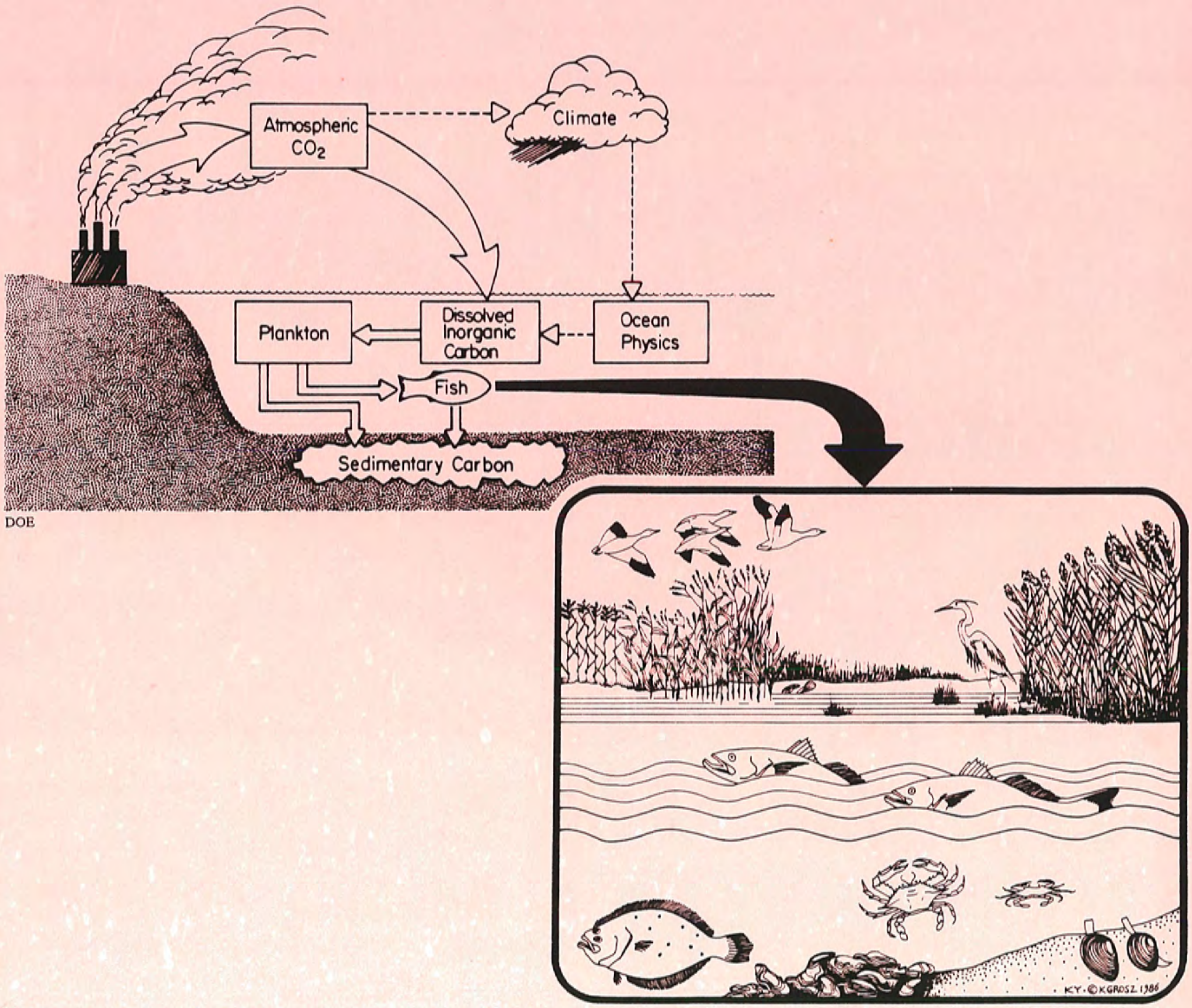
Report
of the
Climate and Fisheries Workshop

7-9 June 1989 • Boulder, CO



ESIG/NCAR • OPPE/EPA • NMFS/NOAA

REPORT

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CLIMATE & FISHERIES WORKSHOP

7–9 June 1989, Boulder, CO

The Workshop was sponsored by the Environmental and Societal Impacts Group of the National Center for Atmospheric Research,* the Office of Policy, Planning, and Evaluation of the Environmental Protection Agency, and the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration. The Workshop was organized by Michael H. Glantz. Lucy Feingold is the project's research assistant. Martin Price served as rapporteur and Maria Krenz provided administrative support.

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* The National Center for Atmospheric Research is operated by the University Corporation for Atmospheric Research under the sponsorship of the National Science Foundation.

Agenda

NCAR/EPA/NOAA Climate and Fisheries Project

7–9 June 1989

Tuesday, 6 June

ARRIVAL – Golden Buff Motel

Wednesday, 7 June

8:45 a.m. Welcome to meeting – M. Glantz, ESIG/NCAR
Brief introduction by participants

9:30–10:00 Global Change and Climate Change: An Overview
Michel Verstraete, Office for Interdisciplinary Earth Studies
(*15-minute presentation; 15-minute discussion*)

10:00–10:30 Break

10:30–11:00 The Statistics of Climate Change
Richard Katz (ESIG/NCAR)

11:00–12:15 Historical Overviews: Session I
Bering Sea Crab – Warren Wooster
Institute of Marine Studies, University of Washington
Peruvian Anchoveta/Chilean Sardine – César Caviedes
Department of Geography, University of Florida
Great Lakes Sea Lamprey – Henry Regier
Deparment of Zoology, University of Toronto
Icelandic Cod Wars – Michael Glantz (ESIG/NCAR)
(*15-minute presentations; 15-minute general discussion*)

12:15–1:30 Lunch

1:30–2:30 Historical Overviews: Session II
Indian Ocean Tuna – Gary Sharp
Center for Ocean Analysis and Prediction
East Coast (US) Menhaden – Lucy Feingold (ESIG/NCAR)
California Sardine – Alec MacCall and Ed Ueber
National Marine Fisheries Service
Pacific Sardine – Tsuyoshi Kawasaki
Faculty of Agriculture, Tohoku University

