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CLIMATE, COMPETITION AND THE MANAGEMENT OF SHARED FISH STOCKS

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ABSTRACT

Long-term climate regime shifts have profound and persistent impacts on ocean temperature and circulation patterns, and on the dynamics of marine fish populations -- affecting abundance, growth and migratory behavior. Such shifts are a particularly important source of uncertainty for marine fisheries. Here, we argue that climate regime shifts can disrupt otherwise satisfactory international fishery management agreements. Game theory provides a powerful analytic perspective on the difficulty of maintaining effective, cooperative management of shared fishery resources in the face of such natural environmental changes. This paper draws upon two case studies of shared fishery management -- Pacific salmon and Norwegian spring-spawning herring -- to demonstrate that a climate regime shift can alter the distribution and productivity of fish stocks in ways that change the comparative advantages of the competing fleets. When that happens, the optimal cooperative solution to the fishery game will change. If the fishery agreement in place is not sufficiently flexible to adjust to the changed opportunities and incentives, it will likely break down. Fishery agreements can be made more resilient to 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.

Keywords: climate regimes; shared fisheries; potential conflicts; uncertainty

INTRODUCTION

Variability in the abundance and spatial distribution of marine fish stocks is an important source of uncertainty facing fishery managers. Despite substantial scientific effort, predictability remains elusive. Nevertheless, this body of research points to a complex interplay between natural climate-related changes in the marine environment and fishing pressure in driving the dynamics of exploited marine fish populations. In recent years, increasing attention has been devoted to the phenomenon of abrupt and persistent changes in patterns of recruitment or migratory behavior that occur at unpredictable intervals. Such biological “regime-shifts” may be linked to large-scale and persistent changes in atmospheric circulation, and associated changes in ocean temperature and circulation patterns [1,2]. These regime shifts are significant, both for domestic and international fishery management. Here, we focus on their significance for the management of shared fisheries, where climate regime shifts can disrupt otherwise satisfactory international fishery management agreements.

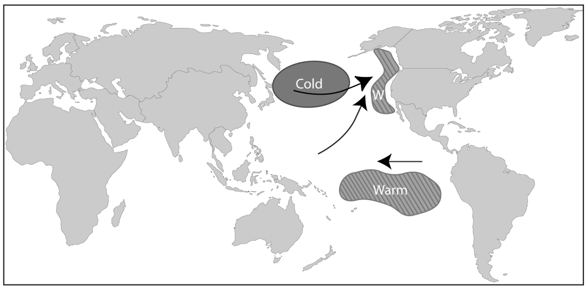
In this paper, we first discuss the nature of climate regimes shifts and evidence of their importance to fisheries worldwide. Next, we briefly review the existing economics of the management of international fisheries, to set the stage and provide an analytical framework. Then we draw upon two case studies of shared fishery management – North American Pacific salmon and Norwegian spring-spawning herring -- to demonstrate how climate regime shifts have affected efforts to cooperatively manage those fisheries. Finally, we discuss possible means by which the impact of climate regime shifts can be mitigated in the management of international fisheries.

CLIMATIC REGIMES AND FISHERIES

Variability in marine fish 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 recruitment, growth rates or migratory behavior occur at unpredictable intervals. Bakun [1] presents evidence for the significance of such 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. This pattern of large, roughly synchronous, shifts in fish abundance often occurs in the absence of any evidence of fleet movements between the fisheries [3]. Paleo-ecological evidence also shows that fish populations experienced significant long-term fluctuations long before harvesting pressure could have played a role [4].

Two recently recognized climatic phenomena warrant particular attention. 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 fish populations. Regarding the PDO, many observers have noted an abrupt climatic and biological shift in the North Pacific, commencing in 1977 and lasting, with minor breaks, for more than two decades. This shift to a positive phase of the PDO (Figure 1), entailed a pronounced warming of coastal sea surface temperatures (SSTs) along the west coast of North America, suppressed plankton productivity in the California current system, intensified onshore winds, increased winter storminess in the Gulf of Alaska and sharp changes in the recruitment of a number of important fish stocks [5,6,7].

A.



