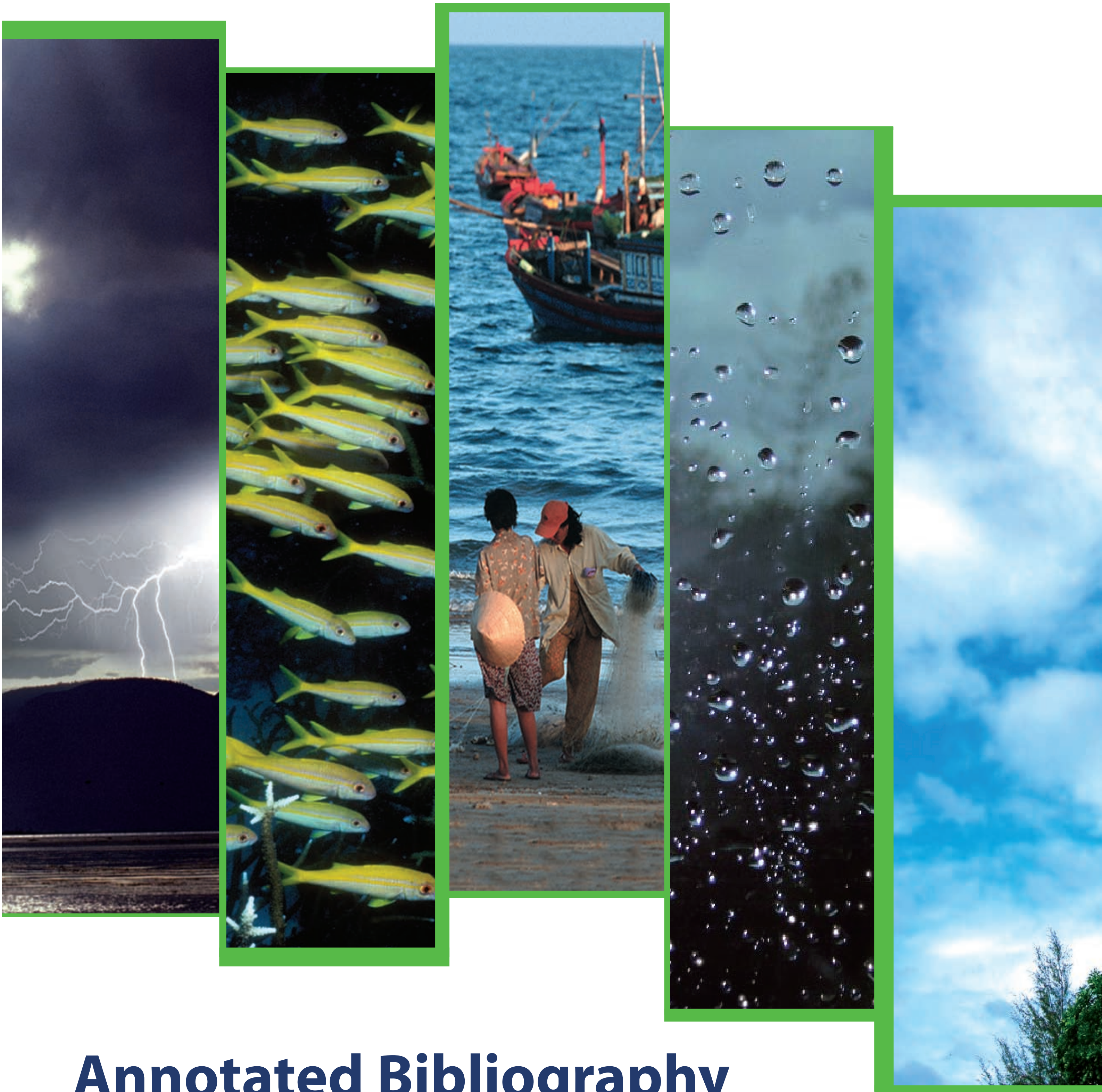

Annotated Bibliography on the Economic Effects of Global Climate Change on Fisheries

Ann L. Shriver, Yeo Bee Hong, Ting Kok Onn, Marissa Garcia and Mahfuzuddin Ahmed

WorldFish CENTER

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Prepared for the Consultation on the Impact of Global Climate Change on Aquatic Resources, Food and Income Security of Fishing-dependent Populations

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The WorldFish Center is one of the 15 international research centers of the Consultative Group on International Agricultural Research (CGIAR) that has initiated the public awareness campaign, Future Harvest.

Preface

Over the past century, a significant warming trend has been experienced worldwide. Global mean surface temperatures have risen by approximately 0.5–0.6℃, with the highest increase registered during the past two decades. Scientists posit a number of different explanations for this phenomenon, including increases in greenhouse gas concentrations (e.g., carbon dioxide, methane and nitrous oxide) from the combustion of fossil fuels (e.g., coal, oil and natural gas) and other human activities. This increase in atmospheric temperature may already be affecting, and may continue to affect the marine environment, which in turn is anticipated to impinge on fisheries resources and fish-dependent coastal communities.

Although both marine resource managers and fishing communities have successfully adapted to minor and brief variations in the earth's temperature throughout history, the vulnerability of tropical coastal communities today to the predicted larger-scale and prolonged changes in climate patterns is increased by the several factors, including but not limited to the following list:

1. the fisheries sector is already beset with critical problems resulting in a declining resource base;
2. most fish species can only tolerate a limited range of temperature variation, such that any shifts outside this narrow band can be expected to affect the resource stock, especially in warmer waters;
3. for a majority of the poor, who lack capital resources and access to employment opportunities, any changes in the availability and distribution of fish stocks will affect coastal communities who depend on these resources as a major source of food and income;
4. socioeconomic and institutional barriers, as well as other current realities may prevent fisherfolk from utilizing long-established coping mechanisms that worked in the past; and
5. the impact of the current trend in climate change may be of a different magnitude and extent from that of historical experience, increasing the risks to these already vulnerable aquatic resources and coastal communities, and rendering past research and experience inadequate to deal with the current variations in atmospheric temperature.

Studies in the past focused on the ecological impacts of global climate change on aquatic resources. There is a need to extend this effort to improve our understanding of the socioeconomic linkages and economic effects of climate change particularly on vulnerable aquatic ecosystems and resources as well as coastal populations. To this end, this bibliography provides a collection of key references and online documents from 1966 to 2006 on the economic effects of climate change on fisheries with a view toward contributing to information generation, analysis and dissemination, and facilitating the identification of research needs and priorities since ultimately, the sustainability of fish stocks and coastal communities will depend on how well these resources were managed. The current collection reflects the thrust of past research which has focused largely on temperate and developed areas, since studies focusing on developing countries/regions in the tropics are few and far between. Our goal is to focus primarily on economic research, but some biological, meteorological and oceanographic sources are included where they have been used extensively as background to economic studies.

This bibliography was compiled by Ann Shriver of the International Institute of Fisheries Economics and Trade (IIFET) in collaboration with the staff of The WorldFish Center under the direction of Dr. Mahfuzuddin Ahmed. It was compiled for distribution at the Consultation on the Impact of Global Climate Change on Aquatic Resources, Food and Income Security of Fishing-dependent Populations, jointly organized by The WorldFish Center and the United States National Marine Fisheries Service Southwest Regional Office (San Diego, California), held on 24 and 25 August 2005. Abstracts from papers presented at the Bergen, Norway (June 2005) Conference are included in draft (thanks to their authors and the conference organizers) and are not for citation, pending eventual publication. The printed document you are now reading includes the collection of references as of early May 2006; however, the collection continues to grow and is regularly updated on the internet, at www.oneFish.org, in the IIFET "Virtual Office". Authors of relevant new economic studies are encouraged to submit them for inclusion in the online collection.

The team preparing this bibliography expresses its gratitude to the United States Agency for International Development for financial support for the project and publication. Authors who contributed to the collection are gratefully acknowledged. The assistance of Hong Meen Chee and Syarifah Khadiejah Syed Mohd Kamil of The WorldFish Center and Victoria Martin and Kara Keenan of Oregon State University in compiling and formatting the bibliography is gratefully acknowledged.

Annotated Bibliography

Aaheim, H.A. and L. Sygna. 2000. Economic impacts of climate change on tuna fisheries in Fiji Islands and Kiribati. CICERO Report. Vol. 4. Center for International Climate and Environmental Research, Oslo, Norway.

This paper discusses the possible economic consequences of a change in the tuna fisheries in the Pacific Ocean resulting from climate change. On the background of Lehodey's (2000) study of potential changes in the tuna fisheries, we survey possible economic impacts in terms of quantities and values and give examples of macroeconomic impacts. The two main effects of climate change on tuna fishing are likely to be a decline in the total stock and a migration of the stock westwards. This will lead to various changes in the catch in different countries. The price of the fish in the export market may also change as a result. The Pacific islands are generally dependent on fisheries, and may therefore be vulnerable to these changes, although some will probably gain while others will lose. Based on a very simple macroeconomic model, it is shown that the resulting effects for the national economy in general may diverge substantially from the expected. This applies, in particular, if the national economies are inflexible and a large part of the population relies on subsistence production, which is the case for many developing countries.

Adger, N.W., S. Huq, K. Brown, D. Conway and M. Hulme. 2003. Adaptation to climate change in the developing world. Progress in Development Studies Vol. 3.

The world's climate is changing and will continue to change into the coming century at rates projected to be unprecedented in recent human history. The risks associated with these changes are real but highly uncertain. Societal vulnerability to the risks associated with climate change may exacerbate ongoing social and economic challenges, particularly for those parts of societies dependent on resources that are sensitive to changes in climate. Risks are apparent in agriculture, fisheries and many other components that constitute the livelihood of rural populations in developing countries. In this paper, we explore the nature of risk and vulnerability in the context of climate change and review the evidence on present-day adaptation in developing countries and on coordinated international action on future adaptation. We argue that all societies are fundamentally adaptive and there are many situations in the past where societies have adapted to changes in climate and to similar risks. But some sectors are more sensitive and some groups in society are more vulnerable to risks posed by climate change than others. Yet all societies need to enhance their adaptive capacity to face both present and future climate change outside their experienced coping range. The challenges of climate change for development are in the present. Observed climate change, present-day climate variability and future expectations of change are changing the course of development strategies – development agencies and governments are now planning for this adaptation challenge. The primary challenge, therefore, posed at both the scale of local natural resource management and at the scale of international agreements and actions, is to promote adaptive capacity in the context of competing sustainable development objectives.

Alheit, J. and E. Hagen. 2001. The effect of climatic variation on pelagic fish and fisheries, p. 19. *In* P.D. Jones, A.E.J. Ogilvie, T.D. Davies and K.R. Briffa (eds.) History and climate: memories of the future? Kluwer, New York, USA.

Evidence is accumulating that marine ecosystems undergo decadal-scale fluctuations which appear to be driven by climate variability (e.g., Beamish 1995; Bakun 1996). Climatic variations affect marine communities and trophodynamic relationships, and may induce regime shifts where the dominant species replace each other on decadal time scales. One way to predict how marine ecosystems will react to future climate variability or to climatic change is to search for causal relationships of past patterns of natural variability and to draw conclusions on the basis of retrospective studies. Long-term biological time-series are essential for such retrospective analysis of climate impact on marine ecosystems; however, they are not readily available. Because of their economic importance, fish populations usually provide longer records than other biological components of marine ecosystems. The dynamics of exploited fish populations are affected by both environmental variability and man-made activities (fishing, habitat alteration) and retrospective studies will help distinguish between the two. Earlier summaries on climate and fisheries have been published by, e.g., Cushing (1982), Wyatt and Larraneta (1988) and Laevastu (1993). More recently, further studies have been stimulated by the worldwide public awareness global changes and the predicted greenhouse effect; the initiation of global international research programmes, such as the World Climate Research Programme (WCRP) and the International Geosphere Programme (IGBP); vastly improved co-operation across disciplinary boundaries; and accumulating knowledge on climate variability, particularly on the decadal scale.

Allan, R., J. Lindesay and D. Parker. 1996. El Niño-southern oscillation and climate variability. Commonwealth Scientific and Industrial Research Organisation Publishing, Collingwood, Australia.

Since the mid-1970s, the El Niño-southern oscillation (ENSO) phenomenon has received considerable attention worldwide. Interest in ENSO has spread to encompass not only scientists from many fields, but also primary producers, policy analysts, management specialists and the wider community. This has resulted primarily because of the severe global impacts of the 1972-1973 and 1982-1983 episodes, and the "persistent" El Niño or climatic anomaly sequence that dominated the climate in the first half of the 1990s. This book uses long-term gridded fields of monthly atmospheric mean sea level pressure and sea surface temperature over the globe to provide the basis for a synthesis of past ENSO phases, and the extension of our understanding of the phenomenon and its relationship to natural climatic variability. It is an atlas which documents ENSO behavior.

Allison, E., F. Ellis, L. Mathieu, A. Musa, P.M. Mvula and R. Tinch. 2002. Sustainable livelihoods from fluctuating fisheries. Final Technical Report DFID Fisheries Management Science Programme (R7336). Department for International Development, London, UK.

The purpose of the project was to identify management regimes and development policies appropriate to the delivery of maximum benefits to subsistence and small-scale commercial fishers dependent on fish stocks that fluctuate extensively, so that livelihoods may be sustained and improved, and poverty in fishing communities reduced.

Research activities were in three main areas:

i. A statistical analysis of variability in time series of fish stock biomass or catches, so that fisheries could be classified on the basis of the extent and pattern of variability. The resultant fisheries "typology" could then be used to derive principles for managing different types of fishery (e.g., steady state, cyclic, spasmodic).

ii. A theoretical study of the consequences of different management regimes on fluctuating fisheries, using bioeconomic simulation models.

iii. Analysis of informal management regimes and community and household level adaptations to fluctuating fisheries in Malawi and Indonesia. Findings were discussed in the context of current moves towards co-management of fisheries in these countries.

These research activities were supplemented by reviews of changing management and policy in the fisheries sector in the target countries, and by research to promote the uptake of livelihoods approaches in the study of small-scale fishing communities. In both countries, the research calls into question prevailing wisdom that fisheries are open-access occupations of last resort, and the refuge for the poorest of the poor. Instead, involvement in fishing is dependent on the ability to raise capital for investment, and the availability of employment opportunities as fishing labor are obviously related to the level of such investment. Fishing still provides rural communities with viable small-scale business opportunities, rather than just the means to subsist, even in the densely populated areas of Malawi and West Java. The project outputs contribute toward the Fisheries Management Science Programme's goal of "optimum sustainable yield from capture fisheries achieved by improved resource management". Recognizing the validity of flexible and adaptive strategies, and seeking ways to promote their effectiveness, should allow yields from fluctuating fisheries to be maximized, while building resilient and adaptive management institutions to ensure sustainability. The outputs also help ensure that fisherfolks' existing livelihoods strategies are recognized and supported, rather than undermined by poorly designed resource management strategies, thereby contributing to poverty eradication in fishing communities.

Anderson, J.J. 1996. Review of the influence of climate on salmon, p. 7. *In* D.R. Marmorek (ed.) Plan for analyzing and testing hypotheses (PATH): final report on retrospective analyses for fiscal year 1996. ESSA Technologies Ltd. Vancouver, B.C., Canada.

Evidence suggests that the year-class strength of salmon populations is related to decadal scale climatic/ocean fluctuations. The interactions have complex latitudinal patterns and appear to involve the major food web and current structures of the North Pacific. To understand the effect of climate on Columbia River salmon, the North Pacific system must be considered. A brief review of the patterns, the postulated mechanisms and indicators of the patterns follow. In general, two major climate regimes have been identified; one associated with cool and wet climate in the Pacific Northwest and another associated with warm and dry Pacific Northwest weather. The warm/dry regime favors stronger year class strengths of many Alaskan fish stocks while the cool/wet regime favors stocks on the West Coast of the lower United States. Within seasons climate factors related to the timing of the spring winds also have been shown to affect survival.

Anderson, J.J. 1997. Decadal climate cycles and declining Columbia River salmon, p. 22. *In* Sustainable Fisheries Conference Proceedings, 1998, Victoria, B.C. Canada. National Marine Fisheries Service and Oregon State University, Hatfield Marine Science Center.

This paper explores the effects of the interaction of anthropogenic trends and climate cycles on salmon declines in the Columbia and Snake River Basins. A basic population model, including anthropogenic and environmental factors, is discussed and literature relating decadal scale climate patterns and the response of the North Pacific ecosystem is reviewed. From this background a ratchet-like decline in Columbia and Snake River salmon production resulted from the interactions of human activities and climatic regime shifts. These interactions are illustrated using hundred year patterns in spring chinook salmon *(Oncorhynchus tshawytscha)* catch, the Columbia River hydroelectric generating capacity and a climate index characterizing the shifts between a cool/wet regime favorable to West Coast salmon and a warm/dry regime unfavorable to West Coast salmon. A half century correlation of the climate index and chinook catch suggests that a favorable climate regime counteracted detrimental impacts of hydrosystem development between 1945 and 1977, while an unfavorable climate regime negated beneficial effects of salmon mitigation efforts after 1977. This hypothesis is elaborated by a comparison of changes in the climate index relative to changes in Snake River salmon survival indicators. Proposed Snake River salmon restoration plans are considered in terms of this counteractive effects hypothesis. The recent declines of salmon stocks have led a number of groups to propose plans that discontinue the present recovery actions, especially transportation of juvenile salmon around the dams. This paper hypothesizes that salmon recovery efforts, in part, have been limited by recent poor climate/ocean conditions. If this hypothesis is true, then eliminating the transportation program could be detrimental to fish. If the hypothesis is false, then eliminating transportation may be a viable recovery measure. In either case, resolving the issue of counteracting processes is essential prior to making major changes to the hydrosystem operations.

Arctic Council and the International Arctic Science Committee. 2004. Impacts of a warming Arctic: Arctic climate impact assessment: overview report. Cambridge University Press, New York, USA.

The overview report, entitled “Impacts of a warming Arctic”, provides the foundations for discussions today and concludes that: “The Arctic is now experiencing some of the most rapid and severe climate change on Earth. Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social and economic changes, many of which have already begun. Changes in Arctic climate will also affect the rest of the world through increased global warming and rising sea levels”. These climate changes are being experienced particularly intensely in the Arctic. Arctic average temperature has risen at almost twice the rate as the rest of the world in the past few decades. Widespread melting of glaciers and sea ice and rising permafrost temperatures present additional evidence of strong Arctic warming. These changes in the Arctic provide an early indication of the environmental and societal significance of global warming. An acceleration of these climatic trends is projected to occur during this century, due to ongoing increases in concentrations of greenhouse gases in the earth’s atmosphere. While greenhouse gas emissions do not primarily originate in the Arctic, they are projected to bring wide-ranging changes and impacts to the Arctic. These changes will, in turn, impact the planet as a whole. For this reason, people outside the Arctic have a great stake in what is happening there. For example, climatic processes unique to the Arctic have significant effects on global and regional climate. The Arctic also provides important natural resources to the rest of the world (such as oil, gas and fish) that will be affected by climate change. And melting of arctic glaciers is one of the factors contributing to sea-level rise around the globe.

Arnason, R., G. Magnusson and S. Agnarsson. 2000. The Norwegian spring spawning herring fishery: a stylised game model. Marine Resource Economics Vol. 15 (No. 4).

This paper presents an empirically based game-theoretic model of the exploitation of the Norwegian spring spawning herring stock, also known as the Atlanto-Scandian herring stock. The model involves five exploiters – Norway, Iceland, the Faroe Islands, the European Union and Russia – and an explicit, stochastic migratory behavior of the stock. Under these conditions, Markov Perfect (Nash) equilibrium game strategies are calculated and compared to the jointly optimal exploitation pattern. Not surprisingly, it turns out that the solution to the competitive game is hugely inefficient leading very quickly to the virtual exhaustion of the resource. The scope for cooperative agreements involving the calculation of Shapley values is investigated. It turns out that although the grand coalition of all players maximizes overall benefits, such a coalition can hardly be stable over time unless side payments are possible.

Attrill, M.J. and M. Power. 2002. Climatic influence on a marine fish assemblage. Nature Vol. 417. Macmillan Magazines Ltd.

Understanding the fluctuations in marine fish stocks is important for the management of fisheries, and attempts have been made to demonstrate links with oceanographic and climatic variability, including the North Atlantic oscillation (NAO). The NAO has been correlated with a range of long-term ecological measures including certain fish stocks. Such environmental influences are most likely to affect susceptible juveniles during estuarine residency, as estuaries are critical juvenile nursery or overwintering habitats. Here we show that, during a 16-year period, climatic forcing (by means of the NAO) is consistently the most important parameter explaining variation in assemblage composition, abundance and growth of juvenile marine fish during estuarine residency. A possible mechanism for the effect of the NAO is a temperature differential between estuarine and marine waters that allows fish to facultatively exploit optimal thermal habitats. The connection has potentially important implications for the size and numbers of individuals recruited to the fishery, for understanding and predicting the composition of juvenile fish stocks using estuaries, and for the appropriate conservation of estuarine systems in relation to fish stocks.

Bakun, A. 1996. Ocean triads and radical interdecadal variation: bane and boon to scientific fisheries management, p. 28. *In* T.J. Pitcher, P.J.B. Hart and D. Pauly (eds.) Reinventing fisheries management. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Recent large-amplitude interdecadal-scale population variations in some of the world's largest fishery stocks have exhibited a remarkable degree of global synchrony. This leads to several conclusions: (1) on these scales, the individual regional fish communities are not driven entirely by their own dynamics; (2) the biological linkages must therefore be quite simple; and (3) the problem of radical interdecadal fish stock variability would consequently appear to be eminently solvable. A "fundamental triad" of enrichment, concentration and retention processes, augments the trophic energy in supporting biological processes with mechanical energy of the earth's ocean-atmosphere system. Examples of such triad configurations in coastal upwelling regions may help scientific understanding of some crucial fisheries issues. The idea that experimental adaptive management could proceed effectively without a well-founded system of accounting for natural environment variability is challenged.