2:30–2:45 Break

2:45–3:45 Historical Overviews: Session III
Pacific Northwest Salmon – Kathleen Miller (ESIG/NCAR) and David Fluharty
Institute for Marine Studies, University of Washington
Gulf of Mexico Shrimp – Richard Condrey
Coastal Fisheries Institution, Louisiana State University
Northwest Atlantic Flounder – Wendy Gabriel
National Marine Fisheries Service/Woods Hole

3:45–4:00 Break

4:00–4:30 Brief Summaries of Historical Overviews (authors not present)
(Presented by Michael Glantz)
Polish Long-Distance Trawlers – Russek
Maine Lobster; Atlantic Herring – Acheson
Norwegian Sea Herring – Steele
Mexican Oysters and Severe Storms – McGoodwin

Thursday, 8 June

7:00 a.m. Breakfast at Chautauqua (optional)
(Informal discussion among participants)

9:30–11:00 Open discussion of limitations and contributions of scenario use for improved understanding of the regional aspects of a CO_2-induced global warming

11:00–12:00 Identification of 2 or 3 common questions that each paper should address to preserve a common theme

12:00–1:00 Lunch

1:00–2:30 (a) What changes might we expect for the marine environment from a global warming?
(b) How can we detect the impacts of a global atmospheric warming in the marine environment?

2:30–4:30 Discussions with NCAR/CU scientists

7:00 p.m. Group Dinner

Friday, 9 June

8:45–9:30 a.m. Second thoughts and new thoughts on the project

9:30–10:15 Discussion (Substantive aspects of publication of Working Group's results and subsequent papers: EPA/NOAA report, book?
Public summary report?
Should any cases be added?)

10:15–10:30 Break

10:30–11:30 Discussion (administrative aspects) of publications:
Content, format, schedule, etc.

11:45 a.m. ADJOURN

List of Participants

CLIMATE AND FISHERIES PROJECT

7–9 June 1989

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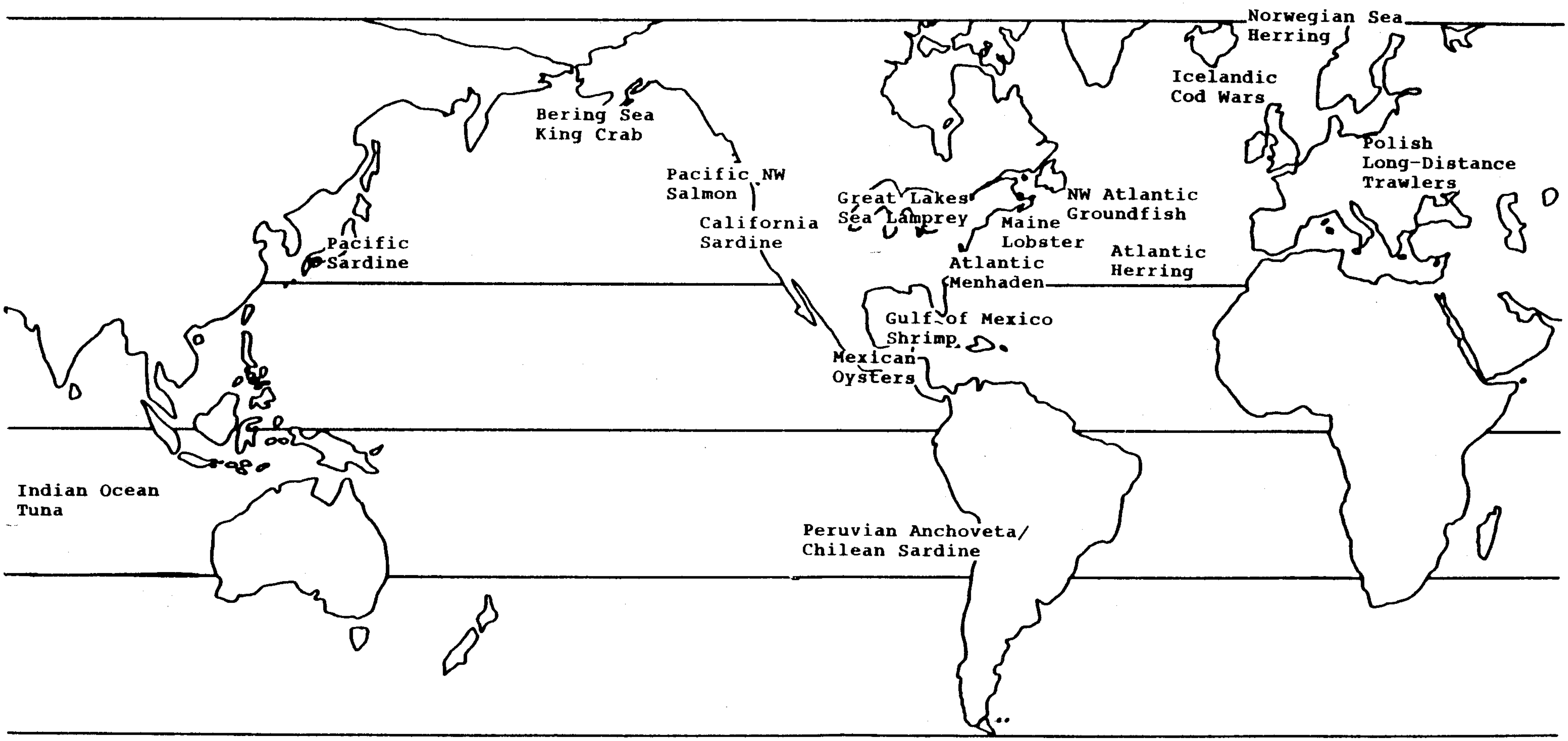
* = Participating in project but unable to attend workshop