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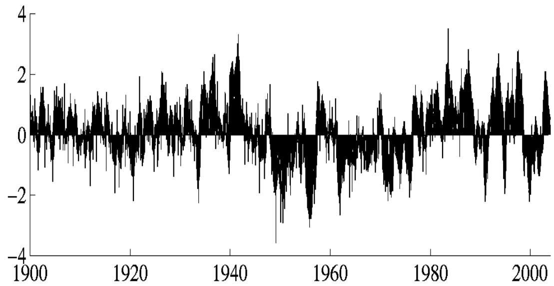
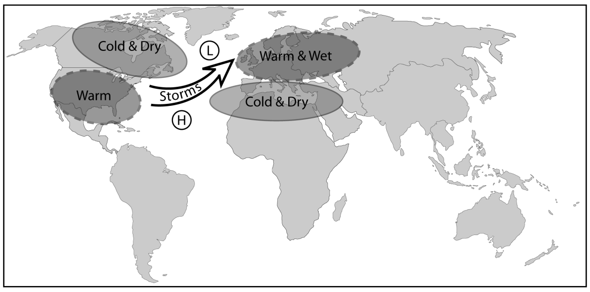


Figure 1. Pacific Decadal Oscillation

- **A.** Sea surface temperature and wind stress anomalies – Coastal Warm Phase (positive values);
- **B.** monthly values – PDO Index – Data Source: Dr. Nathan Mantua, JISAO, University of Washington -- http://www.jisao.washington.edu/pdo/

The North Atlantic Oscillation is an analogous phenomenon with significant impacts on Northern Hemisphere climate. 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 [8]. The NAO was generally low throughout the 1950s and 1960s, and 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 [9](Figure 2). There is substantial evidence that the NAO affects recruitment success and migratory behavior for several important fish stocks in the North Atlantic and adjacent seas.

A.



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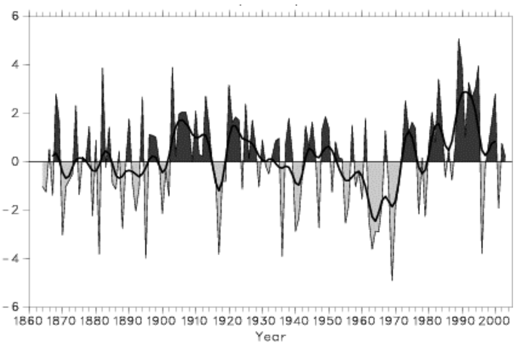

Figure 2. North Atlantic Oscillation

A. Temperature and precipitation anomalies – Positive Phase; **B.** Dec-Mar. values – NAO Index
Data Source: Dr. James Hurrell, National Center for Atmospheric Research
http://www.cgd.ucar.edu/~jhurrell/nao.html

GAME THEORY AND INTERNATIONALLY-SHARED FISHERY RESOURCES

We turn now to a brief review of the relevant existing economic theory of the management of international fishery resources, to provide a framework for the case studies to come. First, let us define international, or shared, fish stocks, with somewhat greater precision. The term "shared fish stocks" is used by the FAO to include all fishery resources that are exploited by two or more countries, including "transboundary" stocks (confined to the EEZs of two or more coastal states) as well as "straddling" and "highly migratory" stocks that are also harvested on the high seas. One of the case studies, Pacific salmon, involves a transboundary stock, while the other, Norwegian spring spawning herring, involves a straddling stock. The states engaged in the exploitation and management of the latter resource, however, currently act like a closed club, so that it is legitimate, for management purposes, to treat the resource as if it were a transboundary stock [10]. Hence, we can confine our review to the relatively simple case of transboundary stocks.

Transboundary fish stocks are of interest as a distinct resource management problem when the harvesting activities of at least one state sharing the resource impinge upon the harvesting opportunities of the others. Strategic interaction among the states becomes inevitable. It is for this reason that the economics of the management of such a resource is a blend of the economist's dynamic economic model of the fishery and the theory of strategic interaction, better known as the theory of games.

The first question to be asked is what the consequences would be if states/entities sharing a fishery resource did not cooperate in the management of the resource. The answer is that we should, with few exceptions, 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. Cooperation thus does matter. The question then becomes what conditions must prevail for a cooperative management arrangement to be stable over the long run.