Bakun, A. and K. Broad. 2002. Climate and fisheries: interacting paradigms, scales and policy approaches. Report of the International Research Institute for Climate Prediction - International Pacific Research Center Pacific Climate-Fisheries Workshop, 14-17 November 2001, Hawaii, USA. International Research Institute for Climate Prediction, Columbia Earth Institute, New York, USA.

An international workshop on research issues related to interactions between climate variations and fisheries was held at the East-West Center of the University of Hawaii in Honolulu on 14-17 November 2001. Forty-eight participants represent a sampling of top-tier international scientific expertise with respect to climatic effects on fishery resource populations, fishing operations and fishery-related socioeconomic issues. An unusual aspect was the interaction of physical, biological and social scientists at all levels of the discussions. No prepared papers were delivered. Rather, the intended focus was on interdisciplinary and interregional "cross-education" and cross-sharing of insights and ideas among scientists with experience ranging over a variety of species and industry types, intended to support a collaborative process of:

- identifying alternative conceptual frameworks and ideas that may better support fruitful interdisciplinary collaborations (particularly between climate scientists and fishery scientists of both the "ecological/biological" and "social science" types);
- exploring associated implications for innovative fisheries management approaches;
- considering potential applications of the comparative method as a means for effective multilateral research on climate/ecosystems/fisheries issues in the Pacific Basin; and
- exploring in this regard the potential utility of certain newly available technologies and methodologies.

Barnett, T.P., D.W. Pierce and R. Schnur. 2001. Detection of anthropogenic climate change in the world's oceans. Science Vol. 292 (No. 5515).

Large-scale increases in the heat content of the world's oceans have been observed to occur over the last 45 years. The horizontal and temporal character of these changes has been closely replicated by the state-of-the-art parallel climate model (PCM) forced by observed and estimated anthropogenic gases. Application of optimal detection methodology shows that the model-produced signals are indistinguishable from the observations at the 0.05 confidence level. Further, the chances of either the anthropogenic or observed signals being produced by the PCM as a result of natural, internal forcing alone are less than 5%. This suggests that the observed ocean heat-content changes are consistent with those expected from anthropogenic forcing, which broadens the basis for claims that an anthropogenic signal has been detected in the global climate system. Additionally, the requirement that modeled ocean heat uptakes match observations puts a strong, new constraint on anthropogenically forced climate models. It is unknown if the current generation of climate models, other than the PCM, meet this constraint.

Beamish, R.J. 1993. Climate and exceptional fish production off the west coast of North America. Canadian Journal of Fisheries and Aquatic Sciences Vol. 50.

From 1976 to 1978 there was a change in the climate over the North Pacific Ocean. The Aleutian Low intensified and there was a warming of the sea surface adjacent to North America and a cooling offshore. Associated with this change was a period of exceptional fish production. Strong year classes and above-average survival occurred for many commercially important species all along the west coast of Canada and the United States. Trends in total salmon catches increased primarily from increased salmon production in Alaska. Some stocks of maturing pink *(Oncorhynchus gorbusha)*, coho *(O. kisutch)* and chinook salmon *(O. tshawytscha)* also had above-average growth in 1977. A majority of commercially important nonsalmon species that spawned from California to the Bering Sea and have a wide range of life history types also had exceptionally strong year classes from 1976 to 1978. The exceptional survival appears to be related to improved ocean productivity caused by changes in the intensity of Aleutian Low.

Beamish, R.J. 1995. Climate change and Northern fish populations. Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences Vol. 121. National Research Council of Canada, Canada.

These proceedings summarize some of the recent studies of the relationships among climate, the aquatic environment and the dynamics of fish populations. The studies are mostly from the North Pacific Ocean, but there are reports of investigations from the North Atlantic Ocean and from fresh water. The various papers include numerous examples of the relationships between fish abundance trends in the environment.

Beamish, R.J. 1995. Response of anadromous fish to climate change in the North Pacific, p. 14. *In* D.L. Peterson and D.R. Johnson (eds.) Human ecology and climate change: people and resources in the far North. Taylor and Francis, Washington DC, USA.

The relative importance of certain environmental factors and fishing effects in the dynamics of fish populations is widely debated in scientific circles as well as in the media. It is worth reviewing a few examples of this controversy because we cannot assess the impacts of climate change unless the impacts of climate on fish populations can be documented.

Beamish, R.J., D.J. Noakes, G.A. McFarlane, L. Klyashtorin, V.V. Ivanov and V. Kurashov. 1999. The regime concept and natural trends in the production of Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences Vol. 56 (No. 3).

Large fluctuations in the trends of Pacific salmon production in this century have been linked to trends in climate in the Pacific that are in turn associated with climate trends throughout the Northern Hemisphere. The close correspondence in the persistence of climate trends and the synchrony of the changes is evidence that a common event may cause the regime shifts. The trends or regimes can be characterized by stable means in physical data series or multiyear periods of linked recruitment patterns in fish populations. The regime concept is important in fisheries management because the natural shifts in abundance may be large and sudden, requiring that these natural impacts be distinguished from fishing effects. An equally important consideration is that biological and physical mechanisms may change when regimes shift, resulting in conditions that may not be characterized in the earlier part of the data series. Fluctuations in Pacific salmon abundance in this century were synchronous with large fluctuations in Japanese sardine abundance, which can be traced back to the early 1600s. The synchrony in the fluctuations suggests that Pacific salmon abundance may have fluctuated for centuries in response to trends in climate. The concept of regimes and regime shifts stresses the need to improve our understanding of the mechanisms that regulate the dynamics of fish and their ecosystems.

Beddington, J.R. and M.M. Robert. 1977. Harvesting natural populations in a randomly fluctuating environment. Science Vol. 197.

As harvesting effort and yield are increased, animal populations that are being harvested for sustained yield will take longer to recover from environmentally imposed disturbances. One consequence is that the coefficient of variation (relative variance) of the yield increases as the point of maximum sustained yield (MSY) is approached. When overexploitation has resulted in a population smaller than that for MSY, high effort produces a low average yield with high variance. These observations accord with observed trends in several fish and whaling industries. We expect these effects to be more pronounced for a harvesting strategy based on constant quotas than for one based on constant effort. Although developed in a MSY context, the conclusions also apply if the aim is to maximize the present value of (discounted) net economic revenue.

Ben-Yami, M. 2005. The effect of climatic shifts on catch composition in the Mediterranean fisheries of Israel. The Second Annual Conference of the Israeli Association of Aquatic Studies – Abstracts. Bar-Ilan University, Ramat Gan, Israel.

Since 1970s, Israel lacks transdisciplinary research that would integrate fisheries with environmental data. This prevents understanding of the causalities of biological changes in its marine ecosystem and using such changes as indicators of environmental processes in the system.

Abundances of herring and cod in the North Atlantic and Baltic Sea and of sardines and anchovy in the Pacific have been alternating. Off California, 1,700 year-old layers of fish scales in bottom deposits indicate interchanging abundances of sardine and anchovy in cycles of 50-70 years occurring in agreement with global climate oscillations and variations in the Earth's rotational velocity, suggesting linkage to planetary dynamics.

Even moderate and short-term climatic shifts affect fish populations sizes, their species/age/size compositions and hence, whole ecosystems. Mediterranean sardine and anchovy populations, for example, are out of phase, a phenomenon ascribed to environmental variations. Since the end of the 19th century, Indo-Pacific fish species have been establishing in the Mediterranean commercially important populations. Following an extremely warm and dry winter of 1954-1955, the Red Sea lizardfish, *Saurida undosquamis*, expanded in the Levant Basin increasing within a single year from nil to 20-25% of the total trawl landings, at the expense of other fishes, mainly hake and sea breams with which the lizardfish competed over food and space. In 1987, substantial quantities of formerly extremely rare here Indo-Pacific predator, Spanish mackerel *Scomberomorus commerson*, appeared for the first time in Israeli landings, and since gained commercial importance.

The present catch composition is quite different to what it used to be 50 years ago, and it keeps changing. It is highly probable that more pronounced and longer-term shift would produce in the Eastern Mediterranean further changes in the specific composition of commercial fishes, and in case of warming, in favor of Indo-Pacific species.

Boesch, D.F., J.C. Field and D. Scavia, Editors. 2000. The potential consequences of climate variability and change on coastal areas and marine resources: report of the Coastal Areas and Marine Resources Sector Team, US National Assessment of the Potential Consequences of Climate Variability and Change. US Global Change Research, Maryland, USA.

The US has over 95,000 miles of coastline and over 3.4 million square miles of ocean within its territorial waters. These areas provide a wide range of essential goods and services to society. Some 53% of the total US population lives on the 17% of land in the coastal zone, and these areas become more crowded every year. Because of this growth, as well as increased wealth and affluence, demands on coastal and marine resources for both aesthetic enjoyment and economic benefits are rapidly increasing. Coastal and marine environments are intrinsically linked to climate in many ways. The ocean is an important distributor of the planet's heat, with major ocean currents moving heat toward the poles from the equator. There is some chance that this distribution of heat through the ocean's "conveyor belt" circulation would be strongly influenced by the changes projected in many global climate models. Sea level rise is another climate-related phenomenon with a major influence on coastlines. Global sea level has already risen by 4-8 inches (10-20 cm) in the past century and models suggest this rise is very likely to accelerate. The best estimate is that sea level will rise by an additional 19 inches (48 cm) by 2100, with an uncertainty range of 5-37 inches (13-95 cm). Geological forces (such as subsidence, in which the land falls relative to sea level) play a prominent role in regional sea-level change. Accelerated global sea-level rise is expected to have dramatic impacts in those regions where subsidence and erosion problems already exist.

Broad, K., A.S.P. Pfaff and M.H. Glantz. 1999. Climate information and conflicting goals: El Niño 1997-98 and the Peruvian fishery. Journal of Policy Management and Analysis (October).

The development of seasonal-to-interannual climate predictions has spurred widespread claims that distributing forecasts will yield benefits for society. Based on the use and non-use of forecasts in the Peruvian fishery sector during the current El Niño event, the authors identify significant potential constraints on the realization of such benefits. Further, they argue that understanding such constraints is only one of the elements necessary for guiding optimal forecast dissemination choices. Forecast providers also require an appropriately detailed definition of societal benefit. That is, forecast providers must consider explicitly whose welfare counts as a benefit among groups such as labor, industry, consumers, future generations and different regions. Both a definition of societal benefit and an understanding of socioeconomic structures in the region of interest should be brought to bear on forecast dissemination choices. The authors conclude with hypothetical examples of dissemination choices made using this process.

Brodeur, R.D., R.C. Francis and W.G. Pearcy. 1992. Food consumption of juvenile coho *(Oncorhynchus kisutch)* and chinook salmon *(O. tshawytscha)* on the continental shelf off Washington and Oregon. Canadian Journal of Fisheries and Aquatic Sciences Vol. 49.

The overall food consumption by juvenile coho *(Oncorhychus kisutch)* and chinook salmon *(O. tshawytscha)* along the continental shelf off Washington and Oregon was estimated for the summer months of 1981-1984 using both a direct field and indirect bioenergetic approach. Both models yielded similar estimates but the consumption estimated by the bioenergetic was 14.8 and 3.2% higher for coho and chinook salmon, respectively. In a given year, overall consumption increased throughout the summer, despite decreasing abundances of both salmon species, but there were substantial differences among the four years within the same month. A preliminary comparison of the consumption estimates for important prey taxa early in the summer with estimated zooplankton biomass suggested that sufficient food levels may have been available for salmon during 1981. During the El Niño of 1983, however, several prey groups were consumed at high levels relative to their estimated availability and the biomass of these taxa may not have been sufficient to sustain the total population of salmon.

Caddy, J.F. 1999. Fisheries management in the twenty-first century: will new paradigms apply? Reviews in Fish Biology and Fisheries Vol. 9 (No. 1).

The last decade has seen growing concern at the uncertain effectiveness of most fisheries assessment and management approaches as reflected by trends in global landing statistics published by the Food and Agriculture Organization (FAO). These imply full exploitation of the majority of fishery resources and a serious overcapitalization of fleets at the global level. Projected increases in demand, future prices for fisheries products and impacts of growing world populations on the ecosystem all require an urgent search for improved management frameworks. Improved management of fisheries requires, first, an understanding of the axioms and working assumptions underlying the current approaches and how these evolved in response to regional or local conditions and target species.

This should promote integration of methodologies which better reflect local situations and can be expressed in the form of one or more working paradigms. These paradigms should incorporate ecosystem considerations, including environmental fluctuations and socioeconomic factors. They should not assume that current production levels are independent of natural fluctuations and human impacts and should recognize the dangers of maintaining open access to marine resources throughout their seasonal cycle, life history and distribution range. "Wide-use" management paradigms incorporating explicit user rights, participatory management and inputs from a variety of disciplines and stakeholders are becoming popular, but must operate within a hierarchy of pre-negotiated responses to pre-specified limit reference points so that social and economic options are not lost because conservation issues have not been given precedence.

Recent international agreements, including the formal ratification of the Law of the Sea, show that governments are prepared for more ecologically appropriate approaches. The key stake of the fisheries industry in sustainable fisheries development needs support, particularly for developing countries, now the major source of aquatic marine products. High priorities for management of marine resources are rebuilding depleted resources and restoring habitats, with concern for maintaining genetic and ecological diversity. There will be a need to consider impacts of global trade on conservation of resources for future generations, if proper management is to be maintained in the face of growing demand. International agreements of relevance to future management paradigms which are compatible with the Law of the Sea Convention (and each other), include the Agenda 21 of the United Nations Conference on Environment and Development (UNCED), the Biodiversity Convention, the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, the Compliance Agreement and the FAO Code of Conduct for Responsible Fisheries. Such agreements, ratified or now open for signature, provide a comprehensive basis for future "customary law" that can assist authorities in constructing appropriate management frameworks. Current concern remains with application of these agreements in international waters, where limited access as required for proper management still has not been established.

Callahan, B.M., E.L. Miles and D.L. Fluharty. 1999. Policy implications of climate forecasts for water resources management in the Pacific Northwest. Policy Sciences Vol. 32 (No. 3).

The Columbia River Basin management system suffers from conflicts over water use and allocation, and vulnerability to climate variability that disrupts hydropower, fisheries, irrigation, water supply and other vital activities. Climate forecasts have the potential to improve water resource management in this system, supporting management decisions that decrease its vulnerability to droughts, floods and other crises related to climate variability. This study shows that despite the potential utility, managers do not use climate forecasts except for background information. The barriers to managers' use of climate forecasts include low forecast skill, lack of interpretation and demonstrated applications, low geographic resolution, inadequate links to climate variability-related impacts and institutional aversion to incorporating new tools into decision making. To realize the potential of climate forecasts for water resources management, we recommend strategies that include technical improvements to the forecast products, and joint efforts between forecast producers and the management community to develop and demonstrate climate forecast applications through reciprocal and iterative education.

Chatters J.C., D.A. Neitzel, M.J. Scott and S.A. Shankle. 1991. Potential impacts of global climate change on Pacific Northwest spring chinook salmon *(Oncorhynchus tshawytscha)*: an exploratory case study. Northwest Environmental Journal Vol. 7.

Increases in atmospheric concentrations, if greenhouse gases are predicted to raise global temperatures by up to 3ºC over the next 100 years, may have significant effects on natural resources. Even a smaller (2ºC) temperature change may impact one prominent Pacific Northwest natural resource, the spring chinook salmon, Oncorhynchus tshawytscha. A computer model was developed by the Northwest Power Planning Council (NPPC) for use in developing the salmon enhancement plan for the council's Fish and Wildlife Program. Using this model, we investigate the impact of global warming on the production of spring chinook salmon in the Yakima Subbasin of the Columbia River System. The model simulates current prevailing environmental conditions and the implementation of improvements in salmon habitat planned by NPPC. The data are then changed to reflect conditions that are inferred to have existed between 6,000 and 8,000 years ago, when temperatures were approximately 2ºC warmer than today. When the NPPC computer model is run under these altered conditions, it shows that projected climate change might reduce by half the Yakima River spring chinook salmon production predicted under both current and NPPC-improved conditions. These results strongly support the need for planned improvements in the fishery, since a 50% decline in existing fish populations could decrease spring chinook salmon – and possibly other salmonid populations – beneath levels needed for the survival of the species. More broadly, the results suggest that if future global warming takes a form similar to that of 6,000 years ago, it could have major effects on the salmon population of the Pacific Northwest. Although some races of salmon might have their survival enhanced, others might be harmed. We recognize that all species and races would not be affected in the same way as Yakima River spring chinook, yet global warming is still a matter of concern because many of the Pacific Northwest salmon stocks are already under stress from other causes. A more comprehensive and thorough analysis is urgently needed.

Cho, J.H. and J.M. Gates. 2001. Environmental factors and natural resource stock: Atlantic herring case, p. 4. *In* R.S. Johnston and A.L. Shriver (comps.) Microbehavior and macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fishery Economics and Trade, 10-15 July 2000, Oregon, USA.

Herring is an important stock as bait for lobster fisheries and a component of the food web of the Northwest Atlantic Ocean. However, herring is very vulnerable to environmental variables such as temperature, food supply, and to the type of sediment on the bottom floor. Egg and larval stage herring are hypothesized to be very sensitive to low temperatures. This paper will analyze the correlation between temperature and two-year old recruitment stock, using satellite sea surface temperature data and stock size data from Northeast Fishery Science Center. Temperature is measured for specific areas that are defined as essential fish habitat, designated habitat for Atlantic herring eggs. The preliminary results suggest that including environmental factors is necessary to understand the cycle of fluctuating stock and is a necessary variable in the production model for a fishery.

Committee on the Human Dimensions of Global Change, Commission on Behavioral and Social Sciences and Education, Committee on Global Change Research, Board and Sustainable Development Policy Division, National Research Council. 1999. Human dimensions of global environmental change: research pathways for the next decade, Chapter 7 in Committee on Global Change Research, Board on Sustainable Development, Policy Division, National Research Council. Global environmental change: research pathways for the next decade, p. 293-376. National Academy Press, Washington DC, USA.

This is Chapter 7 of a larger report which addresses the full range of the scientific issues concerning global environmental change, written by the Committee on the Human Dimensions of Global Change of the National Research Council. It provides findings and conclusions on the key scientific questions in human dimensions research, lessons learned and research imperatives. Research on the human dimensions of global change concerns human activities that alter the Earth's environment, the driving forces of those activities, the consequences of environmental change for societies and economies, and human responses to the experience or expectation of global change. Such research is essential both to understand global change and to inform public policy. Research on the human causes of global change has shown that socioeconomic uncertainties dominate biophysical uncertainties in climate impacts and possibly also in other impacts of global change. It has shown that human activities, such as deforestation and energy consumption, are determined by population growth, economic and technological development, cultural forces, values and beliefs, institutions and policies, and the interactions among all these things.

Committee to Review the US Climate Change Science Program Strategic Plan, Division of Earth and Life Studies, Division of Behavioral and Social Sciences and Education, Division of Engineering and Physical Sciences, National Research Council. 2004. Implementing climate and global change research: a review of the Final US Climate Change Science Program Strategic Plan / Committee to Review the US Climate Change Science Program Strategic Plan. National Academies Press, Washington DC, USA.

The US Climate Change Science Program (CCSP) was established in February 2002 to coordinate climate and global change research conducted in the United States. Drawing on information from the US Global Change Research Program of the previous decade, as well as from other sources, CCSP developed a ten-year strategic plan to guide its activities. CCSP requested that the National Academies review both a discussion draft of this strategic plan, released in November 2002, and a revised version. The revised strategic plan is reviewed in this report.

Cooney, R.T., T.M. Willette, S. Sharr, D. Sharp and J. Olsen. 1995. The effect of climate on North Pacific pink salmon *(Oncorhynchus gorbuscha)* production: examining some details of a natural experiment, p. 8. *In* R.J. Beamish (ed.) Special Publication of the Canadian Journal of Fisheries and Aquatic Sciences Vol. 121. National Research Council Canada, Canada.

Positive correlations between pink salmon production and sea-surface and air temperatures in the Gulf of Alaska demonstrate linkages with long-term, low-frequency oceanographic and meteorological variability. A comparison of a warm spring (1990) and a cold spring (1991) in Prince William Sound, Alaska, suggests that one way these influences may manifest is by modifying the duration of the annual fry emigration into coastal nursery areas. Differences in air and sea-surface temperatures, approximately 2ºC, apparently resulted in an extension of the pink salmon emigration by 38 d in the cold year. Evidence is presented that between-year differences in cloud cover contributed to the variability in thermal histories measured in the spring of 1990 and 1991. An interpretation linking the duration of the wild-fry emigration levels of adult production is proposed on the basis of experimental results from an ocean-ranched pink salmon program in the region.

Costello, C.J., R.M. Adams and S. Polasky. 1998. The value of El Niño forecasts in the management of salmon: a stochastic dynamic assessment. American Journal of Agricultural Economics No. 80.