Location of Fisheries Case Studies



Workshop Summary

7 JUNE: INTRODUCTION

1. Forecasting by analogy

Michael Glantz (Environmental and Societal Impacts Group [ESIG], NCAR) opened the workshop by welcoming everyone and acknowledged the support of EPA's Office of Policy, Planning and Evaluation, NOAA's National Marine Fisheries Service (NMFS), and the National Science Foundation (through NCAR). He noted that interest in the potential impacts of a global climate change is presently very high, both among scientists and policymakers. It appears that a global climate change could manifest itself as a change in variability, as well as a change in the frequency, intensity, duration, and location of extreme meteorological events. However, the projections of region-specific impacts are highly uncertain. In order to understand how societies might respond to the regional impacts of a global climate change, it is important to know how societies deal with present-day climate (its mean state, its variability, and its extremes). It has been suggested that if the climate is changing, the climate of the future will not be like climates of the past. However, it might be argued that societies change slowly (barring external shocks) and that societal (i.e., institutional) responses to regional extreme events in the future will most likely be similar to those in the recent past. Thus, assessments of regional responses to recent extreme meteorological events can provide insights into how well societies have coped with these impacts and how they might impove their abilities to respond to the possible impacts of a changed climate. This approach can be referred to as forecasting by analogy, that is, forecasting society's ability to cope with the impacts of extreme meteorological events some time in the future.

Glantz noted that the "forecasting by analogy" project is a two-stage process. The first stage, based on case studies, assesses past societal abilities to cope with drastic changes in resource abundance, availability, and distribution arising from environmental variability and extremes (whatever their source) and their impacts on resource availability and distribution. The second stage involves analyzing this experience in order to assess ways to improve societal abilities to cope with future climate-related environmental changes. ESIG has already completed a similar study for EPA on land-based resources; this project extends the approach to living marine and freshwater resources.

"Forecasting by analogy" is an alternative approach to assessing society's abilities to deal with climatic change. It complements the popular approach of developing scenarios based on outputs from General Circulation Models (GCMs). GCMs are useful as heuristic devices, enabling the construction of plausible scenarios about climate change impacts on ecological systems. The output of GCMs provides a set of plausible circumstances and is not to be taken as a prediction. However, for societal impact assessment, a finer resolution may be required for improving the credibility and utility of regional societal impact assessments. Also, while studies based on different GCMs seem to agree that there will be an increase in temperature as a result of increasing greenhouse gases in the atmosphere, they differ considerably in their prediction of regional changes in the hydrological cycle. Gary Sharp (NOAA Center for Ocean Analysis and Prediction) pointed out that GCM ocean-related outputs tend to use information only on sea surface temperatures, and that these usually show little seasonal change and are generalized over large areas. Given the importance of the ocean in transfers of energy from low to high latitudes and via large-scale circulation and their dynamics, this is not an adequate utilization of oceanographic information.

2: Global and climate change, oceans, and fisheries

Michel Verstraete (Office of Interdisciplinary Earth Studies, UCAR) outlined some of the major issues of "global change": ozone depletion, desertification, deforestation, air pollution, acid rain, population increase, and climatic change. These issues are all linked to the activities of human populations and the processes of the climate system. The concept of climatology has been changing in recent years; climate is now regarded as a very complex system, including many interacting components (atmosphere, oceans, ice, biosphere, etc.). Such interactions can be represented in terms of cycles of mass, momentum, and energy through the system. The hydrological and carbon cycles are particularly important to an improved understanding of the role of the oceans in the climate system.

Many of these components are changing; for instance, the chemical composition of the atmosphere has been drastically affected by human activities and there is increasing evidence that the global average temperature is increasing. Other relevant issues important to climate change are species extinction, environmental degradation, and changes in ecosystem productivity. It is important to recognize that many of these parameters would change somewhat in the absence of human activities, albeit at a slower rate; the influence of human activities must therefore be differentiated from that of natural processes. Evidence for anthropogenic changes includes increases in atmospheric carbon dioxide and methane concentrations in the atmosphere and the apparent global temperature rise since the mid-nineteenth century. However, there is much debate on the possible linkages between these trends. This important question will require analysis of data collected by remote sensing and ground observations, as well as the development and use of sophisticated climate models. In discussion, Sharp mentioned that a critical need with respect to GCMs and ocean models is to incorporate historical and proxy climate data and to use these to develop more responsive models and outputs and thereby develop improved forecasts. The critical outputs will be those which increase our understanding of the consequences of climate variability and change on local and regional scales.

Oceans affect the climate system significantly. Indeed, the climate is driven by the meridional heat transport; and the atmosphere and oceans transport approximately equal amounts of heat poleward. Oceans are also the major source of water for the hydrological cycle, and store a large fraction of the earth's carbon. The ability of the ocean to absorb carbon dioxide is strongly temperature-dependent. Chemicals emitted by oceanic organisms, e.g., dimethyl sulfide, may affect aerosol formation and thus cloud formation and the absorption of solar radiation by terrestrial and marine systems. It has been suggested that this process might reduce the air temperature increase expected from the greenhouse effect.

The oceans are also affected by the climate. Oceanic circulation, both horizontal and vertical, is largely wind-driven. Since oceanic productivity is generally nutrient-limited, changes in atmospheric wind and temperature patterns, which affect the location and intensity of oceanic upwelling, can alter the availability of nutrients. Climate change may also affect sea level, leading to changes in oceanic circulation and nutrient availability to living marine resources.

3. Climate models and statistics

Rick Katz (ESIG/NCAR) discussed climate modeling and related statistical issues. The main intended use of GCMs is to aid in fundamental research on the atmosphere, rather than provide information useful for assessing societal impacts. The treatment by these models of hydrological processes, air-sea interaction, or oceanic circulation is, at present, not very realistic. While some models, for example, have been able to reproduce El Niño-Southern Oscillation (ENSO)-like behavior, there is little consensus on the likely direction of changes in ENSO frequency. Although there is agreement that the global climate has warmed over the last century, whether one can attribute climate change to greenhouse gases depends very much on one's faith in the GCMs. In particular, there is agreement that the "fingerprint" of global warming has not yet been detected. ENSO events might be used as a covariate in detecting climate change, since they are connected to anomalies in global climate.