In the theory of cooperative games, the players are assumed to be able to communicate and to have some incentive to cooperate, but they also are motivated entirely by self-interest. If the players agree to cooperate, it is because each is convinced that it can gain more from cooperation, than it could by engaging in competitive behavior.

The two well-known *minimum* conditions that must be met for the solution to the cooperative game to be stable are as follows: (a) the solution must be Pareto Optimal; (b) 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. In addition, there is a third condition, of particular relevance to climate regime shift, namely resiliency of the cooperative arrangement through time. We illustrate these conditions as follows.

Consider the following well-known diagram of a two-player cooperative game, as shown in Figure 3. Assume initially that the game is devoid of side payments. 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. Focus on payoffs, θ_0, γ_0; while ignoring payoffs θ_0', γ_0' for the time being. The payoffs θ_0, γ_0 represent the payoffs to two players from non-cooperation, at the beginning of the management program, and thus constitute the initial Threat Point, t_0.

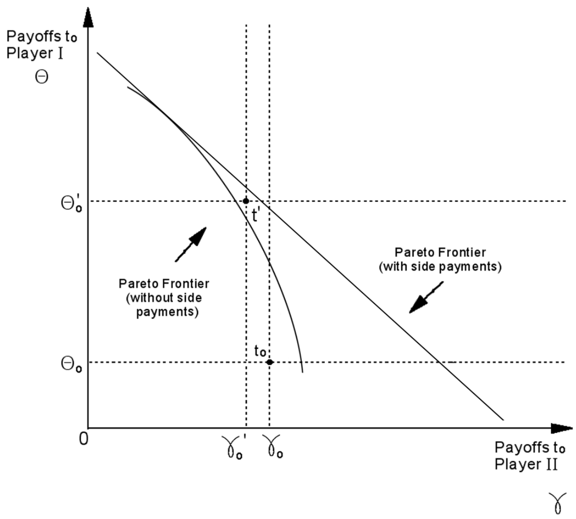

Figure 3. Two Player Game with Change in Climatic Regime

Let us initially assume that both players anticipate that the Threat Point payoffs will remain constant through time. The segment of the Pareto Frontier (without side payments) marked by the dashed lines emanating from the Threat Point payoffs represents the “core” of the game. The “core” is non-empty, in the example shown, 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 is that there would be an equally unpredicted shift in the Threat Point payoffs.

The post climate regime shift Threat Point payoffs are represented in Figure 3 by 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.

One might suppose that if the cooperative arrangement was legally binding, for example in the form of a treaty, this would be sufficient to prevent cooperation from collapsing. It would not. As history has demonstrated, and as the example of Pacific salmon will illustrate, even if the dissatisfied player does not formally denounce the arrangement (treaty), or act in clear violation of its terms, difficulties may arise. There are innumerable ways in which the dissatisfied player can undermine the arrangement, with the consequence that the cooperative management arrangement seizes up, and ceases to function.

This danger highlights the need for cooperative management arrangements to have sufficient flexibility and resiliency to accommodate changing circumstances through time [11]. 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.

Return to Figure 3. Up to this point, it has been assumed that side payments have not been considered. If side payments are allowed, then the Pareto Frontier becomes a 45^0 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, where 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) (see, for example, [12]). In our example, it is assumed that it is Player I, which 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 3. 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 on Pacific salmon reveals that the carefully negotiated, treaty between the two players almost foundered because the scope for bargaining proved, in retrospect, to be too narrow.

Having said all of this, we must not jump to the conclusion that side payments, even in limited form, will always be sufficient. The cooperative management arrangement for Norwegian spring spawning herring has had components, which are at least in the spirit of side payments. Nonetheless, climate regime shifts succeeded in subjecting the arrangement to serious strain.

To this point, our review of the theory has not gone much beyond comparative statics. There have been attempts to incorporate dynamics and uncertainty into the formal analysis of fisheries games, but that literature usually treats environmental variability in ways that are not fully comparable to the effects of an unanticipated climatic regime shift. In addition, 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.