The El Niño-southern oscillation is the largest source of interannual variability in global climate. Variability in climate has been linked to variability in fisheries, specifically salmon stocks of the Pacific Northwest. The ability to forecast El Niño events already exists and is likely to improve in coming years. An accurate prediction may have value because it allows for better management decisions. In this article, we develop a bioeconomic model of the coho salmon fishery and derive the value of information from improved El Niño forecasting ability. We find that a perfect El Niño forecast results in an annual welfare gain of approximately US$1 million while imperfect forecasts lead to smaller gains. Results also suggest that optimal management in the face of uncertainty involves a "conservative" management strategy, resulting in lower harvest, higher wild fish escapement and lower hatchery releases than management in the absence of such certainty.

Costello C., S. Polasky and A. Solow. 2001. Fishery management with environmental prediction, p. 3. *In* R.S. Johnston and A.L. Shriver (comps.) Microbehavior and macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fishery Economics and Trade, 10-15 July 2000, Oregon, USA.

Variations in environmental conditions affect renewable resource growth. The ability to predict such variations is improving, providing scope for improved management. We generalize a common stochastic stock recruitment model to explore how optimal management changes with environmental prediction. We obtain three main results. First, while it might seem that a prediction of adverse future conditions should lead to more conservative management, the opposite may be true. Second, optimal management requires only a one-period-ahead forecast, suggesting forecast accuracy is more important than forecast lead time. Finally, we derive conditions on environmental fluctuations guaranteeing positive optimal harvest in every period.

Downton, M.W. and K.A. Miller. 1998. Relationships between Alaskan salmon catch and North Pacific climate on interannual and decadal time scales. Canadian Journal of Fisheries and Aquatic Sciences Vol. 55.

Using multivariate time series models, Alaska's statewide commercial catch of three salmon species during 1925–1994 is shown to be related to surface temperatures in particular large regions of the eastern North Pacific. Previous research has indicated that interdecadal changes in Alaskan catch levels are related to large-scale changes in the climate regime of the North Pacific. The present work focuses on interannual variability by controlling for climatic shifts in the mid-1940s and mid-1970s. For sockeye *(Oncorhynchus nerka)* and chum *(O. keta)*, relationships with temperature occur within a few months after ocean entry with warmer regional temperatures enhancing survival. For sockeye and pink salmon *(O. gorbuscha)*, relationships with temperature occur at the time and location of the return migration, suggesting that colder ocean temperatures may enhance spawning success or egg survival. In addition, the models show a significant positive relationship of chum catch to pink catch 2 years earlier, suggesting a common influence on smolts of the two species. The results support the contention that climatic factors affecting the marine environment play a significant role in salmon production on interannual, as well as interdecadal, time scales.

Eide, A. and K. Heen. 2002. Economic impacts of global warming: a study of the fishing industry in North Norway. Fisheries Research Vol. 56.

Several studies have been carried out on the possible physical and biological effects of global warming in the Barents Sea area. Based on these studies, this paper discusses the effects global warming may have on the Barents Sea fisheries and the implications for the North Norwegian economy. The first has been studied using the multispecies, multifleet model ECONMULT, and the latter by applying an input–output model. A range of possible environmental scenarios based on physical and biological studies of the effects of global warming has been examined. Both positive and negative biological growth effects have been considered, changing the current growth rates by 25%. A more narrow range of management regimes has been applied, reflecting the current management rules and fishery policy in the region. The paper analyzes the potential of global warming for changing the catches, profitability, employment impacts and income generation by the Barents Sea fisheries.

Francis, R.C. 1993. Climate change and salmon production in the North Pacific Ocean, p. 11. *In* K.T. Redmond and V.J. Tharp (eds.) Proceedings of the Ninth Annual Pacific Climate Workshop, 21-24 April 1992, Asimolar, California, USA. Interagency Ecological Study Program Technical Report 34. California Department of Water Resources, California, USA.

Extreme catches of northeastern Pacific salmon seem to be frequent rather than rare events. Throughout the 1960s and early 1970s, record high catches were realized for stocks originating in streams of Washington, Oregon and California, while record low catches occurred in the valuable commercial salmon fisheries of Alaska. A major shift in relative fortunes took place beginning in the late 1970s. Recent production of salmon has been so high in Alaska that prices have fallen drastically and much of the product cannot be sold profitably. Conversely, salmon production along the West Coast has fallen so low that the Pacific Fishery Management Council recently considered an option that would eliminate ocean sport and commercial harvests in 1992 from California to Washington. Both sudden declines and increases in salmon production have been either blamed on or credited to a number of natural and anthropogenic factors, "the environment" always being mentioned but in a rather nebulous manner.

These recent issues, however, highlight the critical need to understand the long-term effects of the marine environment on the production of northeastern Pacific salmonid stocks and fisheries. Climate fluctuations and their subsequent oceanic impacts are becoming recognized as important phenomena affecting low-frequency (interdecadal) shifts in large marine ecosystems, resulting in subsequent shifts in marine fisheries production. A recent National Oceanic and Atmospheric Administration plan (NOAA 1989) indicates that, with respect to long-term (interdecadal) shifts in fishery production, a major question that needs to be addressed is: how are large-scale atmospheric and oceanic processes linked to major changes in fish community structure? That is the focus of a research project being conducted, under the support of the Washington Sea Grant, by Stephen Wooster (University of Washington School of Marine Affairs) and me. Our specific biological focus is on Pacific salmon for a number of reasons. In general, however, we are attempting to understand the causes and marine biological manifestations of interdecadal shifts in North Pacific atmosphere and ocean regimes. This paper contains three sections. The first presents an overview of the northeastern Pacific in terms of its component large marine ecosystems and their defining physics and biology. The second attempts to answer the question, why salmon? And the third presents a very rough and highly speculative model of how atmosphere, ocean and marine biological production are linked in the North Pacific, resulting in low-frequency and not necessarily in-phase shifts in fisheries production of the major regions.

Gaffin, S.R., C. Rosenzweig, X. Xing and C. Yetman, 2004. Downscaling and geo-spatial gridding of socio-economic projections from the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios. Global Environmental Change Vol. 14. Columbia University, New York, USA.

A database has been developed containing downscaled socioeconomic scenarios of future population and gross domestic product (GDP) at country level and on a georeferenced grid scale. It builds on the recent Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES), but has been created independently of that report. The SRES scenarios are derived from projected data on economic, demographic, technological and land-use changes for the 21st century in a highly aggregated form consisting of four world regions. Since analysts often need socioeconomic data at higher spatial resolutions that are consistent with GCM climate scenarios, we undertook linear downscaling to 2100 of population and GDP to country level of the aggregated SRES socioeconomic data for four scenario families: A1, A2, B1, B2. Using these country-level data, we also generated geospatial grids at 1/4° resolution (~30 km at the equator) for population "density" (people/unit land area) and for GDP "density" (GDP/unit land area) for two time slices, 1990 and 2025. This paper provides background information for the databases, including discussion of the data sources, downscaling methodology, data omissions, discrepancies with the SRES report, problems encountered and areas needing further work.

Glantz, M.H., Editor. 1992. Climate variability, climate change and fisheries. Cambridge University Press, New York, USA.

This volume addresses the potential implications for fisheries and societies of the regional impacts of a global warming of the atmosphere. Fisheries case studies were selected from investigation of the responses to changes in their environment. While most of these changes related to biological factors, some case studies related to abiotic factors, focusing on changes in the availability of fish. This study began with the identification of fisheries around the world that have undergone changes in availability and abundance, with a preference for fisheries affected by such changes in the past few decades. Some of the cases, however, are classic ones. Each chapter provides the general historical background of the fishery, the problems faced as the result of a natural or human-induced change in availability or abundance, and a set of possible lessons to societies that are directly or indirectly dependent on the exploitation of specific living marine resources.

Glantz, M.H. 2000. Currents of change: impacts of El Niño and La Niña on climate and society. 2nd edition. Cambridge University Press, New York, USA.

The periodic warming and cooling of the tropical Pacific Ocean's surface waters generate droughts, hurricanes and floods worldwide. El Niño's impacts are now widely known, but the equally serious consequences of its counterpart, La Niña, are only now being highlighted. Although both phenomena have generally been associated with death and destruction, there are benefits in understanding more about their occurrence, their strength and their impacts worldwide, so that their worst effects can be forecast and mitigated. This new edition of *Currents of change* explains in simple terms what El Niño and La Niña are and how they can be forecast. Examining for the first time the major El Niño of 1997-1998, this book explores what we can learn from past events, what we can do to ameliorate the worst excesses of these phenomena and how climate change might affect them in future decades.

Glantz, M.H. and L.E. Feingold. 1992. Climate variability, climate change and fisheries: a summary. Cambridge University Press, Cambridge, UK.

This chapter provides a summary of the 16 chapters presented in the book of the same title, each on a different fishery, each examining stock fluctuations, relationships with climatic factors and the social impacts of changes in stock levels. Lessons are derived from each chapter.

Government of Canada. 2004. Climate change impacts and adaptation: a Canadian perspective. Natural Resources Canada, Ontario, Canada.

This report presents a brief summary of research in this field over the past five years, as it relates to Canada. Results of research supported by the Government of Canada's Climate Change Action Fund are highlighted in boxes within each chapter of the report. The "Fisheries" chapter focuses on the impacts of climate change on Canada's marine and freshwater fisheries, and the role of adaptation in reducing the vulnerability of the sector. At the same time, it must be recognized that adaptation decisions taken with respect to fisheries will have important implications for other sectors, including water resources, transportation, tourism and human health. A complete assessment of fisheries impacts and adaptation options should therefore take into consideration issues raised in other chapters of this report. Particular attention should be paid to the "Coastal zone" chapter, which focuses on many of the physical impacts of the marine-terrestrial interface.

Hamilton, C., C. Duncan and N.E. Flanders. 1998. Management, adaptation and large-scale environmental change, p. 17. *In* D. Symes (ed.) Property rights and regulatory systems in fisheries. Fishing News Books, Blackwell Science, Oxford, UK.

Fisheries have long been agents of ecological change but in many instances the current level of exploitation is clearly not sustainable. However, the usual response of regulating the fisheries with quotas and licenses also has their share of weaknesses and imperfections. In this article, the authors propose a fishery model system to keep most aspects, including ecological and social ones, in sight.

Hare, S.R. and R.C. Francis. 1995. Climate change and salmon production in the Northeast Pacific Ocean, p. 16. *In* R.J. Beamish (ed.) Climate change and northern fish populations. Canadian Journal of Fisheries and Aquatic Sciences Vol. 121.

Alaskan salmon stocks have exhibited enormous fluctuations in production during the 20th century. In this paper, we investigate our hypothesis that large-scale salmon-production variability is driven by climatic processes in the Northeast Pacific Ocean. Using a time-series analytical technique known as intervention analysis, we demonstrate that Alaskan salmonids alternate between high and low production regimes. The transition from a high (low) regime to a low (high) regime is called an intervention. To test for interventions, we first fitted the salmon time series to univariate autoregressive integrated moving average (ARIMA) models. On the basis of tentatively identified climatic regime shifts, potential interventions were then identified and incorporated into the models, and the resulting fit was compared with the non-intervention models. A highly significant positive step intervention in the late 1970s and a significant negative step intervention in the late 1940s were identified in the four major Alaska salmon stocks analyzed. We review the evidence for synchronous climatic regime shifts in the late 1940s and late 1970s that coincide with the shifts in salmon production. Potential mechanisms linking North Pacific climatic processes to salmon production are identified.

Hilborn, R., J. Maguire and A. Parma. 2001. The precautionary approach and risk management: can they increase the probability of successes in fishery management? Canadian Journal of Fisheries and Aquatic Sciences Vol. 58.

Considerable progress has been made in the implementation of the precautionary approach to the protection of fish stocks, but applying it to the protection of fishing communities lags considerably. The principle of intergenerational equity, one of the main tenets of the approach, and the principle of sustainable utilization both imply that the precautionary approach should explicitly incorporate the protection of fishing communities, not only the resources they depend on. Risk assessment aims primarily at evaluating the consequences of various harvest strategies in terms of probabilistic statements about future trends in yields, biomass and dangers to the stock, while risk management involves finding and implementing management policies, strategies and tactics that reduce the risk to the communities exploiting them. Not all fishery management approaches deal equally well with risk, with some compounding rather than reducing risk. Portfolio management, whereby fishing enterprises have the ability to choose among a diverse portfolio of harvestable resources, would mitigate against the risk of fluctuations in the abundance, availability or price of individual species. Although much remains to be achieved in better assessing risk, fishery management agencies should immediately implement risk management.

Hoffman, J. 2003. Designing reserves to sustain temperate marine ecosystems in the face of global climate change, p. 33. *In* L.J. Hansen, J.L. Biringer and J.R. Hoffmann (eds.) Buying time: a user's manual for building resistance and resilience to climate change in natural systems. World Wide Fund for Nature, Berlin, Germany.

Temperate marine ecosystems include a wide array of habitats: estuaries, marshes, seagrass and kelp beds, rocky coastlines, sandy, muddy and cobble shores, the deep sea and the open ocean. To cover the details of conservation and climate change in each habitat type would turn this chapter into a lengthy book. Instead, I will highlight those aspects of the marine realm in general that set it apart from terrestrial ecosystems and discuss their implications for both reserve design and responses to climate change. Because of their relative accessibility, coastal habitats have received the most attention from marine conservation biologists and the public alike, and information presented in this chapter reflects this bias. Still, we should remember that we are only just beginning to understand the rich diversity of life in the deep and open seas, and the ways in which apparently distinct marine ecosystems interact with each other. While designing conservation strategies with only partial information about the ecosystems in question is difficult, we ignore unfamiliar habitats in our conservation planning at our peril.

Hofmann, E.E. and T.M. Powell. 1998. Environmental variability effects on marine fisheries: four case histories. Ecological Applications Vol. 8 (No. 1).

The changing nature of marine fishes requires management approaches that recognize and include ecosystem and environmental effects. Therefore, we review some examples of exploited fishery stocks in which environmental control is a major contributor to structuring the abundance and distribution of the stock. Four examples, taken from studies of northern cod *(Gadus morhua)*, cod and haddock *(Melanogrammus aeglefinus)* larvae, the eastern oyster *(Crasssostrea virginica)* and Antarctic krill *(Euphausia superba)*, are given that clearly illustrate environmental control on the fishery. For these examples, we argue that future management strategies for exploited fisheries must include effects of environmental variability. In particular, management strategies must be flexible enough to include delayed responses to environmental variations that result from the transfer of perturbations from larger to smaller scales and vice-versa. This capability requires an understanding of where linkages between the physical environment and the species of interest occur. The development of this knowledge requires input from a variety of disciplines, coordinated research programs and considerable cooperation at national and international levels.

Hollowed, A.B., S.R. Hare and W.S. Wooster. 2001. Pacific Basin climate variability and patterns of Northeast Pacific marine fish production. Progress in Oceanography Vol. 49.

Review of oceanographic and climate data from the North Pacific and Bering Sea revealed climate events that occur on two principal time scales: (1) 2-7 years (i.e., El Niño-southern oscillation and interannual variation) and (2) interdecadal (i.e., Pacific decadal oscillation, PDO). The timing of ENSO events and of related oceanic changes at higher latitudes was examined. The frequency of ENSO was high in the 1980s. Evidence of ENSO forcing on ocean conditions in the North Pacific (Niño North conditions) showed ENSO events were more frequently observed along the West Coast than in the western Gulf of Alaska (GOA) and Eastern Bering Sea (EBS). Recruitment data for 23 groundfish and 5 nonsalmonid pelagic species from 3 large geographic regions were examined for evidence of pure temporal variability (PTV) caused by large-scale forcing at one or more of the time scales noted in oceanographic and climate data. Some flatfish stocks exhibited high autocorrelation in recruitment coupled with a significant step in recruitment in 1977 suggesting a relationship between PDO forcing and recruitment success. Five of the dominant gadid stocks (EBS and GOA Pacific cod, Pacific hake, and EBS and GOA walleye pollock) exhibited low autocorrelation in recruitment. Of these, Pacific hake, GOA walleye pollock and GOA Pacific cod exhibited significantly higher incidence of strong year classes in years associated with Niño North conditions. These findings suggest that PTV may play an important role in governing year class strength of some Northeast Pacific marine fish stocks.

Jones, R.N. 2001. An environmental risk assessment/management framework for climate change impact assessments. Natural Hazards Vol. 23. Kluwer Academic Publishers, Dordrecht, The Netherlands.

This paper presents an environmental risk assessment/risk management framework to assess the impacts of climate change on individual exposure units identified as potentially vulnerable to climate change. This framework is designed specifically to manage the systematic uncertainties that accompany the propagation of climate change scenarios through a sequence of biophysical and socioeconomic climate impacts. Risk analysis methods consistent with the Intergovernmental Panel on Climate Change Technical Guidelines for Assessing Climate Change Impacts and Adaptations are set within a larger framework that involves stakeholders in the identification, assessment and implementation of adaptation measures. Extensive consultation between parties occurs in a flexible structure that embeds scientific methods of risk analysis within a broad setting of social decision making. This format is consistent with recent forms of environmental risk assessment/management frameworks.

The risk analysis links key climatic variables expressed as projected ranges of climate change with an upper and lower limit, with impact thresholds identified collaboratively by researchers and stakeholders. The conditional probabilities of exceeding these thresholds are then assessed (probabilities using this method are conditional as the full range of uncertainty for the various drivers of climate change, and their probability distributions, remains unknown). An example based on exceeding irrigation demand limited by an annual farm cap is used to show how conditional probabilities for the exceedance of a critical threshold can be used to assess the need for adaptation. The time between the identification of an acceptable level of risk and its exceedance is identified as a window of adaptation. The treatment of risk consists of two complementary actions, adaptation to anticipated changes in climate and the mitigation of climate change through reductions in greenhouse gas emissions. Both of these actions will reduce the risk of critical thresholds being exceeded. The potential of this framework for addressing specific requirements of the United Nations Framework Convention for Climate Change is discussed.

Jurado-Molina, J. and P. Livingston. 2003. Climate-forcing effects on trophically linked groundfish populations: implications for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences Vol. 59.

Commercially important groundfish populations in the Bering Sea are connected through the food web as predators and prey. In addition to having different trophic roles, the recruitment of these species varies on interdecadal time scales and may be related to climate forcing. We simulate the effects of fishing mortality on eight trophically linked species under two scenarios of climate regimes using the multispecies virtual population analysis (MSVPA) model and the multispecies forecasting model (MSFOR). Species respond differently to climate change assumptions and fishing mortality depending on their position in the food web. Results suggest that the assumptions regarding climate regime shifts on mean recruitment may produce effects comparable to the ones produced by fishing and predation interactions. Therefore, accurate models for fisheries management would require considering these factors and their potential interactions. Because responses are complex and difficult to predict, it is necessary to take a risk-averse approach in managing the species with the largest potential variation. The incorporation of climate regime shifts in fisheries management will require a better understanding of recruitment during a particular regime and a reliable way to identify regime shifts based on biological and (or) physical indices.

Kahn, J.R. 2005. The economic approach to environmental and natural resources. Third ed. Dryden Press, USA.

This book does several things differently from other books. The first is the division into theory and application. The second organizational difference that distinguishes this textbook from others is the integration of environmental and resource economics. Chapters on global warming, energy, biodiversity, agriculture and the environment, the environment and macroeconomy, tropical forests, and issues relating to the environment in developing countries also distinguish this from other existing textbook. Chapter 7 focuses on Global Environmental Change: Ozone Depletion and Global Climate Change, with subsections as follows: Introduction, The Depletion of the Ozone Layer, Greenhouse Gases and Global Climate, Global Warming Policy, Rethinking an International Treaty on Global Climate Change and Summary.

Kawasaki, T. 1992. Climate-dependent fluctuations in the Far Eastern sardine population and their impacts on fisheries and society, p. 31. *In* M.H. Glantz (ed.) Climate variability, climate change, and fisheries. Cambridge University Press, Cambridge, UK.

This article describes the relationship between sardine stock fluctuations and climatic and other variables. It discusses the impact on society of stock fluctuations, and draws lessons for the future about coping with the potential impacts on the marine environment of a global warming.

Kawasaki, T. 2001. Global warming could have a tremendous effect on the world fisheries production, p.3. *In* R.S. Johnston and A.L. Shriver (comps.) Microbehavior and macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fishery Economics and Trade, 10-15 July 2000, Oregon, USA.

A new evidence for the regime shift has been found as to the tuna populations in the northwest Pacific to show that the regime shift is the universal principle throughout fish groups not only at lower trophic levels but at higher levels. The regime shift has been driven by the cyclic climate change resulting from a shift in the patterns of overturning in the northern North Atlantic. Global warming may shut down one of the two downwelling sites linked to formation of the North Atlantic Deep Water, and destroy the system of regime shift itself.

Kawasaki, T. 2003. Toward a new paradigm of the fisheries management, p. 2. *In* B. Shallard (ed.) Fisheries in the global economy. Proceedings of the Eleventh Biennial Conference of the International Institute of Fisheries Economics and Trade. Bruce Shallard and Associates, Wellington, New Zealand.

Fisheries management has been carried out on the assumption that a fish population is in equilibrium with the fishing effort under the average environmental conditions and hence there must be a maximum sustainable yield (MSY). However, since the simultaneous rise and fall of the interdecadal and global scale of sardine populations was pointed out in the early 1980s, many other similar events of long-term changes in marine populations have been emerging, which is called regime shift. On the other hand, abundant evidence for the regime shift of climate-ocean systems has been obtained recently, which is suggested as the driving force causing the fluctuations in marine organisms. Very recently, it has become clear that even groundfish and tunas often show a tremendous increase in spite of the strong exploitation. These facts strongly show that there are no steady conditions in the oceans and the MSY is nothing but an imaginary criterion. A new paradigm of the fisheries management must be sought on the basis of the regime shift theory.