One of the critical issues of the impacts of climate change concerns changes in climatic variability and the frequency of extreme events. Climate models are unlikely to be able to provide such information, especially because extreme events are hard to detect in the results and because overall variability is not reproduced well by the models. Sharp pointed out that the forcing events leading to significant climatic and weather changes are frequently very distant in space and time.

4. Case studies

The following presentations on specific case studies were given by the participants (see page 21 for Case Study Abstracts section).

Bering Sea King Crab	Warren Wooster (Institute of Marine Studies, University of Washington)
Peruvian Anchoveta/ .... Chilean Sardine	César Caviedes (Department of Geography, University of Florida)
Great Lakes Sea Lamprey	Henry Regier (Department of Zoology, University of Toronto)
Icelandic Cod Wars	Michael Glantz (ESIG/NCAR)
Indian Ocean Tuna	Gary Sharp (Center for Ocean Analysis and Prediction)
Atlantic Menhaden	Lucy Feingold (ESIG/NCAR)
California Sardine	Alec MacCall and Ed Ueber (National Marine Fisheries Service/Tiburon, Calif.)
Pacific Sardine	Tsuyoshi Kawasaki (Faculty of Agriculture, Tohoku University)
Pacific Northwest Salmon	Kathleen Miller (ESIG/NCAR), and David Fluharty (Institute for Marine Studies, University of Washington)
Gulf of Mexico Shrimp	Richard Condrey (Coastal Fisheries Institute, Louisiana State University)
Northwest Atlantic Groundfish....	Wendy Gabriel (National Marine Fisheries Service/Woods Hole, Mass.)

Four project contributors were unable to attend the workshop: James McGoodwin (Department of Anthropology, University of Colorado) will focus his research on Mexican oysters; James Acheson (Department of Anthropology, University of Maine) will focus on Maine lobster and Atlantic herring; Z. Russek (Sea Fisheries Institute, Poland) will focus his research on the impacts on and adjustments by the Polish long-distance fishery of the EEZ in the mid-1970s; John Steele (Woods Hole Oceanographic Institution) will focus on Norwegian herring during the past few decades.

8 JUNE, MORNING: LIMITS/CONTRIBUTIONS OF SCENARIOS

Glantz opened this discussion session by noting that the case studies in this project will deal with the changing abundance or availability of fish stocks as a result of many types of factors, not just climatic ones, e.g., biological, environmental, political, legal, economic, and how such changes affect society. Henry Regier (University of Toronto) noted that climate change may lead to significant changes in the location and type of fish stocks; for instance, one species might decline and another species might take over in a specific area. He cautioned, however, that increased information does not necessarily improve our ability to manage resources; sometimes it can create even greater uncertainty.

Jean-Paul Troadec (World Bank Consultant) stated that fishery management is currently affected by shortcomings in the institutions required for allocating scarce resources and, on the biological side, by the limited understanding of fish population reproductive strategies with regard to environment variability. If uncertainty regarding the abundance of fish stocks in the future is going to increase, the institutions required to regulate access will have more difficulty adapting. Many stocks will remain biologically over-exploited, which is already the major cause of variability. On the other hand, improvement in the institutions required for fisheries management will reduce variability as well as the adverse effects of equivalent changes in the environment that might result from a global warming. On the biological side, the understanding of the links between the location and abundance of marine populations and their physical environments is presently making qualitative progress. If the direction of potential changes in ocean circulation could be known, useful assumptions could be made on the likely changes in fish stock abundance and, hence, on fisheries management.

Sharp noted that relevant information is unlikely to be available from ocean models in the near future. In particular, the spatial resolution is presently inadequate for dealing with currents or coastal processes, thermal capacities are treated separately from biophysical properties, and there is little of the vertical structural detail that is so critical to an improved understanding of the distribution of fish species, particularly on and at the edge of continental shelves. However, a high-resolution ocean model being developed jointly by NCAR and the Naval Postgraduate School at NOAA's Center for Ocean Analysis and Prediction will be modified by Staff for application purposes.

Regier noted that there are other approaches to investigating the impacts of climate change on living marine resources. For example, output from the GISS GCM has been used to provide statistical data sets for the Great Lakes region, which can be used to suggest hypothetical impacts of climate change on fish species. Richard Condrey (Louisiana State University) cautioned that outputs of fish population models are severely constrained by input variables. Consequently, sensitivity analyses may be very misleading, since the variability of input variables employed is often far different from reality. It is possible to test models only up to the point that data are available to test hypotheses; past that point, only speculation is possible. If the parameters of a system are barely known, attempts to model that system could prove to be counter-productive. One example relates to stock-recruitment relationships. Troadec mentioned that these are often modeled in terms of normal distributions with stochastic components. However, as the success of recruitment is often the result of more than one specific process, distributions tend to be asymmetric with few high recruitments and many average and low ones. In the past, fishery scientists have spent little time in investigating the underlying processes; few original observations, required for the development of meaningful models, have been made. The primary emphasis has been on repetitive application to conceptually inadequate models of data series differing only by the number of years they cover.

With respect to climate models, Ed Ueber (NMFS, Tiburon) suggested that they could be used to "backcast" in order to look at past changes in fisheries whose environmental requirements are reasonably well known. For example, the tilefish fishery of the Atlantic might be an appropriate focus of study. Sharp said that he had introduced the "backcasting" idea to the NOAA community, but that despite some interest, they were primarily interested in using remote sensing data to assess future changes. Glantz mentioned that originally there was also little interest in climate impacts-related historical analyses; the forecasting by analogy projects are recent exceptions. Condrey suggested that one of the reasons that funding agencies do not understand the types of research required to improve management strategies is their limited understanding of the processes in physical, chemical and biological systems. Regier noted that it is very difficult to put together groups that will provide such information, and that a balance between empirical and modeling approaches is of critical importance.

Lauretta Burke (EPA, Washington DC) asked the participants about the types of climate research that would be most useful for fisheries scientists. Sharp replied that more information was needed from *in situ* direct observation, and at suitably high resolution, more so than a greater effort in satellite remote sensing. Ueber noted the need for collecting and analyzing data of all types (e.g., biological, oceanographic, physical, and socioeconomic) concurrently, as presently proposed by a California interagency group. Sharp pointed out that there is a strong need to share expertise and information related to climate (and its impacts) among the various agencies.