Recent treatments have considered the effects of unobservable environmental shocks [13] and the implications of climate regime-shifts in the context of imperfect and/or asymmetric information [14]. The Laukkanen [13] analysis suggests that unpredicted and/or unobserved environmental changes can foster disputes by making it difficult to determine if cheating has occurred. The paper by McKelvey et al. [14]

addresses the potential value of improved scientific information, demonstrating that better information about the state of a stochastic fish stock is always valuable if cooperation prevails, but that it can do considerable harm in the context of competitive games.

THE ROLE OF THE PDO IN THE PACIFIC SALMON DISPUTE

The history 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 [15]. 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 [6, 16].

Pacific salmon are anadromous fish, meaning that 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. 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. The control of such "interceptions" has been a central focus of U.S. and Canadian efforts to cooperatively manage their Pacific salmon resources.

The 1985 Pacific Salmon Treaty addressed this issue by articulating the following equity objective: ... *each Party shall conduct its fisheries and its salmon enhancement programs so as to: ... provide for each Party to receive benefits equivalent to the production of salmon originating in its waters (Pacific Salmon Treaty, Article III).*

When the Treaty went into effect, the two nations failed to agree on a specific formula to measure the equity balance [17], but both sides assumed that they would fulfill that objective by maintaining a rough balance between U.S. interceptions of Canadian Fraser River salmon and Canadian interceptions of Washington and Oregon coho and chinook salmon. 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 maintained that U.S. interceptions of Fraser River sockeye and pink salmon accounted for 80% of all U.S. interceptions of Canadian produced salmon [18].

Unfortunately, the negotiators and early members of the Commission apparently did not imagine 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 encourage enhancement and conservation efforts by guaranteeing that the *expected* increase in production would benefit the party making the investment. The regimes established by the Commission relied heavily on the use of "ceilings," 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 [19]. However, while enhancement and restoration efforts certainly can increase the number of salmon available for harvest, the effects of such actions easily can be dwarfed by the impacts of natural environmental fluctuations. Negotiators on both sides underestimated the power of such natural changes, and the optimistic assumptions upon which they relied, proved to be grossly incorrect.

The bargaining framework established 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 U.S. Commissioners representing Alaska, Washington/Oregon and the Treaty Indian Nations [20, 21]. 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 policy makers 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."

As noted previously, there had been a largely unrecognized climatic regime shift in 1977 to a sustained positive state of the PDO. The most striking effects of this 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, 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 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 shift were profoundly different. There, chinook and coho salmon abundance declined to the point that some stocks faced a significant risk of extinction, prompting the U.S. National Marine Fisheries Service to list a number of these stocks as "threatened" under the Endangered Species Act.

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. Canadian frustrations over perceptions of a mounting interceptions imbalance in favor of the U.S., led Canada to return to aggressive competitive tactics with respect to its harvests of Fraser sockeye and its interceptions of the chinook and coho salmon stocks migrating to spawn in Washington and Oregon rivers.

The southern U.S. jurisdictions offered to make further concessions on their harvests of Fraser River salmon in exchange for reduced Canadian harvesting pressure on southward-bound coho and chinook, but the offers were insufficient in Canadian eyes. Rather, Alaska's harvests had become the major source of contention, and Alaska proved unwilling to make the concessions requested by Canada. From Alaska's perspective, the requests appeared unreasonable, and as entailing only uncompensated costs. 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 [22, 23] appears to have triggered a shift in Canadian bargaining objectives. 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. This shift facilitated the negotiation of amendments to the Treaty, concluded in 1999. The 1999 Agreement 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 weak stocks by limiting the parties' ability to aggressively fish "up to the ceiling" when the resource is in a fragile state. As such, it serves to enhance the resiliency of the cooperative resource management arrangement.

The Agreement accommodates the Canadian position on the equity imbalance by further decreasing the U.S. 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 U.S. 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 United States. 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.

THE NAO AND NORWEGIAN SPRING-SPAWNING HERRING

On the other side of the world, long-term climatic regime shifts have complicated the management of other internationally shared fisheries. As in the Pacific salmon case, the role of climate was only recently recognized. Notably, changes in oceanographic conditions associated with variations in the NAO have affected both recruitment success and the migratory behavior of Norwegian spring spawning herring.

