 Agreement represents a significant effort to come to grips with some of the major sources of instability in previous efforts to cooperate. In particular, the new long-term, abundance-based approach reflects an increased appreciation of the need to make harvesting arrangements responsive to variations in stock abundance, while avoiding the costly and uncertain process of frequent renegotiations. As such, it serves to enhance the resiliency of the cooperative resource management arrangement. Possible disagreements over abundance estimates have not been eliminated,

[13] 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 US agreed to contribute $75 million to the Northern Fund and $65 million to the Southern Fund over a four-year period. 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 US, they can be viewed as implicit side payments to Canada.

but ongoing efforts to enhance scientific cooperation and further develop and refine joint management models should help to reduce the scope for such disagreements. The success of these collaborative efforts will depend importantly on the provision of adequate financial support and the engagement of a community of credible and impartial scientists.

In addition, the introduction of side payments, in the form of contributions to the endowment funds, enhances the flexibility of the agreement and may allow it to better accommodate the inherent asymmetries among the parties to the agreement. Such side payments provide another avenue for achieving an equitable balance of the benefits of these fisheries when an acceptable balance cannot be achieved through harvests alone. The full potential of this approach is yet to be realized. Moreover, it remains unclear if the endowment funds, as currently conceived, will yield sufficient returns to make a difference.

Finally, it appears that the two nations have given voice to a broader range of interests in the management of their shared salmon resources. The new focus on conservation responds to long-standing requests by environmentalists, sport, and Native American/First Nations groups in both nations to reduce commercial harvests of weak stocks to allow them to rebuild to healthy levels.

The case of the Pacific Salmon Treaty can provide some valuable lessons for other fisheries. Chief among these is the critical importance of providing flexibility to respond to changing circumstances, and to do so in such a way that all parties perceive real gains from continued cooperation. Side payments can be a valuable tool in this regard. Another important lesson is the value of common scientific understandings regarding the status of shared resources. In the Pacific salmon case, divergent views on stock status contributed to past conflicts, while increasing scientific consensus has been an important factor in recent progress.

Implications for Management and Research

Thus far, the discussion has focused on the relatively easy case of a fishery confined to the EEZs of the competing harvesting nations (Category A resources). The history of Pacific salmon demonstrates that failure to anticipate the effects of a climate regime shift can cause serious difficulties even for such Category A type fisheries. In the more complicated cases involving highly migratory or straddling fish stocks — Categories B and C, respectively — the point about the potentially disruptive effects of regime shifts would hold at least as strongly, if not more so.

Throughout the discussion, we have made a distinction between unanticipated and unpredictable changes. Any change that proved, in retrospect, to have been unanticipated, was obviously also unpredicted. A change, which cannot be predicted with accuracy, however, may be anticipated. The climate regime shift, which almost devastated the Pacific Salmon Treaty, was unanticipated, with no blame being attached to the then managers of the cooperative arrangement. Now that we are much more knowledgeable about climate regime shifts and their impacts upon fisheries, there would be little excuse if current managers of cooperative resource arrangements were to fail to anticipate the possibility of such shifts and take appropriate precautionary measures.

An analogy is provided by the case of earthquakes. Since we have discussed at length the Pacific Salmon Treaty, let us consider the neighboring cities of Seattle and Vancouver, B.C. Neither city can predict, with any degree of accuracy, whether a major earthquake will strike in the foreseeable future, or, were it to strike, what its magnitude would be. Both cities, however, fully anticipate the possibility of a major earthquake, because science has assured them that they are indeed located in an earthquake-prone zone. The governments of both cities feel it incumbent upon them to take precautionary measures. We can contrast these two cities in 2004, with the city of San Francisco in 1906, which did not anticipate the earthquake of that year.

Once we take the possibility of regime shifts seriously, making such changes an *anticipated* risk, effective progress can begin on the task of devising appropriate response strategies. The obvious first point to be made about needed strategies is that enhancing flexibility is the key to building resilience. The need for enhanced flexibility in international fisheries arrangements has recently received high-level policy attention. The 2002 Norway-FAO Expert Consultation on the Management of Shared Fish Stocks placed considerable emphasis on the need for flexibility to maintain both appropriate harvest levels and a mutually acceptable allocation of fishery benefits despite the dynamic nature of the shared resources (FAO 2002).