8 JUNE, AFTERNOON: EXPECTED IMPACTS ON THE MARINE ENVIRONMENT FROM A GLOBAL WARMING

Warren Wooster (University of Washington) identified mixing, circulation, and temperature structure as some ocean parameters critical in determining the abundance of fish species. The information available from current climate models does not minimize the need for these. If climate change leads to a decrease in the meridional temperature gradient, as models tend to suggest, oceanic circulation might become less vigorous, leading to less turbulence, vertical mixing, and coastal upwelling. In addition, there would probably be less convective overturn in high latitudes. However, these changes are speculative and, since they are not based on transient models, describe only endpoints in climate change, rather than the processes leading to them.

Sea-level rise is another likely consequence of global warming. Ueber pointed out that this would have considerable impacts on estuarine ecosystems, which are critical for many species in their early and spawning stages, and also for offshore populations, through the providing of nutrients. Sharp noted that structural engineering solutions to sea-level rise, such as dikes and seawalls, could greatly affect interactions between wetland, estuarine, and marine ecosystems.

Regier presented a concept to elucidate these and other issues. As exogenous stress (whether measured in terms of means or of variance) increases, the degree of self-organization of a system decreases. The boundaries of a system may be maintained by either competitive or internal mechanisms; it is also held together by centralizing mechanisms. In the Great Lakes, for example, anthropogenic stresses led to the dissolution of discrete stocks of lake trout, into an integral unit. Isolating mechanisms between similar species can also break down, leading to genetic mixing, as has happened with some trout in alpine lakes. Climate change may be a stress that leads to such processes; such processes may already be occurring. The long-term result of the interaction of cultural and physical stresses may thus be to decrease variability within populations. New stock structures may result, unlike any previously known. These may or may not be stable. Sharp mentioned that work along these lines had been done on populations of Chilean anchovies and sardines. In the sardines, stock structures had certainly changed, whereas for anchovies they probably had not. The anchovies sustained their historical geographical distributions from before the collapse (1972–73) to the present.

Troadec suggested that Regier's concept could bring coherence to information that is presently unlinked, by identifying the critical parameters that might be affected by stresses. According to Sinclair's member-vagrant theory, each population within a species is adapted to a hydrodynamic structure of specific temporal and spatial features, so that a sufficient number of individuals come back annually for reproduction. If the minimum conditions required for closing the life cycle do not occur, a population cannot perpetuate itself. Most species are represented by several populations. Changes in the ocean circulation may lead to the loss of certain populations, or the establishment of new ones, at the periphery of the species' areas of distribution, rather than to changes in the location and absolute abundance of the populations inside the boundaries of the species distribution areas. However, there is little information on the likely changes in the limits of major zoogeographic provinces to say much about the possible loss or establishment of populations.

Lucy Feingold (ESIG/NCAR) pointed out that a population with an extended geographic range can deal with variability in physical parameters by developing a variety of reproductive strategies. These reproductive strategies are specific to the location of the stock within the range of the species. Troadec added that species differ by the number and absolute abundance of the larger populations of which they are a part. Such differences probably reflect differences in the hydrodynamic structures colonized by distinct populations. Variability in individual population abundance would reflect variability in their respective supporting hydrodynamic structures. Sharp noted that the species' and populations' ecological requirements had to be known, and the climate-related changes should be among the vital outputs from GCM/ocean models. For instance, light and temperature are often critical at high latitudes, whereas nutrients tend to be limiting at low latitudes. These variables are climate-driven at all scales.

Glantz mentioned another influence on oceans that might be derived from GCMs: runoff. If, as suggested by various GCMs, the US Great Plains and coastal marsh areas dry out, fewer nutrients would flow into the Gulf of Mexico from the Mississippi River system.

Condrey noted that the drying out of marshes could pass an irreversible threshold (similar to Regier's boundaries). Loss of nutrients would have a greater effect on fish populations than loss of estuaries, and decreased river discharge would affect spawning. Short- and long-term effects would probably be very different. In the short term, e.g., with increasing salinity, production of some species might increase. But this effect would probably not be long-term. Since the Gulf is a major fish production area for the U.S., decreased production could lead to decreased exports, thereby increasing the nation's trade deficit. Other analogues for this process should be sought in estuarine areas that reflect drought or wet conditions in their hinterlands. The Nile (Egypt) and Murray (Australia) estuaries were suggested.

Condrey mentioned another potential impact of sea-level rise on near-shore ecosystems: increased leaching of toxic chemicals. Burke noted that no studies of this issue were planned by EPA in relation to either lake- or sea-level rise. Another potential stress on near-shore ecosystems was mentioned by Regier: migration of human populations to desirable areas along lakes and coasts. He suggested that the potential environmental effects of such migration, which might well result from climate change, should be investigated.

Ueber suggested that human populations can also affect fish populations because of changes in technology and market demands. For instance, new technologies for the processing of menhaden oil could lead to new uses as well as to price increases, causing greater harvests. The consequent effects on the ecosystem would not be predictable. An example of changing demands is provided by sea urchins and abalone in coastal California. As the value of the Japanese yen increased in the 1970s, a demand for sea urchins from the United States developed in Japan. Until that time, urchins were being destroyed as pests. Japanese demand led to a rapid growth in the urchin fishery, which then contracted. New sea urchin fishing areas have been found in northern California in association with a recreation-only abalone fishery. Some people, legally collecting sea urchins, have illegally harvested the more valuable abalone. In the long run, this uncontrolled fishing pressure could lead to the collapse of a $100 million abalone sport-fishery. If this were to happen, it would be attributable in large part to the increase in the value of the yen.