Norwegian spring-spawning herring (C*lupea harengus)* is, historically, the largest fish stock in the North Atlantic. The stock has been an important source of food for centuries, mainly for Norway, Iceland and Russia, but also for other European countries. Historical records indicate that there have been large fluctuations between harvests of Norwegian spring-spawning herring over the past 500 years, with sometimes opposite fluctuations harvests of other herring fisheries in the English Channel, Bay of Biscay and the Bolhusian region between the North and Baltic Seas [3].

Recent research suggests that the NAO may have been a common thread influencing the productivity and distribution of these biologically distinct stocks, although it is difficult to directly compare modern and historical record because pre-modern harvests depended heavily on the proximity of stocks to shore-based fishing operations. The research also suggests that modern levels of fishing pressure may exacerbate natural downturns in abundance.

In addition, the effects of NAO appear to be fairly complex. For example, recruitment success of both herring and cod (its major predator) depends on common environmental factors, where the inflow of warm Atlantic waters (positive NAO) gives strong year-classes. Small cod are however not able to feed on small herring of the same year-class, but they are efficient predators on the following herring year-classes. In 1984 and 1985, average year-classes of herring were reported, but high predation pressure from the strong 1983 year-class of cod reduced these year-classes from average to poor. The reproduction capacity of herring is lower than that of cod, and at low levels of abundance, the herring are even more vulnerable to a stock of predators, resulting in a higher level of natural mortality. If capelin are available, however, the pressure on the herring decreases, as the cod seem to prefer capelin to herring [24, 25].

The NAO was mostly positive during the first half of the 20th century, followed by a decrease and a negative index after 1952 (figure 2B). During the same periods, the Norwegian spring-spawning herring stock was increasing with positive NAO (1900-20, 1930, 1950, 1980-00) and decreasing with negative NAO (1920, 1940, 1960-70) (figure 4). From the 1930s through the 1950s the stock appeared robust despite rapidly increasing harvests, facilitated by new technology. Then during the 1960s, poor recruitment, coupled with continued intense harvesting pressure caused the stock to collapse. The stock remained very small throughout the 1970s and only began to recover significantly during the late 1980s, after several years of severely restricted fisheries.

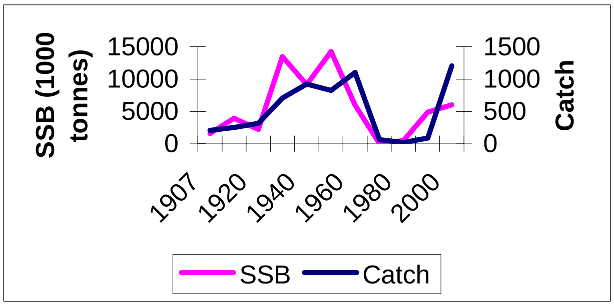

Figure 4. Spawning Stock Biomass and Catch of Norwegian spring-spawning herring. Sources: [26, 27]

In addition to the changes in abundance, there were significant changes in migratory patterns. The migration pattern of the Norwegian spring-spawning herring takes on importance since, as a straddling stock, the herring are exposed to territorial and possibly distant water fleets with strong incentives to harvest the population before it moves elsewhere [28]. If a co-operative management policy, with an equitable distribution of harvest, cannot be agreed upon, Norway, Iceland, Faeroe Islands, countries of the EU, Russia and possibly distant water vessels fishing in the Ocean Loop, may resort to 'strategic over fishing' that could jeopardise the health of the resource. Changes in migratory behavior have made it difficult for these countries to maintain agreement on what constitutes an equitable distribution of harvest.

Prior to the period of cold temperatures and poor recruitment commencing in the mid-1950s, the most important spawning area was along the western coast of Norway, and the juvenile herring stayed in the maturing area along the Norwegian coast and the Barents Sea. The feeding area for the adult herring was located in the Norwegian Sea, north of Iceland, while the wintering area was east of Iceland. During the mid-1960s, a new pattern emerged with the largest portion of the adult stock moving to a feeding area farther north than earlier, in the northeastern part of the Norwegian Sea. After the stock collapsed at the end of the 1960s, both the juvenile and the adult herring stayed in Norwegian coastal waters all year. That pattern prevailed until 1994, when the herring migrated outside the Norwegian EEZ for the first time in 26 years.