Kennedy, V.S., R.R. Twilley, J.A. Kleypas, J.H. Cowan, Jr., and S.R. Hare. 2002. Coastal and marine ecosystems and global climate change: potential effects on US resources. Report prepared for Pew Center on global climate change. Pew Center, Virginia, USA. www.pewclimate.org

Coastal and marine ecosystems and global climate change is the eighth in a series of Pew Center reports examining the potential impacts of climate change on the US environment. It details the likely impacts of climate change over the next century on US coastal and marine ecosystems, including estuaries, coral reefs and the open ocean. Report authors, Drs. Victor Kennedy, Robert Twilley, Joan Klepas, James Cowan, Jr. and Steven Hare find the following:

- Temperature changes in coastal and marine ecosystems will influence organism metabolism and alter ecological processes such as productivity and species interactions. Species are adapted to specific ranges of environmental temperature. As temperatures change, species' geographic distributions will expand or contract, creating new combinations of species that will interact in unpredictable ways. Species that are unable to migrate or compete with other species for resources may face local or global extinction.
- Changes in precipitation and sea-level rise will have important consequences for the water balance of coastal ecosystems. Increases or decreases in precipitation and runoff may respectively increase the risk of coastal flooding or drought. Meanwhile, sea-level rise will gradually inundate coastal lands. Coastal wetlands may migrate inland with rising sea levels, but only if they are not obstructed by human development.

- Climate change is likely to alter patterns of wind and water circulation in the ocean environment. Such changes may influence the vertical movement of ocean waters (i.e., upwelling and downwelling), increasing or decreasing the availability of essential nutrients and oxygen to marine organisms. Changes in ocean circulation patterns can also cause substantial changes in regional ocean and land temperatures and the geographic distributions of marine species. Critical coastal ecosystems, such as wetlands, estuaries and coral reefs, are particularly vulnerable to climate change. Such ecosystems are among the most biologically productive environments in the world. Their existence at the interface between terrestrial and marine environments exposes them to a wide variety of human and natural stressors. The added burden of climate change may further degrade these valuable ecosystems, threatening their ecological sustainability and the flow of goods and services they provide to human populations.

Klyashtorin, L.B. 1997. Global climate cycles and pelagic fish stock fluctuations in the Pacific, p. 2. *In* D.A. Hancock, D.C. Smith, A. Grant and J.B. Beumer (eds.). Developing and sustaining world fisheries resources. The state of science and management proceedings of the Second World Fisheries Congress, 28 July-2 August 1996, Brisbane, Australia. Commonwealth Scientific and Industrial Research Organisation Publishing, Collingwood, Australia. 797 p.

Strongly smoothed global and Northern Hemisphere surface air temperature anomaly (dT°) and Aleutian low pressure index (ALPI) trends demonstrate the general direction of global climate changes, although without reliable prognostic meaning for Pacific fish production. The atmospheric circulation index (ACI) trend characterizing the principal direction of air mass transport in the Northern Hemisphere is in phase with the general trends in the global dT° index and global geophysics characteristic: the earth rotation velocity index (ERVI). The ACI and ERVI trends correlate closely with the main Pacific commercial stock trends: Peruvian, Japanese and California sardines, anchovy, Pacific salmon, Alaska pollock, Chilean jack mackerel, Pacific cod, tunas and some others. It is possible to consider ACI and ERVI as a prognostic index and to forecast the dynamics of main commercial stocks for 2-15 years based on a "climatic regime model." Variation in the harvest of Pacific commercial species over the last century can be pictured as two sequential natural climate-governed production cycles with maxima in the late 1930s and late 1980s-early 1990s. The recent cycle is not yet complete, but is coming to the phase similar to the climatic phase of the 1940s and 1950s. The evolution of the new climatic phase will have serious ecological consequences not only for oceanic but also for terrestrial biota of the Pacific Rim region.

Klyashtorin, L.B. 1998. Long-term climate change and main commercial fish production in the Atlantic and Pacific. Fisheries Research Vol. 37.

Main Atlantic and Pacific commercial species of the subtropic, subartic and arctic zones – Atlantic and Pacific herring; Atlantic cod; European, South African, Peruvian, Japanese and California sardine; South African and Peruvian anchovy; Pacific salmon; Alaska pollock; Chilean jack mackerel and some others – undergo long-term simultaneous oscillations. The total catch of these highly abundant species equals about 50% of the total Atlantic Pacific marine fish harvest. The dynamics of northern hemispheric surface air temperature anomaly (dT) can hardly be correlated with long-term dynamics of marine commercial fish production because of high interannual variability. The so-called atmospheric circulation index (ACI) characterizing a dominant direction of air mass transport was found to be closely related with long-term fluctuations of the main commercial stocks. This index has been registered over the Northern Hemisphere or more than 100 years using the Wangengeim-Girs method. Correlations coefficients between commercial catches and ACI dynamics in the period of 1900-1994, stayed in the range of 0.70-0.90. The global character of the ACI dynamics is confirmed by its close correlation with such global geophysical characteristics as the earth rotation velocity index (ERVI). Approximately 50-70 year simultaneous cycles were observed in stock dynamics of the main commercial species, ACI and ERVI. The dynamics of main commercial stocks in both Atlantic and Pacific follows the alternation of the so-called circulation epochs (meridional or "latitudinal"). The long-term changes of dT, ACI, ERVI and commercial stock dynamics display the beginning of new climate-production phase similar to that of 1950s-1970s.

Klyashtorin, L.B. 2001. Climate change and long-term fluctuations of commercial catches: the possibility of forecasting. FAO Fisheries Technical Papers No. 410.

The main objectives of this study were to develop a predictive model based on the observable correlation between well-known climate indices and fish production, and to forecast the dynamics of the main commercial fish stocks for 5-15 years ahead. Spectral analysis of the time series of the global air surface temperature anomaly (dT), the atmospheric circulation index (ACI) and length of day (LOD) estimated from direct observations (110-150 years) showed a clear 55-65 year periodicity. Spectral analysis also showed similar periodicity for a reconstructed time series of the air surface temperatures for the last 1,500 years, a 1,600-year long reconstructed time series of sardine and anchovy biomass in Californian upwelling areas, and catch statistics for the main commercial species during the last 50-100 years. These relationships are used as a basis for a stochastic model intended to forecast the long-term fluctuations of catches of the 12 major commercial species for up to 30 years ahead. According to model calculations, total catch of Atlantic and Pacific herring, Atlantic cod, South African sardine, and Peruvian and Japanese anchovy for the period 2000–2015 will increase by approximately 2 million t, and will then decrease. During the same period, total catch of Japanese, Peruvian, Californian and European sardine, Pacific salmon, Alaska pollock and Chilean jack mackerel is predicted to decrease by about 4 million t, and then increase. The probable scenario of climate and biota changes for the next 50-60 years is considered.

Knapp, G., P. Livingston and A. Tyler. 1999. Human effects of climate-related changes in Alaska commercial fisheries, p. 20. *In* G. Weller and P.A. Anderson (eds.) Assessing the consequences of climate change for Alaska and the Bering Sea region. Center for Global Change and Arctic System Research, University of Alaska, Alaska, USA.

Marine fisheries are very vulnerable to climate change. Most of the research to date on the relationship between climate change and fisheries focuses specifically on how climate change may affect marine ecosystems and in turn abundance and harvests of specific marine species. This paper focuses on the human effects – economic, social and political – of climate-driven changes in Alaska commercial fisheries, and what can be done to mitigate these effects. Alaska commercial fisheries are the basis of a major industry of economic significance not only to Alaska but also to the nation. In 1995, the ex-vessel value (the value received by fishers) of Alaska landings exceeded US$1.4 billion, while the first wholesale value (the value after processing in Alaska) was almost US$3.0 billion.

Climate change may have significant effects on Alaska fisheries. It is likely to reduce the abundance of some species while increasing the abundance of others, with resulting reductions or increases in commercial harvests. For some species, significant changes in harvests may occur rapidly. How managers respond to climate change may either amplify or smooth out the effects of climate change on harvests. For a given species, climate change may cause harvests to increase in some parts and decline in other parts of Alaska. For most species, we can’t predict accurately how harvests in a given area may change, or when changes may occur. The farther we look into the future, the greater our uncertainty about potential changes in harvests. The history of commercial fishing in Alaska and elsewhere offers numerous examples of the economic and social consequences of climate change.

Krovnin, A.S. and S.N. Rodionov Vniro. 1992. Atlanto-Scandian herring: a case study, p. 30. *In* M.H. Glantz (ed.) Climate variability, climate change and fisheries. Cambridge University Press, Cambridge, UK.

Not long ago, Altanto-Scandian herring was the most common among the herring inhabiting the world’s oceans. Nowadays, despite the fact that its stock has been considerably depleted, it remains an important species from the point of view of commercial potential. This chapter deals primarily with Norwegian spring-spawning herring, although some attention is paid to both of the Icelandic stocks as well. All three stocks have been subjected to similar overexploitation in the 1960s and 1970s but now two of them – Norwegian spring-spawning herring and Icelandic summer-spawning herring – have begun to recover. The study includes sections on distribution, migration and environmental conditions, historical review of the fishery, effects of climate change on stocks, management problems, reactions by various countries to the stock collapse, lessons from the history of this fishery and key points.

Le Blanc J.-L. and F. Marsac. 1999. Climate information and prediction services for fisheries: the case of tuna fisheries. Proceedings of CLIMAR 99 – World Meteorological Organization (WMO) Workshop on Advances in Marine Climatology, 8-15 September 1999, Vancouver, B.C., Canada. WMO, Geneva, Switzerland.

Due to the high average market price of tuna, and because the processing and commercialization of tuna have significant economic implications worldwide, tuna fisheries are of high social and economic importance. Market pressure, increasing human populations, improved standard of living, led to additional demand, and thus to additional pressures on fish populations. Thus, tuna catches by fisheries throughout the world have been constantly increasing since the beginning of the 1950s. Therefore, overexploitation is threatening tuna if their fisheries are not soundly managed. Since both the fisher and the fish are under the influence of weather and climate, it is important to study the relationships between climate and fish behavior in order to better manage and assess their stocks.

Impacts of ocean variability on fish distribution have been known to fishers for centuries. Only recently has science uncovered the functional relationships existing between the fish and its environment on different spatial and temporal scales. This knowledge is useful for fish stock assessment – a very difficult task – necessary to enable responsible and sustainable fisheries. The impacts of climate on fish stocks are two-fold: Climate variations induce anomalies in the upper layer of the ocean (currents, waves, upwelling, advection, convergence, divergence, turbulence) which influence the feeding and spawning success of fish. Climate variations increase or decrease the catchability of fish to the gears (purse seiners and longliners). When a fish stock has suffered from bad feeding and/or spawning conditions, and that catchability is increased, dramatic consequences may occur as was the case for the Peruvian anchoveta fishery during the 1972-1973 El Niño. Another typical example is the decrease in yield of purse seiners in the Atlantic during 1984. The low catches were first believed to be due to overfishing, but it was later recognized to be due to a deepening of the thermocline and hence, to a decrease in catchability (since tuna basically follows the thermocline movements). It is therefore important for accurate stock assessment to be able to determine whether an increase in yields is due to an increase in stocks or in catchability and similarly if a decrease in yields is due to poor environment conditions or overfishing.

Physical atmospheric and oceanic parameters useful for that purpose are those that are ecologically relevant to tunas, i.e., SST (source: COADS); winds (sources: FSU pseudo-wind stress data set, COADS, Servain); upwelling/ thermocline depth (deduced from winds and/or numerical models, TOGA data set); turbulence (deduced from winds and/or numerical modeling, COADS).

In this document, the relationships between these parameters and tuna catches in the Indian Ocean will be summarized considering their spatial and temporal scales. The methodology and processing of data will be presented and the limits of the information will be discussed. Finally, improvements to be made in the quality, processing and distribution of data for better application to sustainable fisheries will be proposed.

Lehodey, P. 2002. Oceanic Fisheries and Climate Change Project, OFCCP Global Ocean Ecosystems Dynamics, GLOBEC: Report to GLOBEC Scientific Steering Committee, SSC on the implementation of the project. (Draft report available from author: patrickl@spc.int)

The OFCCP GLOBEC will investigate the effects of climate change on the productivity and distribution of oceanic tuna stocks and fisheries in the Pacific Ocean with the goal of predicting short to long-term changes and impacts related to climate variability and global warming. The ultimate goal of the project is to conduct simulations with ecosystem models that include the main tuna species, using an input data set predicted under a scenario of climate change induced by greenhouse warming as defined by the Intergovernmental Panel on Climate Change (IPCC). This should lead to the first tentative understanding how greenhouse warming will affect, at the ocean and global scales, the abundance and productivity of marine populations in the pelagic ecosystem, focusing on the major exploited species and fisheries, by a real coupling between atmospheric, oceanic, chemical and biological processes. Potential feedbacks from the changes in the pelagic ecosystem, and socioeconomic consequences will be investigated to propose adaptation measures for the future. However, analyses of simulations based on retrospective series of oceanic and fishing datasets are necessary intermediate steps to increase the reliability in the predictive capacity of the models. In particular, realistic predictions by the models of changes and fluctuations observed at short (e.g., El Niño-southern oscillation) and decadal (e.g., Pacific decadal oscillation) time scales in the ocean ecosystem and the tuna populations are necessary before predictions based on the global warming projection are incorporated. In addition, diverse studies are needed to improve the parameterization (e.g., energy transfer from primary to secondary production) and the modeling of key processes (e.g., recruitment, movements and feeding) and to validate the results of the simulations. Four major components have been identified to achieve these objectives.

Longhurst, A. 1995. Seasonal cycles of pelagic production and consumption. Progress in Oceanography Vol. 36.

Comprehensive seasonal cycles of production and consumption in the pelagial require the ocean to be partitioned. This can be done rationally at two levels: into 4 primary ecological domains (three oceanic and one coastal), or about 50 biogeochemical provinces. The domains differ in their characteristic seasonal cycles of stability, nutrient supply and illumination, while provinces are defined by ocean currents, fronts, topography and recurrent features in the sea surface chlorophyll field. For each of these compartments, seasonal cycles of photic depth, primary production and accumulation (or loss) of algal biomass were obtained from the climatological Coastal Zone Color Scanner (CZCS) chlorophyll field and other data and these, together with mixed layer depths, rendered characteristic seasonal cycles of production and consumption, which can be grouped into eight models: i - polar irradiance-mediated production peak; ii - nutrient-limited spring production peak; iii - winter-spring production with nutrient limitation; iv - small amplitude response to trade wind seasonality; v - large amplitude response to monsoon reversal; vi - canonical spring-fall blooms of mid-latitude continental shelves; vii - topography-forced summer production; viii - intermittent production at coastal divergences. For higher latitudes, these models suggest that the observed late-summer "blooms" result not from a renewal of primary production rate, but from a relaxation of grazing pressure; in mid-latitudes, the observed "winter" bloom represents chlorophyll accumulation at a season when loss terms are apparently smaller than during the period of peak primary production rate which occurs later, in spring. Where an episodic seasonal increase in rate of primary production occurs, as in the Arabian Sea, algal biomass accumulation may be brief, lasting only until consumption is fully re-established. Only in the low latitude oligotrophic ocean are production and consumption perennially and closely coupled.

Lorentzen, T. and R. Hannesson. 2005. Climate change and its effect on the Norwegian cod fishing industry. Institute for Research in Economics and Business Administration, SNF Project No. 5015: Economic Impact on Climate Change on Norway's Fisheries. SNF Working Paper 07/05. Institute for Research in Economics and Business Administration, Bergen, Norway.

The background for the paper is the expected climate change and its effect on the Norwegian cod fishing industry. Global warming is predicted to increase the stock of cod in the Barents Sea. Oceanographers expect that the total allowable catch (TAC) of Northeast Arctic cod will increase by about 50%. The Norwegian part of the TAC is expected to increase by about 100,000 t, given the existing relative distribution of quota Russia, Norway and third countries. During the time period from 1990 to 2001, the average total gross value of the Norwegian landed cod was 2.5 billion kroner (2003 value) per year. The climate-induced expansion in the cod stock is expected to increase the landed value by the Norwegian fleet by 0.5-1.0 billion Norwegian kroner (2003 value) per year, depending on how sensitive the price is for changes in quantity.

Lorentzen, T. and R. Hannesson. 2005. Climate change and its effect on the Norwegian herring fishery. Institute for Research in Economics and Business Administration, SNF Project No. 5015: Economic Impact on Climate Change on Norway's Fisheries. SNF Working Paper 18/05. Institute for Research in Economics and Business Administration, Bergen, Norway.

The effects of climate change on revenues in the Norwegian herring fishery are considered. The catch quota of Norwegian spring spawning herring is assumed to increase by 25% as a result of warming of the Norwegian Sea and the Barents Sea. Two cases are considered, one with a constant price and one with quantity-dependent price. The latter relationship is based on data for prices and landings for 1970-2001. The scenario where price and quantity are independent of each other shows that the average gross revenue will increase by about 300 million Norwegian kroner per year. Because price and quantity change randomly over time, the climate-induced increase can fluctuate between the extremes of 180-450 million kroner per year. The price-quantity dependent models show that a 144,000-t, climate-induced increase in the Norwegian catches of herring represents a gross value between 100 and 130 million Norwegian kroner per year.

Lorentzen, T. and R. Hannesson. 2005. Climate change and its effect on the Norwegian mackerel fishery. Institute for Research in Economics and Business Administration, SNF Project No. 5015: Economic Impact of Climate Change on Norway's Fisheries. SNF Working Paper 19/06. Institute for Research in Economics and Business Administration, Bergen, Norway.

The background for the paper is the expected climate change and its effect on the Norwegian mackerel fishing industry. Global warming is expected to affect the ecosystem in the Northeast Atlantic. Considerable uncertainty surrounds the prediction of how the Norwegian Economic Zone (NEA) mackerel stock will be affected by the climate change. However, qualitative predictions indicate that the NEA mackerel stock will move further north into the northern North Sea, the Norwegian Sea and into the southern Barents Sea. Norway has 31% of the total allowable catch (TAC), and shares can change the migration pattern and spawning areas, and therefore change TAC and how it is distributed between countries. Norway exports mackerel products for about 2.5 billion Norwegian kroner per year. The paper shows that changes in gross revenue are due to changes in elastic demand. If the Norwegian TAC increases by 20%, the gross revenue increases by 25-30 million Norwegian kroner per year in the elastic case and about 120 million Norwegian kroner if demand is infinitely elastic.

Lundberg, A. 2004. Environmental change, human efforts and nature management. Norwegian Journal of Geography Vol. 58.

This short article is an introduction to and a summary of a special issue of the Norwegian Journal of Geography. The article summarizes the impacts of human interactions with natural systems. A paragraph mentions climate change as a significant stressor on natural systems, indicating that it is no longer just a potential future problem, but exists today.

Magadza, C.H.D. 2000. Climate change impacts and human settlements in Africa: prospects for adaptation. Environmental Monitoring and Assessment Vol. 61.

Climate change impacts on Africa human settlements arise from a number of climate change-related causes, notably sea level changes, impacts on water resources, extreme weather events, food security, increased health risks from vector-borne diseases and temperature-related morbidity in urban environments. Some coastlines and river deltas of Africa have densely populated, low-lying areas, which would be affected by a rise in sea level. Other coastal settlements will be subjected to increased coastal erosion. Recent flooding in East Africa highlighted the vulnerability of floodplain settlements and the need to develop adaptive strategies for extreme weather events management and mitigation. In the semi-arid and arid zones, many settlements are associated with inland drainage water sources. Increases in drought will enhance water supply-related vulnerabilities. Interbasin and international water transfers raise the need for adequate legal frameworks that ensure equity among participating nations. Similarly, water supply and irrigation reservoirs in seasonal river catchments might fail, leading to poor sanitation in urban areas as well as food shortage. Hydroelectric power generation could be restricted in drought periods, and where it is a major contributor to the energy budget, reduced power generation could lead to a multiplicity of other impacts. States are advised to develop other sources of renewable energy. Temperature changes will lead to altered distribution of disease vectors such as mosquitoes making settlements currently free of vector-borne disease vulnerable. Rapid breeding of the housefly could create a menace associated with enteric disorders, especially in conditions of poor sanitation. The dry savannahs of Africa are projected as possible future food-deficit areas. Recurrent crop failures would lead to transmigration into urban areas. Pastoralists are likely to undertake more transboundary migrations and probably come into conflict with settled communities. Adaptive measures will involve methods of coastal defences (where applicable), a critical review of the energy sector, both regionally and nationally, a rigorous adherence to city hygiene procedures, an informed agricultural industry that is capable of adapting to changing climate in terms of cropping strategies, and innovations in environment design to maximize human comfort at minimum energy expenditure. In the savannah and arid areas, water resource management systems will be needed to optimize water resource and use and interstate cooperation where such resources are shared. Climate change issues discussed here raise the need for state support for more research and education in impacts of climate change on human settlements in Africa.

Magistro, J. and C. Roncoli. 2001. Anthropological perspectives and policy implications of climate change research. Climate Research Vol. 19 (2). Inter-Research, Germany.

This paper highlights the relevance of anthropological research to climate science. It suggests that localized scales of analysis, that have been the hallmark of anthropology, can complement global modeling exercises that cannot fully capture the complexities of real life decisions. Community and culture are key dimensions that mediate the interaction between humans and climate. Anthropology has a long-standing tradition of studying vulnerability and adaptation to environmental stresses. Political economy and political ecology approaches contextualize climate risk, highlighting the need to integrate climate products with policy solutions. Microanalyses of risk management and decision making strategies can bring science and policy closer to the needs of vulnerable groups. Tools and insights from cognitive anthropology also facilitate communication of climate information by ensuring consistency with local knowledge frameworks.