Troadec pointed out that the steady increase in demand for fish triggered by the finite nature of supply leads to increases in fish prices and, in the absence of effective fishery management, in fishing effort. Institutional improvements are needed to facilitate the decisionmaking processes that are required to regulate fishing. In the event that global warming increases variability and uncertainty regarding future yields, how to improve these institutions may be more difficult to ascertain. Wendy Gabriel (NMFS, Woods Hole) mentioned that the availability of commercial species may also be destabilized by shifts in trophic structure, as critical prey items or competitors respond differentially to warming patterns. Trophic dynamics are as poorly understood as recruitment dynamics; frequently the two areas overlap. In discussion, there was disagreement as to whether stable fisheries were characterized by shorter- or longer-lived species.

Returning to potential impacts of climate change on fishing societies, Troadec noted that institutions change very slowly. It took nearly four centuries in western Europe to adopt property rights on land when the latter became scarce. If the global warming is going to have a significant impact on marine resources and fisheries, changes in institutions may well be lagging behind events. Evolution in fisheries management may require several decades.

Kathleen Miller (ESIG/NCAR) pointed out that there are considerable costs in developing new institutions and changing old ones, especially when conflicts occur between actors. It is important to understand how institutions develop, and how this process can become more flexible in the face of variability (and change) in the resources on which they depend.

9 JUNE: SUMMARY ASSESSMENT OF THE PROJECT

1. Coverage of case studies

Glantz opened this session by briefly outlining the existing case studies in the project, in order to identify possible gaps in coverage. One potential additional subject for research was the effect of decreased runoff from mid-continent hydrological basins, such as the Nile (Egypt) and Murray (Australia), proposed the previous day by César Caviedes (University of Florida). Caviedes also suggested that another possible case study for inclusion could be taken from some tropical Atlantic fisheries. Troadec suggested that research on the Ghanaian/Ivory Coast fishery, which undergoes large fluctuations, would be a good candidate for inclusion in this project. The research, by Binet (from Nantes), is based on thorough biological analysis; possibly a Ghanaian collaborator could be found to provide the socio-economic impacts perspective. Sharp mentioned a study by Bakun and Parrish of sardinella and anchovy off the coast of Brazil, and also wondered whether a study of marine mammal exploitation, such as off Iceland, should be included. Another case study might focus on the effects of the 1970s oil crises, which kept fleets in port even when fish were available. These crises had considerable effects on fishing communities.

Ueber suggested that other case studies might include recreational fisheries, fish stocks which had collapsed in the absence of a fishery, and changes in quotas which influenced the volume of fish discarded at either the harvesting or the processing stage. Another recommended area for study related to changes in market demands resulting from public perceptions. Specifically, Ueber mentioned the loss of the Japanese market when radiation was perceived to be affecting Californian fish; Gabriel mentioned the decreased demand for New England fish in summer 1988, linked (at least by perception) to concern about pollution. Regier suggested that a study of shifts in red tide might also be appropriate. Condrey proposed that Caribbean islands fisheries could also be a topic, especially because the availability of fish affects the islands' political stability. Ueber, however, pointed out that information on these fisheries is sometimes not released by governments or industries because of its potentially adverse societal effects.

2. "Winners and losers" from global warming

Glantz introduced for discussion the notion of winners and losers that might result from a global warming, noting that perhaps there might be short-term winners, but in the long term, everyone might lose. Troadec suggested that the major impact would be on societies where fisheries were important in the economy, and there is little prospect for compensatory income because of the state of the economy, with little alternative opportunities because their economies were undiversified. This is often the case in developing countries bordered by major upwelling regions (e.g., Mauritania, Namibia, Peru, Somalia). Furthermore, the ability of societies to react to changes in natural ecosystems differs in relation to their domestic social and economic organization. Traditional small-scale societies adapt generally more rapidly to variations of the renewable resources on which they are dependent; however, their livelihood is integrally linked to the productivity of such resources. Industrialized societies, on the other hand, are less dependent on primary production. Technology can help to overcome the variability of natural ecosystems, e.g., by controlling the reproduction of commerical species, such as through bivalve culture or salmon ranching. Modern societies, however, are vulnerable to changes in their environment when those changes depart from the range with which they have learned to cope. Finally, the tendency towards sedentarization which, in fisheries, goes in parallel with the full exploitation of resources, seriously reduces the capacity to use space to offset temporal variability in resource abundance.

Ueber suggested that climate change might lead to greater volatility in commercially-important fish stocks, thus requiring even greater adaptation by fishing industries, through new fishing and processing techniques. In addition, requirements for energy efficiency might lead to changes in engine and ship design. There might be greater pressure on institutions to react quickly to the appearance of new species. Consequently, the maximum sustainable yield (MSY) approach to management, fishing, and capital structure formation might become even more inapplicable. Sharp proposed that, to ensure access to resources, higher levels of international fishing collaboration might be needed, for which there is no general global analogue from the past.

Regier noted that, while some groups are able to adapt and exploit newly arising opportunities, many people with a strong interest in (or dependence on) a resource tend to "hang in" too long on the exploitation of a declining resource and lose out on the exploitation of new ones. Condrey and Ueber suspected that the latter was most common, and typified North American society because of inadequate awareness and because government assistance (e.g., subsidies) has been available. For this reason, Regier recommended that the concept of a "safety-net" for disadvantaged populations might have to be considered in relation to the effects of climate change.

Commenting on the notion of winners and losers, David Fluharty (University of Washington) said that it is very difficult to generalize in regard to the issue, as both the spatial and temporal scales of impact, and differential effects must be identified. Jim Thomas (NMFS, Washington DC) mentioned that, even at a local scale, there can be winners and losers and, even if a local population loses, the larger-scale context can often be most important. A major problem with responses to change, however, is that people view events from their individual perspectives. Desired responses to change will also vary: for instance, some may want more regulation, some less, while others will want subsidies. With respect to this project, Glantz suggested that the question of winners and losers should only be addressed in individual case studies, if appropriate.

3. Related research programs

Burke outlined current and forthcoming EPA projects relating to fisheries. The EPA–Duluth laboratories are starting a three-year project on thermal tolerance of fish species in the north-central and southeast states, which will be integrated with hydrological modeling studies. Some of the projects on biological diversity consider fish populations. There is consideration of projects on marine issues next year.