The drastic declines in catches in the 1960s led all participants in the fishery to conclude that exploitation had to be reduced, and they introduced a sequence of strict control measures, with Norway playing the leading role. The restrictions gave results, and the fishery on the Norwegian stock was reopened in 1984. Beginning in 1987, the Norwegian government set the Total Allowable Catch (TAC) for Norwegian spring-spawning herring, giving Russia a share of the TAC after the yearly fishery negotiations between the two countries. However, international disagreements arose as soon as the herring resumed a pattern of migration to feeding grounds outside of Norwegian waters. In 1994, for example, Iceland demanded a share of the TAC in recognition of the new status of the herring as an international stock. EU, Russia and the Faeroe Islands also began to pressure Norway to engage in negotiations for a multi-national management arrangement, based on the argument that the new migratory pattern created new conditions for the fishery and for the management of the stock. The Norwegians feared that their strict regime during the last decade would be wasted and that the involvement of more nations in the fishery would cause another collapse of the stock.

Beginning in 1995, Norway and the other harvesting nations negotiated a series of agreements regarding the size of the TAC and its distribution among the parties. These agreements have been imperfect – for example, harvests in 1995 were almost twice the quantity recommended by the Advisory Committee on

Fishery Management (ACFM) of ICES [28]. Nevertheless, in spite of these high catch levels, the herring spawning stock continued to increase due to good growth and recruitment.

In 1996, with a Four-Party-Agreement in force, Norway, Russia, Iceland and the Faeroe Islands shared a quota of 1,107,000 tonnes, but the EU was not yet part of the agreement and fished at full capacity in international waters. From 1997, Norway, Russia, Iceland, Faeroe Islands and EU have jointly set a yearly quota based on the recommendations of ICES, negotiating on the shares to the respective countries, and the parties negotiate bilaterally on the rights to fish within the different countries' EEZs. According to the UN Fish Stocks Agreement, the North East Atlantic Fisheries Commission (NEAFC) maintains the formal responsibility for the distribution and the fixation of the TAC in international waters [29]. At present, the yearly negotiations on the TAC continue to cause conflict, with Norway and Iceland generally arguing for smaller quotas than desired by the other countries.

There also has been discontent over the distribution of the shares of the TAC. From 1997 to 2001 Norway received 57 percent of the quota, Russia 14 percent, Faeroe Islands five percent, Iceland 16 percent and the EU eight percent. In 2002, however, the Norwegian share increased to 61 percent at the expense of Iceland and the EU [30]. This was a result of years of frustration among Norwegian fishermen who consider themselves entitled to at least 70 percent of the quota, according to the migration pattern of the herring. The distribution for 2003 was similar to that of 2002, under the condition of allowing foreign fishermen to catch more of their quota in Norwegian waters. The first meetings between the parties concerning the quotas for 2004 have so far been fruitless, as the Norwegians are still pushing for a 70 percent share, based on their estimates of the current zonal attachment of the herring.

OPTIONS FOR ENHANCING RESILIENCE TO SHIFTING CLIMATIC REGIMES

Once we take the possibility of regime shifts seriously, making such changes an *anticipated* risk, progress can begin on devising appropriate response strategies. The obvious first point about the needed strategies is that enhancing flexibility is the key to building resilience. This point 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 [31].

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 and indirect transfers among the parties are possible as well. For example, U.S. contributions to the endowment funds under the 1999 Pacific Salmon Agreement constitute rather direct side payments to Canada. Mutual access agreements and provisions allowing quota trading also can be tailored to provide implicit side payments [32]. The literature suggests other strategies that can be used to maintain cooperation in the face of significant changes in the abundance or availability of fish stocks. Hilborn et al. [33] suggest negotiating a pre-agreement that outlines actions to be taken under a variety of contingencies. 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 take the form of clearly articulated 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 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 exceptions, treat uncertainty only as 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.

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