We have noted above that side-payments, broadly construed, are an indispensable tool for achieving flexibility. While monetary side payments are certainly among the possible options, a variety of more subtle, indirect transfers among the parties are possible as well. For example, US contributions to the endowment funds under the 1999 Pacific Salmon Agreement constitute rather direct side payments to Canada, while the cooperative arrangements between Norway and Russia in the Barents Sea provide more subtle avenues for side payments. In the Barents Sea case, Norway and Russia share an important cod resource, along with haddock, capelin, redfish, blue whiting, and other species. The Mutual Access Agreement of 1976 enables each country to take parts of its quotas in the other country's EEZ. This arrangement provides an implicit side payment to Russia in the form of access to a more valuable component of the resource (the mature cod found in the Norwegian EEZ as opposed to the juveniles found in the Russian zone). The practice of quota swapping also has developed, allowing the two fleets to rearrange their quota allocations across several species to mutual advantage (Stokke, Anderson, and Mirovitskaya 1999).

In the Baltic, the International Baltic Sea Fisheries Commission provides a vivid example of the use of side payments in a cooperative management arrangement. The Commission was established in the early 1970s and has, in its history, involved as many as eight states/entities that were, at one time, on two sides of the Cold War divide. It was very difficult to allocate the total allowable catches (TACs) for the stocks, within the Commissions' purview, on a basis that was perceived by all as rational. The TAC allocations were, therefore, essentially arbitrary. To prevent the arrangement from collapsing, the Commission had to permit side payments. Originally the permitted side payments were strictly in the form of quota swaps. Now the Commission appears to be moving gingerly away from what is essentially a barter system, to one in which quotas can be exchanged for cash. The cooperative management arrangement has, to date, proven to be very successful (Ranke 2003).

The literature suggests other strategies and tools that can be used to maintain cooperation in the face of significant changes in the abundance or availability of fish stocks. Negotiating a pre-agreement that outlines actions to be taken under a variety of contingencies is an option suggested by Hilborn, Maguire, and Parma (2001). They note that the control rule approach adopted by the International Pacific Halibut Commission (IPHC) has allowed that organization to easily reduce or raise catch in response to fluctuations in the condition of the stock. In addition, the new abundance-based approach in the Pacific salmon case is intended to allow the same type of automatic adjustments to changes in stock status. Pre-agreements can simply take the form of a clearly articulated set of rules for adjusting quotas and allocations as a function of mutually agreed upon indicators of changes in the shared stock. Clearly, *anticipation* of possible changes in the condition or distribution of the stock is a necessary condition for negotiation of workable pre-agreements.

The same authors also suggest adopting a portfolio management approach to managing the risks associated with uncertain fluctuations in abundance by promoting fleet diversification and flexible licensing that would allow vessels to move more easily between fisheries. While they focus on the issue of efficient reallocation of effort across a set of domestic fisheries, a similar approach could be applied to international fisheries as well. To some extent, the practice of multi-species quota swapping in the Baltic and Barents Seas can be seen as a tool for achieving the flexibility needed for this sort of risk management. Perhaps greater attention to the need to manage risks associated with significant regime shifts could allow such an approach to be refined and extended to other international fishery management agreements, where the focus is now largely confined to management of a single species or closely related group of species.

The economics community can contribute to the analysis of workable policy alternatives. To do so, further development of the theory is needed. At present, most attempts to incorporate uncertainty in fishery game models, with a few notable exceptions, deal with uncertainty only in the form of add-on disturbances. The possibility of large and persistent regime shifts suggests the inadequacy of that approach.

In particular, attention should be given to developing models of cooperative games in which the players anticipate the possibility of a regime shift that radically alters the strength of their relative bargaining positions. The models of cooperative games that we reviewed do not really do this in any rigorous sense. We thus conclude with a call to the profession to develop such models, to explore their properties, and to test their applicability to actual cases of international fishery agreements subject to the stress of major biological regime shifts.

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