Thomas outlined NMFS interests, which include: oceanographic changes; sea-level rise and loss of wetlands; freshwater flows and sediment loading; and socio-economic impacts of climate change on fisheries. NMFS is particularly interested in assessing linkages between these issues, and modeling for predictive purposes. The aim is to incorporate lessons in policymaking in order to offset adverse impacts, especially on U.S. fisheries.

Sharp mentioned that, while there have been some attempts within NSF to link ocean sciences research to policymaking, there has apparently been little response from the research community. The predominant attitude appears to be that science observations are for research use and not for real-time, real-world applications.

4. Project and report content

The workshop concluded with discussions of the time-frame for the project, and of the content of the introductory chapters for the final project's report. Glantz proposed that introductory chapters might include the current status of GCMs and ocean models, an overview of forecasting by analogy, and a review of the research on the impacts of climate variability and change on fisheries. In response to a question on the topic, Glantz proposed that the question of world food security might best be included in the overview, with mention of aqua- and mari-culture.

With respect to forecasting by analogy, Regier quoted Keynes: "analogy is an aid for getting into the saddle, but an encumbrance on a long journey." Troadec noted that, if analogies are important to analyze issues and to detect signals, it is critical to understand the processes involved, i.e., the mechanisms linking the physical environment and the biological resources, as well as the institutions required to optimize the productive linkages between societies and exploited marine ecosystems, because the understanding of the causal relationships between natural and man-made factors, on the one hand, and the abundance of renewable resources, on the other, conditions the capacity to predict and to act. This requires original research.

Glantz also emphasized that the objective of the forecasting by analogy approach is to gain a first approximation of how well prepared societies might be to deal with the yet unknown regional impacts of global warming. Finally, Regier noted that another important reason for this approach is to create awareness among people working in other fields that they have valuable experience which can contribute to dealing with the issue of climate change. Glantz pointed out that such awareness is important in any case: climate variability is an issue that has to be coped with whether or not the climate changes.

Case Study Abstracts

(4 additional abstracts to be added)

The Peruvian-Chilean Fisheries During Their Inception, Maturity and Stabilization Periods: Trends and Singularities

(C. Caviedes)

Industrial fisheries began to develop in Peru and Chile during the early 1950s based on the exploitation of pelagic species. Ecuador did not experience a similar development due to its fishing emphasis on equatorial water species.

The dramatic growth of the Peruvian-Chilean fisheries, mainly anchoveta, is illustrated by the combined landings in 1964 in excess of 11 million tons. An El Niño event during the following year (1965) demonstrated the impact of this oceanic-atmospheric anomaly on the pelagic fish stocks of the Peru Current. Since that time, Peruvian fisheries have continued an upward trend that peaked in the late 1970s when anchoveta landings surpassed 12 million tons, well above the 9–10 million tons judged as a critical threshold to overfishing by an FAO commission of fisheries experts.

The onset of a major El Niño in 1972 coupled with overexploitation and apparent recruitment failure caused the Peruvian fishing industry to suffer an insurmountable crisis in the following years. Since 1974, Peruvian landings have seldom surpassed 4 million tons. The Chilean fishery, which did not undergo rapid speculative growth as did Peru, suffered a relatively small contraction after the 1972–73 El Niño. After the military overthrow of the Chilean government, the landing levels based mainly on sardine and jack mackerel began to increase. The collapse of the Peruvian anchoveta was compensated for in part by an increased exploitation of sardine, jack mackerel and hake.

By 1980 Chilean trawler landings surpassed those of Peru, making Chile the number one South American fishing nation. The 1982–83 El Niño caused yet another contraction of the Peruvian fisheries, but not of the Chilean fisheries, which continued to exploit sardine and jack mackerel. By 1987 a new development appeared: a contraction of the Chilean sardine stocks prompted an increased emphasis on sardine and an increase in the anchoveta landings. In sum, the 1972–73 collapse of the Peruvian fisheries marked the beginning of a shift to fishing other species which, in the cooler waters of northern Chile, had "weathered" the effects of the 1972–73 El Niño much better than those of Peru.

Although warming and cooling phases of sea surface temperatures have been scientifically well documented at least since 1951 and an SST warming trend has been observed since 1976, the level of warming has not yet been so large as to be considered a major "change," but rather a short-term fluctuation within an oceanic-atmospheric system known for its persistence. In addition to environmental factors, the levels of landings of particular species in the coastal waters of Peru and Chile are also affected by political and economic circumstances in these countries; for example, the exploitative/speculative character of Peruvian fisheries managers pursued during the rule of Velazco Alvarado and Bermudez (late 1960s and most of the 1970s), and in Chile by the export-oriented economy introduced by that government since 1973.

U.S. Gulf of Mexico Shrimp Fishery

(R. Condrey)

The U.S. Gulf of Mexico shrimp fishery is one of the most valuable and diverse in the nation. In the past 30 years the reported annual commercial catch has more than doubled to 175,000,000 pounds (tails), while nominal effort has more than tripled to 10,000,000 hours of trawling time/year. The industry, however, is faced with a number of problems.

The dominant shrimp in this fishery are estuarine-dependent and use the flooded marsh surface as an important nursery ground. In many areas of the Gulf the marshes are deteriorating and in time being converted to water bottoms—which are far less productive as shrimp nursery areas. It may be that recent increases in recruitment of juvenile shrimp to the fishery are due to a short-term increase in nursery area because of marsh loss. If this is so, and the stimulus declines, then the high levels of current fishing mortality could result in a collapse of the stock. The fishery is growth-overfished, and the level of growth-overfishing has continued to increase during, at least, the last 30 years.

The rapid expansion of the fishing grounds, which began in the early 1950s with the discovery of large shrimp off the coasts of Texas and Florida and which continued with the exploitation of shrimp along the Mexican and South American coasts in the 1960s and 1970s, has come to a halt. That halt was triggered by the passage of the U.S. 200-mile limit (which prompted reciprocal [retaliatory] actions by Mexico and South America) and was strengthened by US enforcement of the Lacey Act (which is used to prosecute US shrimpers attempting to return from illegal trips to Mexican and South American grounds).