Markowski, M., A. Knapp, J.E. Neumann and J. Gates. 1999. The economic impact of climate change on the US commercial fishing industry, p. 28. *In* R. Mendelsohn and J.E. Neumann (eds.) The impact of climate change on the United States economy. Cambridge University Press, New York, USA.

The analysis presented in this chapter is intended to provide preliminary economic estimates of the sensitivity of the commercial fisheries sector to a broad range of climate change scenarios. Under restrictive methodological assumptions, the conservative climate change scenarios show potential damage to the domestic commercial fisheries. In our results, we find that the effects of climate change on domestic commercial fisheries could be large in terms of total value of fisheries, although these effects may be considered small in comparison with those on other economic sectors (e.g., agriculture). The screening level results highlight the possibilities for directing future research in the following areas: coverage, regulatory regime, substitutes, richer scenarios.

McCay, B.J. and A.C. Finlayson. 1995. The political ecology of crisis and institutional change: the case of the Northern cod. Paper presented to the Annual Meetings of the American Anthropological Association, 15-19 November 1995, Washington, DC, USA. The paper also appears online as: Natural resources: the case of the northern cod. Rutgers University. 2 January 2004. http://arcticcircle.uconn.edu/ArcticCircle/NatResources/cod/mckay.html

The tragedy-of-the-commons model has played a strong if implicit role in the diversion of effort away from understanding and improving the knowledge base for decision-making and toward the task of reducing the population's dependence on a patently uncertain and difficult resource. It has led to overly simplified accounts of both problem and solution. If overfishing was the major cause of the collapse of the northern cod, then overfishing must be prevented. So far so good; but what does an attempt to reduce the number of people licensed to fish have to do with overfishing? The collapse of the northern cod is indeed a tragedy, and it is indeed a tragedy of the "commons" broadly construed. However, the northern cod fishery "commons" was neither unregulated nor open-access, certainly not since 1978. But at this point the thinking represented in the economic model of the open-access fisheries intrudes, leading too quickly to the "downsizing" solution to what are complex problems caused in some potentially measurable part by government policies, corporate interests, international situations, and the errors and uncertainties of science.

McFarlane, G.A., J.R. King and R.J. Beamish. 2000. Have there been recent changes in climate? Ask the fish. Progress in Oceanography Vol. 47.

It is generally accepted that a climate shift occurred about 1977 that affected the dynamics of North Pacific marine ecosystems. Agreement on the possibility of further climate shifts in 1989 and the late 1990s is yet to be achieved. However, there have been changes in the dynamics of key commercial fishes that indicate changes in their environment occurred in the early 1990s, and possibly around 1998. One method of measuring climate change is to observe the dynamics of species that could be affected. Several studies have described decadal-scale changes in North Pacific climate–ocean conditions. Generally, these studies focus on a single index. Using principal components analysis, we use a composite index based on three aspects of climate ocean conditions: the Aleutian Low Pressure Index, the Pacific Atmospheric Circulation Index and the Pacific Interdecadal Oscillation Index. We link this composite index (Atmospheric Forcing Index) to decadal-scale changes in British Columbia salmon and other fish populations. Around 1989, there was a change from intense Aleutian Lows (above average south-westerly and westerly circulation patterns and warming of coastal sea surface temperatures) to average Aleutian Lows (less frequent south-westerly and westerly circulation and slightly cooler coastal sea surface temperatures in winter). These climate–ocean changes were associated with changes in the abundance and ocean survival of salmon *(Oncorhynchus* spp.*)*, distribution and spawning behavior of hake *(Merluccius productus*) and sardines *(Sardinops sagax)* and in recruitment patterns of several groundfish species.

McGoodwin, J.R. 1992. Human responses to weather-induced catastrophes in a West Mexican fishery, p. 19. *In* M.H. Glantz (ed.) Climate variability, climate change and fisheries. Cambridge University Press, New York, USA.

The coastal plain in the south of the modern-day Mexican state of Sinaloa is the site of Mexico's most productive inshore marine fisheries, producing shrimp, fish and, until recent times, oysters and similar mollusks. This study indicates that: a change in climatic patterns prompted by global warming will lead to less predictable and perhaps chaotic transitions in patterns of marine resource availability in a region, requiring more flexibility and adaptability from fishers; the severity of adverse impacts on humans due to climate-induced catastrophes will be inversely proportional to availability of resources and degree of flexibility in socioeconomic and political structures; degree of government commitment to contingency planning for climate-induced catastrophes will be proportional to the frequency with which they occur.

McKelvey, R. and K.A. Miller. 2002. Chapter 16 - The Pacific salmon dispute: rationalizing a dysfunctional joint venture, p. 28. *In* K.D. Lynch, M.L. Jones and W.W. Taylor (eds.) Sustaining North American salmon: perspectives across regions and disciplines. American Fisheries Society, Maryland, USA.

On 30 June 1999, the Canadian and US governments signed a new Pacific salmon treaty that they hope will end a period of crisis and disarray in the efforts of the two nations to coordinate management of their North Pacific salmon fisheries. The recent turmoil was part of the long and rocky history of alternation between cooperation and discord in this arena. These fisheries are inherently binational because harvesters in one jurisdiction can intercept salmon heading to spawn in the rivers of another jurisdiction. As is so often the case with such fisheries, cooperation has proved to be elusive and difficult to maintain. In this paper, we explore the sources of this instability using game theoretic concepts to describe the negotiation process, and to discuss the new agreement in light of this analysis. The approach is characterized as a binational multiregional joint venture seemingly novel but has precursors such as proposed management for southern bluefin tuna.

McKelvey, R. and K.A. Miller. 2002. A stochastic split-stream harvesting model: insights on information and the Pacific Salmon War. Proceedings of an International Conference on Risk and Uncertainty in Environmental and Resource Economics, June 2002, Waginingen, The Netherlands.

The motivation for this work is a long history of conflict between the United States and Canada over harvests of Pacific salmon stocks – stocks that spawn in a number of rivers in these two countries, and then mingle and are harvested in the oceanic jurisdictions of both. The Stochastic Split Stream Model, developed here, is based loosely on Canadian-US harvest competition over Canada's Fraser River sockeye salmon stock. Fraser sockeye stocks vary considerably over time, both in biological productivity and in their return migration route around Vancouver Island, and thus their accessibility to the two national fleets. Our focus here is on the role, in the outcome of the game, of incomplete, often asymmetric, information. Thus we compare game versions that incorporate alternative information structures. The central issue addressed is how an increase of available information (or a reduction in its degree of asymmetry) affects the outcome of cooperative or competitive harvest.

McKelvey, R. and P.V. Golubtsov. 2002. The effects of incomplete information in stochastic common stock harvesting games. A preliminary version appeared in the Proceedings of the International Society for Dynamic Games, 8-11 July 2002, St. Petersburg, Russia.

Here the dynamic fishery harvesting game is generalized to a stochastic environment in order to examine the implications of incomplete and asymmetric information. The main emphasis is on a split-stream version of the game. At the beginning of each harvest season, the initial fish stock (or "recruitment") divides into two streams, each one accessible to harvest by just one of the two competing fishing fleets. The fleets simultaneously harvest down their streams, achieving net seasonal payoffs for the catch. After harvest, the residual substocks reunite, to form the brood stock for the subsequent generation. The strength of this subsequent generation is determined by a specified "stock-recruitment relation", and the cycle repeats. In this cyclic process, both natural environmental factors (stream-split proportions and stock-recruitment relation) and economic factors (harvest costs and benefits) will incorporate Markovian stochastic elements. At the beginning of each season, the fleets both know current recruitment, and also have some (generally incomplete or delayed, and often asymmetric) knowledge of the current values of stochastic elements. The knowledge-structure of each specific game version is held in common by the competitors. In the dynamic game each fleet sets its harvest policy, with the objective of maximizing the expected discounted sum of seasonal payoffs, and conditional on the extent of its current knowledge, and of the anticipated policy of its competitor. The implications of alternative knowledge-structures are explored, through dynamic programming and simulation. Both information-structures and the stochastic characteristics of bioeconomic parameters are varied continuously, to explore their interplay. Asymmetric tradeoffs among them are examined. Particular focus is on demonstrating the often unexpected, and sometimes counter-intuitive, effects that knowledge enrichment may have, in these incomplete-information, common-property games.

McKelvey, R., K. Miller and P. Golubtsov. 2003. Fish-wars revisited: stochastic incomplete-information harvesting game, p. 19. *In* J. Wesseler, H.P. Weikard and R. D. Weaver (eds.) Risk and uncertainty in environmental and natural resource economics. Edward Elgar Publishing, Massachusetts, USA.

This study employs a spatially distributed extension of the classical "fish-war" harvesting game. The model addresses the bioeconomic impact of exploiting a transboundary fish stock in a stochastic marine environment subject to natural fluctuations and long-term regime changes. Our goal is to study the evolution of the fishery, either with cooperative or noncooperative harvesting gleets possessing limited, possibly asymmetric, information of environmental changes. More specifically, we shall investigate how such information limitations and asymmetries will influence harvesting strategies and thus the outcome of the game. In particular we shall compare game versions that incorporate alternative information structures to determine the effect, on the evolution of the fish stock and the payoffs to the fleets, of an increase of available information (or a reduction in its degree of asymmetry). It will often be the case that, with competitive harvesting, information enrichment will be destructive both to the biological resource and to the welfare of the competing harvesters. This circumstance casts light on the design of cooperative institutional arrangements that will be stable in the presence of imperfectly predictable environmental stochasticity. As an illustration we examine, in light of the model, the history of the long-running dispute between the US and Canada over management of their binational Pacific salmon fishery. The Stochastic Split Stream Model, developed here, is based loosely on Canadian-US harvest competition over Canada's Fraser River sockeye salmon stock. Fraser sockeye stocks vary considerably over time both in biological productivity and in return migration route from Vancouver Island and, thus, their accessibility to the two national fleets. In addition, the model sheds light on other aspects of the dispute. Our analysis focuses on the effects of a pronounced warming in coastal ocean conditions that began in mid-1970s and continued for two decades. This climatic regime shift contributed to dramatic increases in Alaskan salmon abundance, declining ocean survival rates for southern salmon populations and changes in the migration behavior of Fraser River sockeye that favored the Canadian fleet. These anticipated changes destabilized cooperation under the terms of the 1985 Pacific Salmon Treaty. The positions taken by Alaska, Canada and the southern jurisdiction during the subsequent period of turmoil and renegotiation are consistent with our model results.

McKelvey, R.W., L.K. Sandal and S.I. Steinshamn. 2002. Fish wars on the high seas: a straddling stock competition model. International Game Theory Review Vol. 4. World Scientific Publishing Company.

The post-World War II era saw the development of powerful self-contained fishing fleets, so-called distant-water fleets (DWFs), which roamed the world's oceans, seeking out rich harvesting targets and practicing pulse fishing. With the creation in the 1980s of coastal states' extended economic zones (EEZs), to manage fisheries out to 200 miles from the shore, it was hoped that the DWFs would close down. But the ranges of many important commercial fish stocks straddle the boundaries of several EEZs, and continue out into international waters. Thus, the consequence of creating the EEZs has been to encourage development of coastal countries' national fleets, while the DWFs continue to harvest in international waters. Here, we model the fish war between a DWF and a regionally-based coalition of coastal states, operating out of their EEZs. The outcome is again a pulse fishery, but one which may be even more destructive than was the former situation, when the DWF was unopposed. Finally we point out the relevance of the fish war model to the issue of creating effective multinational Regional Fisheries Management Organisations, a necessary step for achieving sustainable benefit from the harvest of the regional seas.

McKelvey, R.W., L.K. Sandal and S.I. Steinshamn. 2003. Regional fisheries management on the high seas: the Hit-and-Run Interloper Model. International Game Theory Review Vol. 5.

The 1993 UN Straddling Stock Agreement prescribes a multinational organizational structure for management of an exploited marine fish stock, one which range straddles both "extended economic zones" and high seas waters. However, the agreement provides to the Regional Organization no coercive enforcement powers. In this connection, two problems in particular have been cited. The first, called the "interloper problem", concerns the difficulty of controlling harvesting by nonmember vessels. The second problem, called the "new-member problem", concerns the inherent difficulties of negotiating mutually acceptable terms of entry. Here we explore the extent to which the coalition, by exerting economic power alone, might be able to attain effective leverage in these management-control controversies. Specifically, we will examine whether the coalition might successfully employ traditional monopolistic "entry barriers". Game-theoretic economic analysis provides some helpful insights into this question, but the open-access character of resource exploitation on the high seas complicates its applicability here. On the other hand, the game is asymmetric with the incumbent coalition enjoying certain advantages. Our analysis lends support to the thesis that usually leverage to enforce regional management control must be sought elsewhere, other than through direct application of economic power within the harvesting sector.

McKelvey, R., P.V. Golubtsov, G. Cripe and K. Miller. The incomplete information stochastic split-stream model: an overview. *In* T. Bjørndal, D.D. Gordon, R. Arnason and R. Sumaila, (eds.) Advances in the economics of the fishery: festschrift in honour of Professor G.R. Munro. Blackwell, Oxford, UK. (Forthcoming).

The split-stream harvesting model describes the evolution of a nonoverlapping generation fish-stock being harvested by two competing or cooperating fleets, denoted by α and β. At the beginning of each harvest season, the initial stock (the "recruitment" R) splits into two parts, respectively R α and R β , with each fraction accessible to harvest by just one of the fleets. The residual substocks, following harvest, merge to form an escapement stock S, and then, following spawn and growth of the offspring, give rise to the subsequent-generation recruitment. Schematically: $S^- \longrightarrow R = F(S^-,b)$ □ $R\alpha = \theta\alpha R \longrightarrow S\alpha$ □ $S \longrightarrow R +$ □ $R\beta = \theta\beta \longrightarrow S\beta$ □ $S \longrightarrow R+$. Here the time series of annual substream stock fractions $\theta\alpha$ and $\theta\beta$ (with $\theta\alpha + \theta\beta = 1$) and of annual growth parameters b (in the stock-recruitment relation F) are random, forming Markov sequences. The two fleets observe independent imperfect measurements of the current valuation of these random variables and conditional on these measurements and on perceptions of the opponent's policy, each chooses a harvest strategy to maximize the value of its discounted stream of annual harvest returns. Using analytical, numerical and (where necessary) simulation methods, we have studied the implications, for the outcome of this incomplete-information dynamic game, of its specific information structure (i.e., alternative levels of uncertainty and degrees of transparency, or specified asymmetries in any held private information). We have also examined the implications of differing levels of risk-avoidance (or of risk-seeking) by the fleets, given our assumed conditions of uncertainty and incomplete information. We here offer an overview of our observations, of the most interesting, often surprising and sometimes seemingly counterintuitive outcomes of the many variants of the game.

Miller, K.A. 1996. Salmon stock variability and the political economy of the Pacific Salmon Treaty. Contemporary Economic Policy Vol. 14 (No. 3).

Since the mid-1970s, changes in the marine environment along the west coast of North America and in the Northeastern Pacific appear to have greatly enhanced the productivity of Alaskan salmon runs while contributing to declining runs of some salmon spawning in Washington, Oregon and California. These inverse fluctuations in northern and southern salmon stocks may have aggravated a recent breakdown in cooperation between the United States and Canada in setting harvest allocations under the Pacific Salmon Treaty. This paper examines the establishment of fishing regimes by the Pacific Salmon Commission. A game theoretic model is used to analyze the possible contribution of stock variability to the current conflict. Shifts in the parties' incentives to manage the fishery cooperatively, together with significant transaction costs, explain much of the recent difficulty in negotiating mutually acceptable fishing regimes. The paper concludes by addressing the question of whether the regime-setting process can be made more resilient to such stresses.

Miller, K. A. 2002. North American Pacific salmon: a case of fragile cooperation. Supplement: Papers presented at the Norway-Food and Agriculture Organization Expert Consultation on the Management of Shared Fish Stocks, 7-10 October 2002, Bergen, Norway. FAO Fisheries Report No. 695.

The current management arrangements for Pacific salmon are not perfect, and much could be learned from the experiences of other fisheries. Nevertheless, 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 maintain time consistency. However, possible disagreements over abundance estimates have not been eliminated. Ongoing efforts to enhance scientific cooperation and to 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 on the engagement of a community of credible and impartial scientists in these efforts.

Miller, K.A. 2002. Pacific salmon fisheries: climate, information and adaptation in a conflict-ridden context. Climatic Change 45(1).

Pacific salmon are anadromous fish that cross state and international boundaries in their oceanic migrations. Fish spawned in the rivers of one jurisdiction are vulnerable to harvest in other jurisdictions. The rocky history of attempts by the United States and Canada to cooperatively manage their respective salmon harvests suggests such shared resources may present difficult challenges for effective adaptation to climate change. On 30 June 1999, the two nations signed an agreement which, if successfully implemented, may end several years of rancorous conflict. For the previous six years, they had been unable to agree on a full set of salmon "fishing regimes" under the terms of the Pacific Salmon Treaty. This conflict was sparked by strongly divergent trends in the abundance of northern and southern salmon stocks, and a consequent change in the balance of each nation's interceptions of salmon spawned in the other nation's rivers. The trends are attributable, in part, to the effects of large-scale climatic fluctuations. This case demonstrates that it may not be exploited by multiple competing users who possess incomplete information. If, in addition, their incentives to cooperate are disrupted by the impacts of climatic variation, dysfunctional breakdowns in management rather than efficient adaptation may ensue. Institutional factors will determine the extent to which the management of such resources can adapt effectively to climate variability or long-term climate change.

Miller, K.A. Fish soup: uncertainty, conflicting interests and climate regime shifts. *In* T. Bjørndal, D.D. Gordon, R. Arnason and R. Sumaila, (eds.) Advances in the economics of the fishery: festschrift in honour of Professor G.R. Munro. Blackwell, Oxford, UK. (Forthcoming).

Many of the world's marine fisheries are shared between the fleets of two or more nations. Efforts to cooperatively manage harvests are complicated by uncertainties caused by large natural variations in the abundance or migratory behavior of shared fish stocks. Cooperation may collapse if natural variations are unanticipated or misinterpreted, have asymmetrical effects on the availability of fish to the different fleets, or lead the competing parties to advocate incompatible management responses. In particular, unanticipated long-term climate regime shifts have played a significant role in destabilizing international fisheries cooperation. This chapter reviews the scientific evidence regarding the impacts of such climate regime shifts on commercially important fish stocks, and draws upon case studies in the Atlantic and Pacific to demonstrate how such natural events can alter incentives to cooperate, sometimes leading to destructive fish wars. The chapter concludes with a discussion of the role of science in the management of shared fish resources, and suggestions for improving the resilience of cooperation to natural shocks.

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 and 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, sports, and Native American/First Nations groups in both nations to reduce commercial harvests of weak stocks to allow them to rebuild to healthy levels. Just as the parties to the Pacific Salmon Treaty could learn from experiences in other fisheries, their experiences also can provide lessons. 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 understanding 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.

Miller, K.A., and D.L. Fluharty. 1992. El Niño and variability in the Northeast Pacific salmon fishery, p. 49-88. *In* M.H. Glantz (ed.) Climate variability, climate change and fisheries. Cambridge University Press, New York, USA.

In 1982 and 1983, an intense El Niño spread warm water far northward along the North American west coast. This event contributed to poor salmon harvests along the US west coast. The purpose of this study is to gain insight into the impacts of climatic variability on a complex fishery system and potential impacts on fisheries of climate change, comprising biological oceanography and societal components as well.

Miller, K.A. and G.R. Munro. 2002. Cooperation and conflict in the management of transboundary fishery resource, p. 37. Proceedings of the Second World Congress of Environment and Resource Economics, June 2002, California, USA.

This paper, prepared for the World Congress of Environmental and Resource Economics, provides a great deal of explanatory background describing the history of fishery management and its current situation. It then provides a review of the economics of management of transboundary fisheries, combining the basic dynamic model of a fishery resource within the waters of a single state, with game theory. It uses the example of the conflicts between the US and Canada over Pacific salmon as a case study.

Miller, K.A. and G.R. Munro. 2004. Climate and cooperation: a new perspective on the management of shared fish stocks. Marine Resource Economics Vol. 19 (No. 3).

Climate regime shifts occur at irregular intervals and have profound and persistent impacts on ocean temperature and circulations 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 the Pacific salmon management to illustrate the dangers that unpredicted, unanticipated environment regime shifts pose for efforts to maintain international cooperation This suggests a need for greater attention to this issue. Fishery arrangements 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.

Miller K.A. and M.W. Downton. 2003. Transboundary fisheries: Pacific salmon, p. 851-864. *In* T. Potter and B. Colman (eds.) Handbook of weather, climate and water. John Wiley and Sons, New York, USA.

Climate variations often affect the abundance, location or migratory patterns of fish populations. Even when a fishery is entirely contained within a single jurisdiction, these climate impacts complicate the difficult task of maintaining economically efficient and biologically sound harvest management while balancing the interests of competing harvesters. When fish stocks are harvested by more than one nation, or when they cross internal jurisdictional boundaries, the management task is further complicated by the efforts of each nation or jurisdiction to promote the interests of its own harvesters. The faltering attempts of USA and Canada to cooperate on Pacific salmon management illustrate the fragile nature of such cooperation and the destabilizing role that clime variations can play. These two nations have a long and rocky history of alternating between cooperative salmon conservation efforts and predatory grabs at one another's returning adult salmon. The most recent breakdown in cooperation began in 1993. For six years, USA and Canada were unable to agree on a full set of salmon "fishing regimes" under the terms of the Pacific Salmon Treaty. The conflict was sparked by strongly divergent trends in the abundance of northern and southern salmon stocks and a consequent change in the balance of each nation's interceptions of salmon spawned in the other nation's sustained increase over the past two decades, while harvests of some salmon stocks in British Columbia and chinook and coho harvests in Washington, Oregon and California (i.e., southern) have fared poorly. These trends appear to be influenced by the impacts of climatic variability. Because it is not easy to disentangle natural and anthropogenic sources of variability, the negotiation process has been complicated by differences of opinion over the biological "facts". This case exemplifies many of the problems that arise in the management of transboundary fishery resources.

Miller, K.A., G.R. Munro and T. Bjørndal. 2004. Climate, competition and the management of shared fish stocks, p. 11. *In* Y. Matsuda and T. Yamamoto (eds.) International Institute of Fisheries Economics and Trade Japan Proceedings. International Institute of Fisheries Economics and Trade, Oregon, USA. (CD ROM).

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.

Miller, K.A., G. Munro, R. McKelvey and P. Tyedmers. 2001. Climate, uncertainty and the Pacific Salmon Treaty: insights on the harvest management game, p. 13. *In* R.S. Johnston and A.L. Shriver (comps.) Microbehavior and macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fishery Economics and Trade, 10-15 July 2000, Oregon, USA.

Pacific Salmon are anadromous fish that cross state and international boundaries in their oceanic migrations. Fish spawned in the rivers of one jurisdiction are vulnerable to harvest in other jurisdictions. The rocky history of attempts by the US and Canada to cooperatively manage their respective salmon harvests suggests that environmental variability may complicate the management of such shared resources. In recent years, an extended breakdown in cooperation was fueled by strongly divergent trends in Alaskan and southern salmon abundance, and a consequent change in the balance of each nation's interceptions of salmon spawned in the other nations' rivers. While several natural and anthropogenic factors contributed to these trends, there is considerable evidence that changing ocean conditions played a significant role. The period of high productivity in Alaska contributed to increased Alaskan interceptions of BC salmon at a time when Pacific Northwest coho and chinook could least withstand retaliatory actions on the part of the Canadian fleet. Only recently has the mounting crisis led to a fundamental shift in the approach taken by the two nations to determine their respective salmon-harvest shares. On 30 June 1999, Canada and the US signed an agreement which, if successfully implemented, may lay the groundwork for a more sustainable cooperative management regime. However, there are many unanswered questions regarding the viability and sustainability of the new Pacific Salmon Treaty Agreement. This paper draws lessons from the recent period of turmoil to identify strengths and weaknesses in the new abundance-based management approach, and to suggest avenues for further negotiations to secure more rational management of Pacific salmon resources.

Miller, K., G. Munro, T. McDorman, R. McKelvey and P. Tydemers. 2001. The 1999 Pacific Salmon Agreement: a sustainable solution to the management game? Orono Maine No. 47. Occasional Papers: Canadian-American Public Policy. Canadian-American Center, University of Maine, Maine, USA.

When Canada and the United States signed the Pacific Salmon Agreement on 30 June 1999, they hoped that it would put an end to the pattern of bickering, failed negotiations, conservation-threatening harvest practices and blame-laying that had prevailed over the previous six years. The agreement does not replace the 1985 Pacific Salmon Treaty, but rather places additional obligations on the parties and replaces the expired short-term harvest management regimes, contained in an annex to the treaty, with new longer-term arrangements. In reaching the agreement, the two nations consented to temporarily set aside a long smoldering dispute about the equitable division of the harvest and to focus on implementing multiyear abundance-based harvesting regimes that would foster conservation and restoration of depressed salmon stocks. The agreement has been in place now for two full fishing season, and at the time of this writing, the two nations are in the midst of a third year of coordinated management under the new regime. While the ultimate success of the new agreement is yet to be determined, sufficient time has passed to allow a preliminary assessment of its performance and the challenges that may lie ahead. Success can be gauged by the extent to which the agreement facilitates stable cooperation, while promoting such diverse goals as preservation and restoration of salmon resources, efficient management of fisheries and a mutual perception that the distribution of the benefits is equitable. Is the 1999 agreement designed for success? What other changes might be needed to ensure continued binational cooperation on Pacific salmon management? To address these questions, we begin by briefly reviewing previous analyses of the breakdown of cooperation under the 1985 Pacific Salmon Treaty (Huppert 1995; McDorman 1995; Miller 1996; Munro et al. 1998; McDorman 1998a). We then examine the negotiation process which led to the new Agreement, evaluate the differences between new and old approaches, and draw upon both game theoretic analysis and actual experience to assess the extent to which the 1999 Agreement is likely to succeed.

Munro, G.R. 2002. The management of shared fish stocks. FAO Fisheries Report No. 695 Supplement: Papers presented at the Norway-Food and Agriculture Organization Expert Consultation on the Management of Shared Fish Stocks, 7-10 October 2002, Bergen, Norway.

The Government of Norway, in cooperation with FAO, is to hold an Expert Consultation on the Management of Shared Fishery Resources. The consultation is being convened in recognition of the fact that the management of these resources stands as one of the great challenges on the way towards achieving long-term sustainable fisheries. The objective of the consultation is to assist countries in improving their efficiency performance in meeting this challenge. This paper is designed to serve as one of several background documents for the Expert Consultation. As such, it will attempt to perform two tasks. First it will review definitions, legal and otherwise, of shared stocks, and attempt to outline the scope and magnitude of the relevant resource management issues, on a worldwide basis. The Concept Paper for the Expert Consultation refers to the academic, or theoretical, aspects of the management of shared fishery resources, and in so doing, states that these aspects should serve as a background for Expert Consultation. The second task of this paper, then will be to review these academic aspects in a nontechnical manner, and go on to illustrate key points arising from the academic analysis, by drawing upon brief case studies from the real world. It is anticipated that all of the case studies drawn upon in the paper will be discussed in detail during the Expert Consultation.

Norton, J.G and J.E. Mason. 2005. Relationship of California sardine *(Sardinops sagax)* abundance to climate-scale ecological changes in the California Current system. CalCOFI Reports Vol. 46.

Empirical orthogonal function (EOF) analyses link sardine abundance to large-scale processes of the California Current ecosystem. These analyses of the California fish and invertebrate landings (CACom) detect two patterns of variability (EOF1 and EOF2), which indicate climate-scale changes in CACom species composition during 1930-2000. California sardine landings are related to EOF1 (nominal correlation coefficient, r'>0.9), linking fluctuation in sardine abundance to many other California Current species. Log_e – transformed sardine landings are closely related (r'>0.9) to accumulated sea-surface temperature (SST) anomalies at La Jolla, California, and to accumulated equatorial process indices (r'≥0.8). We found that the length of time physical anomalies persist is related exponentially to the effects the physical processes indexed will have on sardine abundance. When the sardine series is extended backward to 1890, using sardine scale deposition rates as an abundance proxy and the equatorial indices as physical proxies, the relationships between sardine abundance and the physical environment holds (r'≥0.8).

Pearcy, W.G. 1966. Salmon production in changing ocean domains, p. 22. *In* D.J. Stouder, P.A. Bisson and R.J. Naiman (eds.) Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York, USA.

The ocean's carrying capacity for anadromous salmonids is dynamic in time and space. It is constantly changing on interannual, decadal, centennial and millennial time scales. Since 1976, a major change has occurred in the Northeast Pacific Ocean, with unfavorable ocean conditions for salmonids in the Coastal Upwelling Domain, and highly favorable conditions farther north in the Coastal Downwelling and Central Subarctic domains and the Bering Sea. High sea levels and warm temperatures along the coast, an intense Aleutian Low and weak upwellings are associated with these recent changes. During the 1960s and early 1970s, when hatchery releases of smolts were increased to compensate for loss of freshwater habitat, the opposite trend prevailed, with good ocean survival in the Coastal Upwelling Domain and lower survival in the Gulf of Alaska. Although the exact mechanisms that affect high or low salmon production are still speculative, ocean climate is clearly implicated and should be considered in management decisions. Favorable ocean conditions will be required for full recovery of many depressed stocks.

PFEL (Pacific Fisheries Environmental Laboratory). Climate change and global warming. National Southwest Fisheries Science Center, Marine Fisheries Service. http://www.pfeg.noaa.gov/research/climatemarine/cmfclimate/cmfcc.html

An important topic in fisheries science is the influence of climate on fish populations and fisheries. In order to maintain and rebuild sustainable fisheries, we need to understand how the populations of some species are influenced by both short and long-term changes in the climate and adjust our estimates of optimal sustainable yield when conditions change. These National Oceanic and Atmospheric Administration-sponsored webpages bring together information on the response of pelagic fish to El Niños, the differing response of salmon in Alaska and Oregon to decadal scale North Pacific warming, and theories of how global warming may affect our fisheries. Previously there was no unified presentation of the effects of climate variability of different time scales on fisheries. There are good webpages on the El Niño events and some on global climate change, but it is difficult to find material relating these phenomena to fisheries. PFEL's many years of experience exploring the relationship of variations in climate to fisheries led us to develop such a site. This website provides the public with easily understood, up-to-date information on how climate variability affects fisheries. It provides background information and illustrations on the components of climate and what is meant by climate variability as well as references to important journal articles and links to related websites.

Pontecorvo, G. 2001. ENSO and the Peruvian anchovetta catch: some preliminary observations, p. 2. *In* R.S. Johnston and A.L. Shriver (comps.) Microbehavior and macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fishery Economics and Trade, 10-15 July 2000, Oregon, USA.

Two developments – investigation of the relationship between climate and the size of small pelagic fish stocks, and the extension of this relationship to include its impact on economic activity – indicate the importance of specifying the linkage among changes in the environment, a profitable and stable industry, and conservation of the resource base. Here we examine one case, the catch of Anchovetta by Peru over the 40-year period from 1960 to 1999 where the reported catch (supply) ranges from a high of 12.3 million mt to a low of 23 thousand mt. At its high points, in physical volume, this is the world's largest fishery. The output, fishmeal, is an important element in the world market for animal feed and therefore it resembles other commodities such as soy beans, etc.

Reilly, J. 2004. US agriculture and climate change: perspectives from recent research. Choices Vol. 3rd quarter.

This article covers the implications of climatic change for agriculture. The results of the research presented in that paper suggest that yields for many crops in the United States could increase with climatic change, with projected economic benefits ranging from $0.8 to 7.8 billion in 2030 and from $3.2 to 12.3 billion in 2100.

Russek, Z. 1992. Adjustments of Polish fisheries to changes in the environment, p. 34. *In* M.H. Glantz (ed.) Climate variability, climate change and fisheries. Cambridge University Press, Cambridge, UK.

This assessment of some dramatic changes in the Polish fishery system has been inspired by the general assumption that a warming of the global climate may turn out to be unavoidable over the next several decades. The consequences of increasing CO_2 emissions as a result of industrial activities are highly complex. The rise of average atmospheric temperatures by about 2-3°C could have numerous implications for marine ecosystems. Primary production and natural fish habitats will be disturbed to some, as yet unpredictable, extent. Consequently, the distribution of some living marine resources could shift, adversely affecting some fishing communities while benefiting others.

Sandler, T. and F.P. Sterbenz. 1990. Harvest uncertainty and the tragedy of the commons. Journal of Environmental Economics and Management Vol. 18: 155-167.

This paper demonstrates that a fixed number of risk-averse firms faced with harvest uncertainty owing to resource stock uncertainty will typically reduce of a commons. In addition, the total exploitation of the industry will decrease when entry is permitted and uncertainty is compared with certainty. This result holds for perfectly competitive output markets and also characterizes imperfectly competitive output markets with linear market demand and risk-neutral firms. In the latter case, the socially optimum number of firms is determined based upon the degree of uncertainty, the price elasticity of market demand and the elasticity of input productivity.

Sharp, G.D. 1992. Climate change, the Indian Ocean tuna fishery, and empiricism, p. 40. *In* M.H. Glantz (ed.) Climate variability, climate change, and fisheries. Cambridge University Press, Cambridge, UK.

This article discusses the political backdrop for Indian Ocean tuna activities, the development and evolution of the industry, identifying potential tuna grounds, comparison of the success of Spanish and French tuna seiners, Indian Ocean climate histories and prognoses, and tuna population responses to climate change. Conclusions include: climate modeling communities must focus more attention on the regional aspects of global warming – the local and seasonal weather patterns and their impacts. We must face the problem of monitoring the ocean with an eye toward building data-driven empirical models from which future scenarios might be devised. These well-adapted populations are far more responsive, and informative than newly hatched technologies and satellite sensors which tend to degrade at rates faster than the regional climate change.

Sharp, G.D. 2003. Future climate change and regional fisheries: a collaborative analysis. FAO Fisheries Technical Paper No. 452.

First, issues of global change versus global warming are discussed. The larger perspective is presented of earth as a warm, wet planet that experiences frequent cold periods via climate history graphics of Earth's recent million years of climate variation, from paleoclimate research. The hydrological cycle is described, and its relevance to fisheries is made clear. Climate-related dynamics have had serious consequences in evolution of species, society and fisheries variability. Both production variabilities and changes in vulnerability due to constant dynamics of ocean motion effects are described. The records available for major fisheries are interpreted as we understand them from a century of in-depth research and analysis of various proxies, in particular, bioindicators. The history of climate as it relates to fisheries is addressed. The various spatial and temporal scales that are reflected in fisheries responses are described in an attempt to isolate weather from climate, or other events. Regional ecological responses to climate change are reviewed. Examples are given for the main ocean ecosystems, as defined by seasonal thermal properties. Synchrony and systematic transitions are discussed. Several forecast approaches are described, and their similar conclusions merged to provide a realistic expectation over the next few decades, and beyond. Likely impacts are ranked by fishery system type, and coping measures identified, where they are known, emphasizing the role of humans in habitat protection and maintenance of options.

Sharp, G.D., L. Klyashtorin and J. Goodridge. 2001. Climate and fisheries: costs and benefits of change, p. 12. *In* R.S. Johnston and A.L. Shriver (comps.) Microbehavior and macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fishery Economics and Trade, 10-15 July 2000, Oregon, USA.

Many records provide the bases for a clearer understanding of the roles of climate regime shifts and short-term perturbations in ecosystem dynamics, hence fisheries responses. Too few have taken the long view of the role of humans in this "Grand Fugue". As one of many predators, it is imperative that humans begin to understand that our various activities are subject to basic ecological principles, such as the concepts of growth limitations imposed by scarcities and habitat debilitations. Most of human history (evolution, growth, colonizations, displacements, resource scarcity, competition for resources) are direct consequences of normal, natural climate fluctuations, and local, regional and global ecological responses. Early fisheries were subsistence levels, with some situations where fishing communities bartered or traded for goods from adjacent highlands or forest cultures. We have also become extremely vulnerable to any persistent climate changes. Following the Medieval Warm Period (~900-1180), the onset of the Little Ice Age brought changes in regional productivity, disease and death that began the global transition from feudal society to the "pay as you go" economics that now dominate the world's major economies. Over the recent two to three centuries, humans have swarmed over the remaining terrain, and spread out onto the seas. Modern history relates the continuous growth, expansion and generalized superposition of industrial fisheries onto older coastal subsistence communities, initiating extensive competition, overexploitation and with resultant dwindling resources and habitat destruction.

I have started a Timeline of Fisheries Development that provides a framework of information upon which these facts are derived: <.http://www.monterey.edu/faculty/SharpGary/world/FisheryTimeline.html> I will continue to develop the timeline, so that others might learn how humans resolve the issues of complex aquatic ecosystems, limited resource sharing, or not.

Stenevik, E.K. and S. Sundby. 2003. Impacts of climate change on commercial fish stocks in Norwegian waters. Working Paper No. 76/03, Institute for Research in Economics and Business Administration, SNF Project No. 5015 "Economic Impact of Climate Change on Norway's Fisheries". Centre for Fisheries Economics Discussion Paper No. 11/2003. Institute for Research in Economics and Business Administration, Bergen, Norway.

Declines in the abundances of the most important commercial fish species have often been considered as a result of overfishing and occasionally from a combination of environmental effect and fishing pressure. The impacts of climate variations have, however, been shown to have substantial effects on decreases as well as increases in stock abundance, and the success of future fish stock assessment depends to a large extent on the ability to predict the impacts of climate change on the dynamics of marine ecosystems. The sea temperature in the north-eastern North Atlantic has shown an increasing trend over the recent two to three decades. This might be an indication of climate change caused by emission of greenhouse gases. However, in addition to long-term climate change induced by anthropogenic activity, there is natural variability in the climate. Long-term variations caused by solar end tectonic factors and short and mid-term variations related to atmospheric and oceanic conditions exist and have to be separated from the long-term climate change even though it is difficult to distinguish between them (IPCC 2001). The longest time series on ocean climate is the Russian time series from north of Kola (Loeng 2001). It goes back to 1900 and shows a slightly increasing trend over the entire time series. However, on top of this trend, several longer and shorter-term periods are displayed. An approximately 60-year cycle is evident with a maximum in the 1930-1940s and a minimum in the 1960-1970s. Another period displayed in the Kola time series is the 18.6-year cycle due to the earth nutation (Yndestad 1999). In addition, there are decadal-scale periods associated with the North Atlantic oscillation (NAO), and there is also a clear biannual signal. However, presently we do not have sufficient knowledge to make prediction of these periodicities.

Stenevik, E.K. and S. Sundby. Addendum to "Impacts of climate change on commercial fish stocks in Norwegian waters". (Unpublished).

This addendum provides technical information as background to the article cited in the title on cod abundance and location in the North Sea.

Sugimoto, T., S. Kimura and K. Tadokoro. 2001. Impact of El Niño events and climate regime shift on living resources in the western North Pacific. Progress in Oceanography Vol. 49: 113-127.

Features of El Niño events and their biological impacts in the western North Pacific are reviewed, focusing on interactions between the El Niño-southern oscillation (ENSO) and the East Asian monsoon. Impacts of El Niño on the climate in the Far East become evident as "cool summers and warm winters". Effects of climate regime shift on ENSO activities, western boundary currents and upper-ocean stratification, as well as their biological consequences are summarized. These consequences are as follows:

1. In the western equatorial Pacific, an eastward extension of the warm pool associated with El Niño events induces an eastward shift of main fishing grounds of skipjack and bigeye tunas.
2. The surface salinity front in the North Equatorial Current region retreats southward, associated with El Niño events. This leads to a southward shift of the spawning ground of Japanese eel, which is responsible for a reduction in the transport of the larval eels to the Kuroshio and Japanese coastal region, causing poor recruitment.
3. Intensification of winter cooling and vertical mixing associated with La Niña (El Niño) events in the northern subtropical region of the western (central) North Pacific reduces surface chlorophyll concentration levels and larval feeding condition for both Japanese sardines and the autumn cohort of neon squid during winter to early spring. The semi-decadal scale calm winter that occurred during the early 1970s triggered the first sharp increase of sardine stock around Japan.
4. A remarkable weakening of southward intrusion of the Oyashio off the east coast of Japan during 1988–1991, resulted in a decrease in chlorophyll concentrations and mesozooplankton biomass in late spring to early summer of the Kuroshio-Oyashio transition region. Changes occurred in the dominant species of small pelagic fish, through successive recruitment failures of Japanese sardine.

Toman, M.A., Editor. 2001. Climate change economics and policy. Resources for the Future, Washington, DC, USA.

This book does not contain chapters specifically dedicated to fisheries. Part 1 covers the historical evolution of concern for climate change and the development of the existing international regime for climate policy, and the backdrop of energy use and economic activity that gives rise to greenhouse gases (GHG) emissions. It then discusses how the benefits and costs of climate change, mitigation and adaptation should be addressed. In part 2, several possible impacts of climate change are addressed from an economic as well as a physical perspective. In several of the chapters, the authors show how economic analysis combines scientific information about climate change impacts with social scientific information about human responses and valuations. They illustrate how adaptation can greatly reduce the expected negative impact of climate change. Attention is drawn to the importance of policies that can increase resilience and the possible constraints on resilience measures. Chapter 8 looks at how reducing GHG emissions can have benefits beyond emission reduction in the long-term risk of climate change. Part 2 does not address the whole panoply of concerns about climate change. Part 3 addresses the questions that surround the development and implementation of climate policies as well as climate aspects of other policies that can have important implications for GHG emissions. Part 4 contains discussions of various issues related to the establishment and maintenance of the effective international agreements for GHG control. In chapter 26 there is a summary of the editors' own view on productive future directions for climate policies.

Troadec, J.-P. 2000. Adaptation opportunities to climate variability and change in the exploitation and utilization of marine living resources. Environmental Monitoring and Assessment Vol. 61: 101-121.

Because they contribute little to climate change, fisheries, aquaculture and other uses of marine renewable resources and environment have limited means to mitigate climate impacts. Adaptation is, therefore, critical. Though likely effects on oceans and fisheries can be identified, few can be quantified and, thus, prioritized. Consequently, adaptation strategies should aim at enhancing the resilience of marine renewable resources and their uses and the current capacity to respond to surprises. Already, these uses are characterized by massive overcapacities, excessive resource exploitation and pervasive conflicts within and between uses. Two complementary adaptation strategies are available. The first consists in adjusting conventional management systems to the new conditions of resource scarcity. The second aims at reducing the current resource constraint by promoting the development of aquaculture and a better utilization of fishery and aquaculture harvests. In this respect, small and large-scale production systems, and developing and developed countries, have different capabilities. In summary, climate change does not modify, but enhances, existing priorities of environment and fisheries management and aquaculture development.

Van Kooten, G.C. 2004. Climate change economics. Edward Elgar Publishing Limited, Cheltenham, UK. 167 p.

Climate change constitutes a long-term threat to the earth's ecosystems and to the way people lead their lives. Climate change poses a tremendous challenge for forestry and agriculture, particularly for subsistence farmers in developing countries, and for coastal dwellers who could lose their homes and livelihoods as a result of flooding caused by sea level rise. While the full extent of the potential damage from global warming remains unknown, scientists have argued that action should be taken to mitigate the potentially adverse consequences of global warming. In making such a policy recommendation, however, economic arguments have to be considered as much as science-based ones. It is the purpose of this book, therefore, to examine the economic case for policy to mitigate climate change, and to investigate the types of policies that should be implemented, if any. The book does not deal with fisheries.

Vilhjálmsson, H. 1997. Climatic variations and some examples of their effects on the marine ecology of Icelandic and Greenlandic waters, in particular during the present century. Rit Fiskideildar Vol. 15 (No. 1): 8-29.

The environment variables that cause climate change are explored. The impact of these changes on the fishing stock around Icelandic and Greenlandic seas, coupled with overfishing, has contributed to a rapid decline of especially the Greenlandic cod and the Icelandic spawning herring.

Walters, C. and A. Parma. 1996. Fixed exploitation rate strategies for coping with effects of climate change. Canadian Journal of Fisheries and Aquatic Sciences Vol. 53: 148-158.

Survival rates and carrying capacities for larval and juvenile fishes may be strongly affected by long-term, unpredictable climatic fluctuations. When climate impacts produce strongly auto correlated interannual variations in recruitment, harvesting a constant fraction of the stock each year allows the spawning stock to track such variations. Dynamic programming analysis indicates that this tracking effect is likely to produce long-term harvests that are very close (within 15%) to the theoretical optimum that could be achieved if all future climatic variations were known in advance. Fixed harvest rate strategies are likely to degrade performance more than 10% only when there is little interannual correlation in environmental effects or when there is a large, abrupt climate change that can be predicted well in advance if it is going to increase carrying capacity, or detected immediately if it causes a decrease in capacity. This finding implies that it may be more cost-effective to invest in research on how to implement fixed harvest rate strategies than to invest in research on explaining and predicting climatic effects. Successful implementation may require a combination of improved stock size assessments, and stringent regulatory measures to substantially restrict the proportion of fish at risk to fishing each year.

Ware, D.M. and R.E. Thomson. 1991. Link between long-term variability in upwelling and fish production in the northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences Vol. 48 (No. 12): 2296-2306.

The biomass of pelagic fish in the Coastal Upwelling Domain off the west coast of North America decreased by a factor of 5 in the first half of the century. We assemble several physical and biological time series spanning this period to determine what may have caused this decline in productivity. Based on an observed link between time series of coastal wind and primary production, we conclude that there was strong relaxation in wind-induced upwelling and primary production between 1916 and 1942 off southern California. The fact that the individual biomasses of the dominant pelagic fish species tends to rise and fall in phase through the sediment record off southern California is consistent with our belief that these species are responding to a long period (40-600-year) oscillation in primary and secondary production, which in turn, is being forced by a long period oscillation in wind-induced upwelling. Our extended sardine recruitment time series indicates that there is a nonlinear relationship between Pacific sardine *(Sardinops sagax)* recruitment and upwelling and suggests that optimal recruitment occurs when the wind speed during the first few months of life averages 7-8 m/s.

Weller, G. and P.A. Anderson, Editors. 1999. Assessing the consequences of climate change in Alaska and the Bering Sea region. Proceedings of a Workshop, 29-30 October 1998, University of Alaska, Fairbanks, Alaska. Center for Global Change and Arctic System Research, University of Alaska, Alaska, USA.

The objectives of this interdisciplinary workshop were to assess the nature and magnitude of changes in the Alaska/Bering Sea region as a consequence of climate change; predict/assess the consequences of these changes on the physical, biological and socioeconomic systems in the region; determine the cumulative impacts of these changes on the region, including assessment of past impacts; and begin to investigate possible policy options to mitigate these cumulative impacts. The assessment covered climate-related consequences on fisheries, forestry, infrastructure, subsistence, wildlife, etc.

PAPERS PRESENTED AT A CONFERENCE HOSTED BY THE CENTRE FOR THE ECONOMICS AND MANAGEMENT OF AQUATIC RESOURCES (CEMARE) OF THE UNIVERSITY OF PORTSMOUTH, SEPTEMBER 2004.

THE PAPERS WERE SUBSEQUENTLY PUBLISHED IN THE BOOK:
HANNESSON, R., M. BARANGE AND S.F. HERRICK, EDITORS. 2006. *CLIMATE CHANGE AND THE ECONOMICS OF THE WORLD'S FISHERIES: EXAMPLES OF SMALL PELAGIC STOCKS. EDWARD ELGAR CO., CHELTENHAM, UK.*

Arnason, R. 2006. Global warming, small pelagic fisheries and risk.

Global warming leads to increased uncertainty about biomass growth, geographical location and catchability of fish stocks. This means that the risk associated with the fishing activity is increased. This is of particular relevance for fisheries based on small pelagic species, which typically exhibit extreme schooling behavior and are, consequently, more prone to collapse in the face of unduly high fishing pressure. This paper explores these issues. Among other things, it shows how global warming may increase the risk of stock collapse and how the increased risk implies even more conservative optimal harvesting policies than would otherwise be the case. The analysis is then used to throw light on some challenges facing the future management of the small pelagic fisheries of the North Atlantic.

Barange, M., R. Hannesson and S. Herrick, Jr. 2006. The economics of small pelagic fish populations and climate change: an introduction.

The workshop took place in Portsmouth, hosted by CEMARE of the University of Portsmouth, UK, quickly realized that little research had been undertaken on this topic. This could hardly be due to widespread indifference about climate change, but rather because of the great uncertainty regarding the predictability of such effects, in comparison with pressing shorter-term issues such as fishing effort controls or stock recovery plans. People could be understandably reluctant to address unpredictable events which consequences were also equally unpredictable. Yet the participants soon learned that climate change and climate variability are two sides of the same coin. Climate variability has already had major economic consequences, and the interest in dealing with it and avoiding serious economic consequences is the same that requires us to understand climate change impacts. This volume groups 10 case studies that range from historical fluctuations of Atlanto-Scandian herring and their impacts, to H126 management adaptations to possible regime shifts; from the differential consequences of pelagic fisheries collapses in Southeast Asia to the globalized nature of fishmeal markets. The case studies are complementary and yet self-standing, highlighting the need for a more coordinated assessment of impacts, and calling for more focused research. While this volume may not provide detailed solutions to global problems of growing concern, it aims to enthuse practitioners to embark on research in an area intimately linked to the sustainability of our marine resources at a time when pressures on them appear to be greater than ever.

Briones, R.M., L.R. Garces and M. Ahmed. 2006. Climate change and small pelagic fisheries in developing Asia: the economic impact on fish producers and consumers.

In developing Asia, small pelagic fisheries make a prominent contribution to the livelihoods of inshore fishers, as well as the protein consumption of poor households. However, decades of overexploitation have dramatically reduced small pelagic fish stocks in the region, which likely increases the vulnerability of these stocks to adverse climate change. Anticipating the potential welfare loss to society from climatic shock is needed to confront this threat. A supply and demand model for three Asian countries (India, the Philippines and Thailand) is applied to calculate the likely welfare loss based on climatic shock scenarios. Simulation analysis finds that consumers absorb the brunt of the welfare loss. On the producer side, the larger the relative size of the small pelagic fisheries, the greater the welfare loss inflicted on other related fisheries. The paper argues for an economic system approach to risk evaluation, analogous to the ecosystem approach to stock assessment. Several promising avenues for widening the scope of the analysis are highlighted, such as an expanded definition of social welfare, and the incorporation of biological resource dynamics.

De Oliveira, J.A.A. 2006. Long-term harvest strategies for small pelagic fisheries under regime shifts: the South African fishery for pilchard and anchovy.

Management procedures (MPs, *sensu* the International Whaling Commission) are used to evaluate long-term harvesting strategies under conditions of environmental regime change, here based on the South African purse seine fishery for pilchard (sardine) and anchovy. The MPs considered are loosely based on those currently applied, which account for between-species technical interactions. Summary statistics incorporate an economic submodel, based on actual data from the fishery, which calculates the net present value of future profits and the proportion of future years that experience zero or negative profit. Regime shifts are modelled as sinusoids and are incorporated in the functions used to generate future recruitment to the pilchard and anchovy resources. Cycles for the two species are 180° out of phase, and a range of amplitudes (from 0 to halving/doubling of recruitment) and periods (30 and 50 years) are considered. Two types of estimators are used to “track” the pilchard adult biomass, namely, a 6-year running mean, and the actual position in the cycle subject to different levels of measurement error.

The MPs considered differ according to the management action taken when the estimators show the pilchard cycle to be in a trough. These management actions include reducing anchovy catches to avoid juvenile pilchard, reducing the juvenile pilchard bycatch ratio with anchovy initially allowed, and reducing directed catches of pilchard. The MPs are compared with one another, and with a baseline MP, in which no management action based on the estimators is taken. Key results are: (i) comparing the estimators, the 6-year running mean outperforms knowledge of the actual position in the pilchard cycle in most cases. Where there are any gains for the latter, these would need to be judged against the feasibility and likely cost of obtaining the necessary information; (ii) MPs not focused on fishery-related interactions (e.g., those that reduce only the pilchard-directed catches) do not show improvements over the baseline MP. These MPs show rapid deterioration in performance as the amplitude of regime cycles increases; (iii) effective management of fishery-related interactions becomes more important for pilchard as the amplitude of regime cycles increases, to the extent that it is possible to maintain levels of average catch and profit, even though the frequency of low pilchard biomass and no-profit situations increases with increasing regime cycle amplitude.

Hamilton, L.C., O. Otterstad and H. Ögmundardóttir. 2006. Rise and fall of the herring towns: impacts of climate and human teleconnections.

The story of Siglufjörður, a north Iceland village that became the “Herring Capital of the World”, provides a case study of complex interactions between physical, biological and social systems. Siglufjörður’s natural capital - a good harbor and proximity to prime herring grounds - contributed to its development as a major fishing center during the first half of the 20th century. This herring fishery was initiated by Norwegians, but subsequently expanded by Icelanders to such an extent that the fishery, and Siglufjörður, in particular, became engines pulling the whole Icelandic economy. During the golden years of this “herring adventure,” Siglufjörður opened unprecedented new economic and social opportunities. Unfortunately, the fishing boom reflected unsustainably high catch rates. Overfishing by an international fleet was steadily reducing the huge herring stock by mid-century. Then, in the mid-1960s, large physical changes took place in the seas north of Iceland. The physical changes had ecological consequences that led to the loss of the herring’s main food supply. Severe environmental stress, combined with heavy fishing pressure, drove herring stocks toward collapse. Siglufjörður found itself first marginalized, then shut out as the herring stocks progressively vanished. Over the decades following the 1968 collapse, this former boomtown has sought alternatives for sustainable development.

Hanesson, R., S. Herrick, Jr. and M. Barange. 2006. On the consequences of climate change in pelagic fish populations: a workshop conclusion.

We have mentioned a number of research issues that were broached or were brought to the fore by the various papers given at the workshop. One of the most obvious conclusions is that much fisheries-related research is going on in various places, but little of it addresses the economic effects of climate change or climate variability. This is likely due to the great uncertainty regarding the predictability of the effects of global warming. However, global warming notwithstanding, climate variability in the ocean is, and has long been, a real issue. This variability can have, and has had, major economic consequences, and it is of major interest to deal with them and thus to avoid their most serious consequences, if possible. It is our impression that this aspect of fisheries management and economics has received too little attention. We hope that this volume will stimulate further activity along those lines.

Herrick, S. Jr., K. Hill and C. Reiss. 2006. An optimal harvest policy for the recently renewed United States Pacific sardine fishery.

In this paper, we consider the biological and economic implications of the recent resurgence of Pacific sardine in the US west coast, coastal pelagic species fishery (Pacific sardine, Pacific mackerel, jack mackerel, northern anchovy and market squid). Pacific sardine supported the largest fishery in the eastern Pacific Ocean during the 1930s and 1940s, and were taken along the coast of British Columbia, Washington, Oregon, California and Mexico, with the bulk of the catch off California. The fishery began a southward decline in the late 1940s, when landings ceased in the northwest. By the 1960s, Pacific sardine landings had fallen to extremely low levels off California, which resulted in a moratorium on its directed fishery, beginning in 1967. The collapse of the Pacific sardine fishery has been attributed to a combination of overfishing and unfavorable environmental conditions. Prior to its collapse, there was no mechanism in place to limit catches in accordance with what the resource could sustain. At the same time, ocean waters were cooling, which has been associated with lower biological productivity of sardine. Evidence of a vigorously recovering spawning biomass led California to lift its moratorium on Pacific sardine harvest in 1986, and by the 1990s, favorable biomass and environmental conditions were fueling a rapid resurgence in availability along the west coasts of the US, Mexico and Canada. In order to avoid the earlier experience off the US west coast, the US Pacific Fishery Management Council responded to this situation by instituting a fishery management plan for its coastal pelagic species fishery in 1998. Here we focus on the biological and economic aspects of the fishery management plan's domestic harvest policy for Pacific sardine, paying particular attention to the development of an environment-based harvest control rule formula, a capacity-based, fleet-limited entry programme, and efficient allocation of the US portion of the total allowable catch between traditional sectors and the rapidly developing Pacific northwest sector within the domestic fishery.

Lorentzen, T. and R. Hannesson. 2006. The collapse of the Norwegian herring fisheries in the late 1950s, 1960s and 1970s: crisis, adaptation and recovery.

This paper deals with the economic effects of the collapse of the Atlanto-Scandian and North Sea herring stocks on Norwegian fisheries. In the late 1950s, the Norwegian winter herring fishery failed, and in the 1960s, the entire stock of the Atlanto-Scandian herring collapsed. A few years later, the North Sea herring stock suffered the same fate. Prior to these events, the herring fishery was the single most important fishery in Norway in terms of employment and landings. It was particularly important in western Norway, not least in the county of Hordaland, on which this paper focuses in particular. The immediate consequence of the collapse of the herring stocks was a severe decline in income and raw material for the processing industry.

These difficulties were, however, overcome relatively quickly. The fishing fleet found substitute stocks, such as mackerel and capelin. The government took some measures for immediate employment relief, but over time, redundant fishers were absorbed into other industries, mainly the emerging petroleum and fish farming industries. The time of the herring collapse was also a time of transition to a greater specialization in the labor market. Earlier, people had combined fishing with other occupations (farming, carpentry, etc.), but specialization on a single occupation became more and more common. This is likely to have made the adjustment to the herring collapse easier. The demise of the herring stocks in the 1960s and 1970s is generally believed to have been the result of overfishing, which in turn was caused by major technological leaps (the power block, the asdic) enabling the fishing fleet to increase its catches by an order of magnitude. At the time, there was no framework in place for international fisheries management to limit catches to what the fish stocks could bear. The herring collapses did, however, coincide with a change in ocean climate, so the causal relationship may have been more complicated. The technological changes that contributed to the herring collapse also made it easier to adjust to this event; the bigger and more powerful boats could be directed to fish stocks previously only lightly exploited owing to their distance from port and other factors making them less easily accessible.

McKelvey, R., P.V. Golubtsov, G. Cripe and K. Miller. 2006. Bi-national management of a transboundary marine fishery: modeling the destabilizing impacts of erratic climatic shifts.

It is now widely understood that climatic regime shifts, which a-periodically alter a harvested fish stock's biomass and spatial distribution, may disrupt harvesting patterns in ways which negatively impact the fishery, both biologically and economically. This is particularly true for migratory transboundary stocks, where optimal management relies on cooperative understanding among independent national authorities. Unanticipated changes in stock distribution and abundance can upset expectations of national authorities, leading them to sanction destructive competitive harvesting. We and our colleagues have undertaken to analyze this situation through theoretical studies based on a spatially distributed stochastic incomplete-information model, which we have called the "split-stream model". In this survey paper we shall provide an overview of this work, examining in particular the effects of incomplete and asymmetric information, and the sometimes perverse consequences of achieving information transparency.

Mullon, C. and P. Fréon. 2006. Prototype of an integrated model of the worldwide system of small pelagic fisheries.

A bioeconomic model is currently being designed to integrate the biological and economic processes at work in the "worldwide system of small pelagic fisheries". It will allow simulations of various scenarios according to hypotheses about the impacts of climate change, effects of globalization, etc. The model integrates the dynamics of exploited stocks and their fisheries, and economic mechanisms of supply and demand in the market for fish products. Here we present a prototype of the model, relating the dynamics of 12 marine areas, 15 regional fisheries and 40 markets for fish products. The dynamics are modelled in a conventional way, using production models, and including climate effects. Markets are characterized by supply/demand functions. Fishing effort is distributed among various areas, and the yield among markets to maximize income. The goal of this modeling approach is to support negotiations between stakeholders, specifically fisheries managers, fishers and fishery biologists. The model is designed to be used in game-playing role sessions.

Sumaila, U.R. and K. Stephanus. 2006. Declines in Namibia's pilchard catch: the reasons and consequences.

The annual catch of Namibian pilchard declined from a peak of about 1.4 million tonnes (official statistics) in 1968 to the current annual catch of less than 20 000 tonnes. Two key reasons have been advanced in the literature for the decline, overfishing and an adverse environment. This contribution explores further the possible reasons for the decline, and explains what happened to the fish, the fishers, the processing sector and the fishing fleet targeting pilchard after the steep declines in catches over the past half century. Finally, it explores whether the collapse can be considered the consequence of economic overfishing.

ABSTRACTS OF PAPERS PRESENTED AT THE WORKSHOP ON ECONOMIC EFFECTS OF CLIMATE CHANGE ON FISHERIES, 20-21 JUNE 2005, BERGEN, NORWAY. THESE ABSTRACTS AND THE PAPERS THEY REPRESENT ARE IN DRAFT FORM AND ARE NOT YET FOR CITATION.

Arnason, R. Climate change and fisheries: assessing the economic impact in Iceland and Greenland.

Climate changes in the 21st century are expected to significantly increase ocean temperatures and modify other oceanographic conditions in the North Atlantic. Fisheries biological predictions suggest that the impacts on the commercially most important fish stocks in the Icelandic-Greenland ecosystem may well be quite substantial. Obviously, there will be a commensurate impact on the economies of these two countries. However, the timing, extent and biological impact of global warming is quite uncertain. As a result, the economic impact is similarly uncertain.

This paper attempts to provide estimates of this impact on the Icelandic and Greenland economies. The approach is one of stochastic simulations, which involves essentially three steps: The first step is to obtain predictions of the impact of global warming on fish stocks and, even more importantly, a probability distribution for that prediction. The second step is to estimate the role of the fisheries sector in the two economies. This is done with the help of modern econometric techniques based on standard economic growth theory and historical data. Obviously these estimates are also subject to stochastic errors and uncertainty. The third step is to carry out Monte Carlo simulations on the basis of the above model and the associated uncertainties. The result of the Monte Carlo simulations consists of a set of dynamic paths for gross domestic product (GDP) over time with some expected value and distribution in each future year. On this basis, it is possible to calculate confidence intervals for the most likely path of GDP over time. Preliminary results indicate that the fisheries impact of global warming on the Icelandic GDP is more likely to be positive rather than negative and unlikely to be substantial compared to historically experienced growth rates and fluctuations. The uncertainty of that prediction, however, is large. For Greenland, the impact on fish stocks and the GDP is highly likely to be positive and quite substantial relative to the current GDP. Due to less knowledge of the relationship between the fisheries sector and the Greenland economy, however, the confidence interval of this prediction is even wider than in the case of Iceland.

Ben-Yami, M. Commercial and socio-economic consequences of a minor climate shift in the Levant Basin.

The description of the present history case required transdisciplinary study integrating fisheries ecology, catch and environmental data, and historical information on the economical and operational dynamics of the Israeli trawl fishery of half-a-century ago (Ben-Yami and Glaser 1974; Porat 1996; Ben-Yami 2005). The term “fisheries ecology” is understood here as the discipline that studies fishery ecosystems in which interact fish, fishers and environment. Transdisciplinary research in fisheries ecology enables understanding of the causalities of biological changes in marine ecosystems. In some cases, such changes may be viewed as indicators of environmental processes in the system (Sharp 2003). Stergiou et al. (2003) propose that records of employment in the fishing industry, production of canned tuna or fat-content in sardines (which indicates their planktonic food availability), might render information on the state of the environment in the Mediterranean, while Ben-Yami and Glaser (op cit.) consider variations in important commercial fish populations, reflected in catches of multispecies fisheries, as significant indicators of changes occurring in the ecosystem. In fisheries, extension of transdisciplinary studies into the socioeconomic realm may explain impacts of past environmental shifts and fluctuations on the economies of fisheries and fishery-related services, industries and commerce, and associated social processes, and perhaps offer indications for the future. Similarly, past case histories of economic boom-and-bust in some fisheries could help in learning the chronology and character of environmental fluctuations. In the mid-1950s, as a young skipper trawling in the Levant Basin, I witnessed a climatic anomaly and a major change in the composition of trawl catches. I drew the attention of scientists at the Haifa Sea Fisheries Research Station (SFRS) to my observations and the SFRS Director, O.H. Oren immediately employed me for 10 days to describe them. The result was an article in the (Hebrew) Fishermen’s Bulletin (Ben-Yami 1954), and two decades later, a major follow-up study (Ben-Yami and Glaser 1974). The present paper leans heavily on both, as far as fishing and environmental data are concerned. When it comes, however, to economic and social effects that occurred half-a-century ago, I must rely on my own and my colleagues’ memory, and on a historical book on the fishery in my country (Porat, op cit).

Brandt, U.R. Entry deterrence or conservation in a fishery model as a policy contest: the effect of climate change on the probability of conservation.

The paper considers a policy outcome as a result of a policy contest between two opposing interest groups: the incumbent fishers and the group of conservationalists. The objective of the fishermen is to reduce future profitability in order to reduce entry by inflating current catches, while the conservationalists with the aim to reduce current fishing effort in order to protect the fish resource. The probability of the policy resulting in overfishing is dependent on the relative benefits the two groups receive if their preferred policy wins the contest. This model enables us to predict how climate change-induced changes in the underlying bionomic model affect the probability of overfishing.

Eide, A. Economic impacts of global warming: the case of the Barents Sea fisheries.

Regional analyses of possible physical and biological effects of global warming in the Barents Sea area have recently been covered out. Based on such studies, economic impacts of global warming on the Barents Sea fisheries have been quantified for a range of different management regimes. The ecosystem model AggMult and the fleet model EconMult, covering the Norwegian fisheries, have been parameterized according to the findings from studies on regional changes in oceanographic parameters and primary production pattern. Global warming scenarios are simulated by running the EconSimp2000 model which is the joint model of AggMult and EconMult. The current environmental situation, including normal seasonal and other variations, has been used as a zero scenario. A range of biological and economic indicators have been employed in order to evaluate simulations performed under the two environmental scenarios. The findings of this study support earlier findings where economic impacts of relatively small changes in management regimes are found to be more pronounced than the economic impacts from physical, biological and economic changes caused by global warming.

Esmaeili, A. Impacts of climate change on commercial fish stocks in Iran.

Around 50% of 380,000 t fish landings in Iran come from the Northern Persian Gulf. This amount of fish is captured by 108,000 fishermen and 8,900 fishing fleets. The fish stocks in the region are very important for the Iranian economy. The major problems facing Iranian fisheries are uncertain availability of fish and overfishing. The Persian Gulf, as one of the sensitive marine ecosystems, is a partially closed sea of salty water with an average depth of 35 m. Replacement of waters in the Persian Gulf takes place every 3-5 years. Climate change has major effects on fish stocks in such sensitive ecosystems. Many researchers have mentioned the influence of climate parameters on fish stocks (Walters 1990; Caputi 1993; Hansen et al. 1998; Daskalov 1999; Carseadden et al. 2000; Arnason 2003; Esmaeili and Omar 2003; Byrne et al. 2004; Hannesson 2004). The present study attempts to test the influence of climate change on fish stocks in the Persian Gulf and to determine the minimum sustainable yields for fisheries management. Climate parameters, including temperature, rainfall, wind and sea level pressure, are used in this study. Multivariate panel data and surplus production bioeconomic models with climate parameters are used for determination of optimal harvest and forecasting. It was found that climate parameters had significant effects on fish stocks. The management implication of this study is that the fisheries should be managed based on climate parameters in the Persian Gulf.

Gallagher, C. Variable abundance and fishery movements in New Zealand squid fisheries.

The variable nature of squid abundance translates into fishery movements that span regions and oceans as a result of changes in climate conditions. Fishery institutions vie to understand and predict squid abundance to achieve fishery stability. Fishery management organizations strive to predict squid abundance and allow either greater fishing opportunities or resource protection. This paper reviews recent squid fishery participation in New Zealand as a result of changes in oceanic conditions and develops a preliminary model to investigate the economic effect of global and regional fishery movements. Squid trawl and jig fishery movements for *Notodarus gouldi* and *N. sloanii* reveal the importance of examining changing conditions from environmental and economic forcing.

Golubtsov, P and R. McKelvey. The incomplete-information split-stream fish war: examining the implications of competing risks and differing attitudes toward risk.

It is now widely understood that climatic regime-shifts, which periodically alter a harvested fish stock's biomass and spatial distribution, may disrupt harvesting patterns in ways which negatively impact the fishery, both biologically and economically. This is particularly true for migratory transboundary stocks, where optimal management relies on cooperative understanding among independent national authorities. Unanticipated changes in stock distribution and abundance can upset expectations of national authorities, leading them to sanction destructive competitive harvesting. In particular, we and our colleagues have been analyzing the situation where two independently managed fleets compete, at different times and in different places, for harvest of the same breeding fish stock. Our theoretical studies are based on a spatially distributed stochastic model, which we have called the "split-stream model".

In this paper we examine the effects of incomplete and asymmetric information, introducing a more complex (but perhaps more natural) information structure than had been assumed in our earlier work. Now both stock-growth and stock-split parameters vary stochastically and asynchronously. Furthermore, the two fleets' knowledge levels may be asymmetric, and their attitudes toward risk may differ. As before, our emphasis will be on comparing differing knowledge structures, and noting the sometimes perverse consequences of enhancing information transparency.

Hannesson, R. 2005. Global warming and fish migrations. Also published as Institute for Research in Economics and Business Administration, SNF Working Paper No. 01/05. Institute for Research in Economics and Business Administration, Bergen, Norway.

Ocean temperatures are expected to rise over the next decades. This is likely to affect the distribution of fish stocks between the exclusive economic zones (EEZs) of different countries. Such changes are likely to be triggered as temperature rise beyond certain threshold levels, and they are likely to be irregular because temperature changes would displace a fish stock out of the EEZ of one country and into the EEZ of another, with a transition period in which the stock is shared. It is examined how this might affect the risk of extinction and degree of overfishing, under different cost scenarios and different assumptions about how countries react to observed changes in the distribution of the stock between their economic zones.

Herrick, S. and J. Norton. Environmental and economic influences on California fish and invertebrate landings.

Interactions between landing weights, ex-vessel value of landings and physical environment will be examined using empirical orthogonal function (EOF) techniques. This study extends investigations that used EOF analysis of the California commercial fish and invertebrate landings data (CACom) to find patterns of variability describing major changes in CACom species composition from 1930 through 2000. Temporal variations in the first two EOFs (principal components), accounting for more than 45% of the temporal variability of the landings, are closely correlated to Pacific Basin-scale physical processes. These relationships suggest that major changes in CACom species composition begin as basin-scale processes that are transmitted throughout the California Current ecosystem to harvested species with predictable economic results. Significant opportunities for proactive fisheries management would result from identifying consistent temporal associations between recurring physical-environmental and climatic phenomena, and the availability of species groups of economic consequence. In turn, this could greatly reduce the adverse impacts of changes in species availability on existing economic and social systems.

Kaje, J.H. and D. Huppert. Evaluating climate forecast value in fishery management: an application to the coho salmon *(Oncorhynchus kisutch)* fishery in Washington State.

Over the course of the past 20 years, our understanding of the intricate connections between climate variability and climate change, marine and freshwater environmental conditions, and biotic responses of fish stocks has improved considerably. If these efforts bear fruit in the form of predictable relationships between the environment and stock abundance, the ability of fishery managers to forecast variation in stock survival and recruitment should also improve. Utilization of such forecasts presents an opportunity for increasing the economic value of fisheries, and for achieving other management objectives, such as stock conservation and maintenance of population diversity.

In Part 1 of this paper, we outline a method to evaluate forecast value that is broadly applicable in a variety of fishery (and non-fishery) contexts. This provides a step-by-step framework for answering the question "What is a forecast worth?" in a particular decision-making context. Alternatively, the same framework can be used to guide the identification of data collection and modelling priorities, as well as the development of management strategies that enable forecasts to be utilized in ways that produce value. Part 2 of the paper describes the application of the framework and an associated bioeconomic model to estimate the value of forecasting run sizes in the annual harvest management of coho salmon *(Oncorhynchus kisutch)* in Washington State. Our modelling approach applies a primarily descriptive rather than prescriptive approach to forecast valuation. Prescriptive models seek to produce decisions that are optimal according to some normative theory of decision-making (e.g., Bayesian utility maximization). Descriptive models, on the other hand, attempt to mimic the behavior of decision-makers in a particular decision-making context (Stewart 1997) by incorporating existing decision rules and institutional constraints. We conclude with a discussion of opportunities and constraints to the use of forecasts in fishery management on various spatial and temporal scales, and we consider the challenges associated with forecasting patterns of climate (and fishery) variability in contrast to those unique to the consideration of human-induced climate change.

Krishnan, M. and S. Ayyappan. Economic effects of climatic changes on fisheries in India.

Sugunan and Maurye (2003) find emerging evidences that indicate most of the changes in climate will have impacts on water temperature, hydrological regimes and biological traits of animals and plants. The research efforts needed in the case of fisheries pertain to:

- assessment in terms of marine, estuarine, riverine ecosystems' responses to global warming with a view to evolving conservation norms for fish germplasm;
- strategies to be evolved for dealing with decreased water availability for freshwater aquaculture and brackishwater aquaculture;
- resolving possible accentuation of conflicts in sharing the already scarce water among fisheries and nonfisheries sectors;
- assessment of impact on coldwater fishes in individual and population level;
- basic research on physiological aspects of fish behavior with special reference to feeding metabolism, reproduction, muscle function, cardiac function, toxicity and biochemical genetics aspects; and
- assessment of any adverse effect of already introduced exotic species in the event of global climatic changes affecting indigenous fish species.

The observed experiences of Indian fisheries resulting from El Niño-southern oscillation events need to be studied in depth. It is to be determined by means of a detailed study if the climate change has had a positive or a negative effect on landings. If so how do the movements of prices of fish landed respond in both the domestic and international markets? Similarly, it is also important to understand if changes in shrimp yield resulting from climate changes can lead to a comparative national advantage or disadvantage. The fact remains that fisheries play a key role in providing livelihood for the socially and economically deprived sections of the coastal communities. It is very important to make a comprehensive scientific assessment of the possible changes in their income and consumption pattern resulting from changes in fisheries consequent to climate change.

McGoodwin, J.R. Effects of climatic variability on fishing economies in high-latitude regions: implications for fisheries policies.

Research exploring how climatic variability affects local fishing economies was conducted in south-central Iceland during 2001, 2002 and 2003, and in southwest Alaska during 2003 and 2004. Many scientists believe the impacts of global warming and climatic change will be especially severe in high-latitude regions, and while long-term forecasts remain difficult to make, climatic variability is already well-documented. The high-latitude communities explored in this study were chosen because collectively they comprise a broad spectrum of social, cultural and economic diversity. The fishing community in Iceland is fully modern and produces seafood entirely for commercial-export markets, whereas in southwest Alaska there are two principal fishing communities: one that is fully modern and produces salmon entirely for commercial-export markets, the other a traditional native subsistence economy in which salmon is the main dietary staple. Important differences were found regarding the economic impacts of climatic variations in the commercial economies in Iceland and Alaska, versus in the native Alaskan subsistence economies. Overall, the commercially inclined economies in both regions seem less resilient to ordinary climatic variability. Moreover, both are importantly influenced by fluctuations in global fish markets that are prompted by climatic variations taking place in places that are geographically very distant from them. The native subsistence-oriented economies, on the other hand, are less vulnerable to ordinary climatic variability and little influenced by world fish prices. But, like their modern-commercial counterparts, they too would likely be catastrophically impacted by longer-term climatic and ecological changes. Overall, a better understanding of how climatic variability affects various types of fishing economies in high-latitude regions should help to inform the development of more sustainable fisheries policies in these regions – which already may be experiencing radical climatic and ecological changes.

Meynecke, J.O. Effect of climate change on estuarine fish production in Queensland, Australia: evaluating potential economic losses.

Over the last century, average temperatures have risen by 0.7ºC. Climate variability has increased with a tendency towards extreme weather events and the sea level has risen by up to 8 cm per decade. For years, there has been speculation that climate change effects may impact on sustained fish production indicating a need to place monetary value on these effects to demonstrate their importance. With a gross annual value of A$2.2 billion, the fish industry is a significant primary industry in Australia, and the value of estuaries, in particular, is estimated at A$39,000/ha/year. Many commercially important fish species use estuarine habitats, such as mangroves, tidal flats and seagrass beds, as nurseries or breeding grounds and have life cycles bound to rainfall and temperature. Correlation of catches of banana prawns *(Penaeus merguiensis)* and barramundi *(Lates calcarifer)* with rainfall suggests that fisheries may be sensitive to affects of climate change on rainfall. This work identifies and synthesizes ecological and biophysical links of estuarine habitats that influence capture fisheries production. Fish and crustacean species associated with estuaries and their dependence on this system and climate factors are reviewed. A conceptual model demonstrates the projected relationships between climate change, tidal wetland loss and fish production. The difficulty involved in placing a monetary value on climate factors and estuarine habitats because of the lack of ecological knowledge may be overcome by relating them with long-term fish catch data. A regional economic value for these drivers is created. This approach allows evaluation of economic values of potential losses, thus highlighting the need to identify and manage estuaries for climate change effects.

Miller, K. Climate variability and highly migratory fish stocks: challenges for tropical tuna management.

It has long been recognized that competitive harvesting of internationally shared fishery resources tends to dissipate the potential economic value of the resources and often results in biological depletion of the stocks and related environmental damage. Efforts to avoid these unwelcome outcomes have driven major recent developments in the body of international law governing marine resources, including transboundary fishery resources. In particular, the 1995 United Nations Fish Stocks Agreement has provided an international legal framework for creating regional fishery management organizations (RFMOs) to govern harvests of straddling and highly migratory fish stocks. The stability and success of these organizations will depend, in part, on how effectively they can maintain member nations' incentives to cooperate despite the uncertainties and shifting opportunities that may result from large climate-driven changes in the productivity or migratory behavior of the fish stocks governed by the agreement. This paper surveys the current state of scientific understanding regarding the impacts of climate variability on several commercially important shared fish stocks, including ongoing efforts to understand the climate-driven dynamics of tropical tuna stocks. Next, the paper outlines previous case studies that highlight the management problems posed by the effects of climate variability. In these cases, limited understanding and poor predictability of the biological impacts contributed to the dysfunction or breakdown of existing cooperative management arrangements. The paper then turns to a comparative analysis of the climate/fishery/management situation facing the new RFMOs that have been established to govern rapidly developing tropical tuna fisheries in the Western and Central Pacific and Indian Oceans. The significant role of distant water fishing nations (DWFNs) in harvesting these stocks creates an incentive structure that is quite different from the previously described cases. The paper explores these differences and their possible implications for the design of effective governance arrangements in the presence of climate-driven variability in the productivity and behavior of the tuna stocks.

Njaya, F. Economic impact of climatic change on fish production from shallow lakes: case of Lake Chilwa.

Lake Chilwa is one of the highly productive shallow lakes in Africa with an estimated productivity of 159 kg/ha. Being declared a Ramsar site, the management of the fisheries and other natural resources in the wetland area calls for participation of the surrounding community. The previous valuation of the fishery in 1999 was estimated at around US$8 million per year and reaches around US$17 million when the valuation includes other natural resources such as birds. The main challenge lies on the seasonal and periodic fluctuations of water levels. With continued drought of five years, the lake dries up as was the case in 1968, 1973 and 1995. The livelihoods of the fishing community of about 10,000 fishers and many fish traders including women become threatened. It is recommended to seek other livelihood strategies so that economic dependence of the fisherfolk on the wetland is sustained by switching from fishing to other alternative income-generating activities.

Perry, I and U.R. Sumaila. Marine ecosystem variability and human community responses: the case of Ghana, West Africa.

We describe in this paper the variability in the marine ecosystem of Ghana, West Africa, over the last decades, and discuss how the human communities using this ecosystem and the resources it holds have responded to these changes in order to cope both socially and economically. The Gulf of Guinea marine ecosystem, of which the Ghanaian ecosystem is a part, consists of an upwelling system with strong seasonal and interannual environmental variability. In the pre-1972 period, sea-surface temperature (SST) declined and the SST was low. From 1972 to 1982, the SST and sea-bottom temperature were below average with relatively high salinity. After 1982, the sea temperatures were high with low salinity. This environmental variability coupled with the impacts of fishing meant that the abundance of fishery resources in Ghanaian waters also varied significantly over this period. As would be expected, fishers in Ghana have had to device coping strategies to deal with this variability. Coping strategies include: (i) ensuring multiple income sources; (ii) using flexible and diverse fishing practices; (iii) engaging in seasonal and permanent migrations, sometimes outside the country; and (iv) diversifying their protein sources, e.g., by hunting bush meat. In addition, the national government resorts to the importation of fish into the country to deal with shortages.

Schrank, W.E. The ACIA, climate change and fisheries.

The Arctic Climate Impact Assessment (ACIA) is a project of the Intergovernmental Arctic Council, intended to synthesize knowledge of the effects of climate change on the Arctic. This paper is based on the yet to be published scientific document that will be the primary output of the ACIA Project. Our concern is with the effects of Arctic climate change on fisheries. To set the stage, however, we first discuss those chapters that logically precede the fisheries discussion, the chapters on past and present climate change, climate modelling and marine systems. The conclusion notes that moderate climate warming will probably benefit most Arctic fisheries and considers the role of anthropogenic causation in climate change and its policy implications.

Sigurdsson, T. The collapse of the Atlanto-Scandian herring fishery: effects on the Icelandic economy.

Fishing for herring has a long history in northern Europe. For centuries, this fish was a staple food and commercial product with a widespread distribution net. The traditional fishing grounds were in the Baltic, the North Sea, around Iceland and along the shores of Scandinavia and Russia to the White Sea, finally extending far into the high seas of the North Atlantic Ocean. After 1950, the fishery developed rapidly because of a new technology: sonar, power block, larger purse seine nets and bigger boats. As a result, all major herring stocks in the Northeast Atlantic collapsed. The most dramatic decline was that of the Atlanto-Scandian stock (mostly Norwegian spring spawners) in the ocean between Iceland and Norway from millions of tons to the border of extinction in a decade. It was one of the largest fish stocks in the world until the fishery crashed in the late 1960s. The catch in 1971 was only 20 thousand mt in contrast with the record of 2 million mt in 1966, and the spawning stock declined from 10 million mt to 10 thousand mt in 20 years. After 25 years of almost no fishing, the stock finally recovered.

With hindsight the cause of this disaster was a combination of biological, technological, economical and ecological factors, but the most important one was the cooling of the East-Icelandic current which was one aspect of a global climatic change in this part of the world during the period 1965-2000. Despite the optimism of marine biologists this development was predictable by a simple time-series model: $S = AeBt [1 + Csin(Dt)]$. After statistical estimation of the parameters A, B, C, D and extrapolation of the stock S from measured data the herring was doomed at least five years before the collapse was realized. Whether it could have been prevented is an open question, however, because at that time there was no fisheries management authority to limit either catch or effort. This is a classic case of an unstable open-access equilibrium in a stock-effort phase diagram. The sudden closure of the fishery was a shock to many communities in Norway and Iceland. The Icelandic economy was especially vulnerable because salting and reduction of herring was for many years the biggest export industry in the country, sometimes exceeding 40% of the total, and a source of wealth that trickled down the society. We will first demonstrate some macroeconomic quantities before and after the collapse and then take a closer microeconomic look at some of the communities that based their existence on the herring fishery. Finally we will describe the recovery when other species, e.g. shrimp and capelin, replaced the herring and other industries diversified the economy.

Torres, J.P. El Niño's effects, recruitment and risk versus harvest trade off: the Chilean jack mackerel fishery.

This paper develops a modeling structure to perform quantitative analysis of tradeoffs between expected yearly catch and risk of fishing collapse, considering different (exogenous) harvest strategies. The analysis is based on the Chilean jack mackerel fishery. An ordinary least squares (OLS) estimation of a Ricker recruitment function is performed, controlling for effects from El Niño episodes. Then we estimate a sinusoidal generating function for replicating a cyclical occurrence of El Niño episodes. Next we introduce numerically simulated random shocks which hit linearly the recruitment function and also the generating function of the El Niño phenomenon. Combining the previous modelling with an age-structured biological growth model, we obtain biomass and annual catch yield projections, considering a 20-year planning horizon. The numerically simulated randomness, embedded in the recruitment function, allows us to calculate probabilities of facing fishing collapse, the latter being defined accordingly to ad hoc policy criteria.

This bibliography provides a collection of key references and online documents from 1966 to 2006 on the economic effects of climate change on fisheries. It is aimed towards information generation, analysis and dissemination, and facilitating the identification of research needs and priorities since ultimately, the sustainability of fish stocks and coastal communities will depend on how well these resources are managed. The current collection reflects the thrust of past research which has focused largely on temperate and developed areas, since studies focusing on developing countries/regions in the tropics are fewer and more recent. Some biological, meteorological and oceanographic sources are included where they have been used extensively as background to economic studies.

This bibliography was compiled by Ann Shriver of the International Institute of Fisheries Economics and Trade (IIFET) in collaboration with the staff of The WorldFish Center under the direction of Dr. Mahfuzuddin Ahmed. It was compiled for distribution at the Consultation on the Impact of Global Climate Change on Aquatic Resources, Food and Income Security of Fishing-dependent Populations, jointly organized by The WorldFish Center and the United States National Marine Fisheries Service Southwest Regional Office (San Diego, California), held on 24 and 25 August 2005. The printed document you are now reading includes the collection of references as of early May 2006; however, the collection continues to grow and is regularly updated on the internet, at www.oneFish.org, in the IIFET "Virtual Office". Authors of relevant new economic studies are encouraged to submit them for inclusion in the online collection.

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