Yet another contraint on the shrimp industry has been the mandatory uses of Turtle Excluder Devices (TEDs) in shrimp trawls in some offshore waters by at least July 1989, which has resulted from the continued decline in the numbers of nesting Kemp's Ridley sea turtles. There has been vocal opposition to the uses of these devices, and many shrimpers will enter the period of mandatory TED use with little or no knowledge of how to deploy the devices properly so as to minimize shrimp loss.

There has been a dramatic and largely unexpected increase in shrimp imports during the last decade, the immediate impact of which has been on the domestic price of shrimp. The most devastating impact, however, may prove to have been a shift in the dependence of the US consumer from predominately domestic to predominately imported shrimp.

Recognition of the possibility that the shrimp industry may be subject to a precipitous decline is recent and is the direct result of a stock assessment workshop held in June 1989. How management responds to this uncertainty, given the other unresolved problems which characterize the industry, will be assessed.

Atlantic Menhaden Analogy
(L. Feingold)

The use of menhaden has a long history along the U.S. Atlantic Coast. During colonial times, it was used as a fertilizer by the Pilgrims, and in the post-World War II period as a poultry and cattle feed supplement, as well as an ingredient for paints and cosmetics. Today it is also used as a protein-rich additive for direct human consumption. Menhaden range inshore along the Atlantic Coast from Maine to Florida. Its distribution is stratified by age and size. The older and larger fish can be found farther north. Menhaden are euryhaline (can survive in a wide range of salinity) with spawning occurring predominantly at sea. Larvae are carried by ocean currents into bays and estuaries to develop into juveniles. Menhaden begin forming large, dense surface schools as juveniles and continue throughout adult life with extensive migrations. The predictability of the migration and the age structure, along with the large surface schools, make menhaden easy to fish.

The industry reached peak production between 1953 and 1962, followed by a drastic decline that lasted until the late 1960s. This decline was due to poor recruitment and truncation of the stock's age structure, causing a scarcity in the northern half of the species range. Landings have steadily increased from 1975 to the present with fluctuations occurring between 1970 and 1975. Reduction plants opened again in the mid- to late 1970s in New England with increasing recruitment and broadening of the age structure, and closed because of local factory-odor abatement problems. The number of active plants and the size of the fleet remained fairly stable south of New England. As the stock rebuilt and landings increased from 161,000 mt in 1969 to 418,600 mt in 1983, greater number of age–0 menhaden were harvested, and the mean length of sampled fish (ages 1–4) declined 30–60 mm and weight declined 50–250 g.

The early life history of the menhaden, as well as the stratification of stock structure, open the fishery to great influence by changes of climate and the alteration of physical oceanic parameters. These physical changes, in the form of oceanic productivity and change in circulation patterns, could have a direct effect on mortality and recruitment. Temperature changes could affect relocation of abundance and alter the location of age groups.

Society has been greatly influenced by changes in the menhaden fishery. Lessons based on society's response to the changes in this fishery are numerous and valuable. Flexibility in the development of technological uses of the fishery has progressed with society's demands, maintaining the menhaden as the largest fishery by pound landings in the United States. The adjustment to the opening and closing of reduction plants by plant employees as well as increased mobility, consolidation, and increased efficiency of fishing fleets is another example. Fishery managers are also actively seeking new ways to maintain the fishery based on environmental conditions, early life history characteristics, and the number, size and age of the fishable stock in order to predict catches at a level to maintain the fishery in relation to society's needs.

Northwest Atlantic Groundfish
(W. Gabriel)

The Northwest Atlantic groundfish fishery has operated in the Gulf of Maine, off Georges Bank, and in the waters off southern new England since the 1700s. The primary gear in the fishery (in the twentieth century) has been the otter trawl, which harvests a mixture of roundfishes and flatfishes. In the past fifty years, the fishery has proceeded through three phases: (1) a domestic fishery yielded relatively stable production up until the 1960s. In the 1960s, the distant water fleet arrived, which led to dramatic increases of landings of most species, followed by precipitous declines to historical low levels of landings and stock abundance. (2) In 1976, with the implementation of the Magnuson Fishery Conservation and Management Act (MFCMA), the distant water fleet left the region and effort by the domestic fleet increased. (3) From 1976 on, landings increased somewhat until 1982 but recently have again declined to levels as low as those after the intensive distant water fleet effort.

The domestic groundfish fishery has made adjustments in response to declining stock abundance affected by the foreign fleet, changes in regulatory structure brought about under the MFCMA, and, most recently, changes in available fishing grounds as a result of a World Court Boundary decision, as well as further declines in stock abundance affected by the domestic fleet. At this point, relatively little adjustment has been made by the fishermen themselves: most recent effort patterns do not show large numbers of vessels leaving the fishery or large spatial shifts in fleet operations. Recent fishery management policy providing for, among other things, minimum disruption of fishery behavior, freedom of choice to participate in various components of the fishery, and avoidance of abrupt economic dislocations may have contributed to this continuity in the past seven years. Processing and marketing appear to have changes more significantly: prices have increased, many more species are processed and marketed, and alternate (Canadian) sources are readily available.

Icelandic Cod Wars Analogy

(M.H. Glantz)

Iceland is a nation whose economy has been largely dependent on fishing activities for employment as well as for the generation of foreign exchange. In Iceland "fish is politics" so any decision related to the fisheries generates poltical interest.

On several occasions between 1951 and 1976 Iceland unilaterally extended its fishing jurisdiction, from 3 to 4 miles, from 4 to 12, from 12 to 50 and from 50 to 200 miles. These changes put Iceland in direct conflict with other nations whose fleets were fishing within these limits, principally Great Britain and West Germany. Conflicts with the British caused Britain to send its naval vessels into the disputed zone to protect British trawlers. These naval operations and Icelandic naval responses to them are popularly referred to as the "cod wars."

Since the series of cod wars between Great Britain and Iceland began, the share of Iceland's foreign exchange generated by the fishery has declined from a high of about 90% in the early 1950s to about 80% in the mid-l970s. This still represented a sizeable dependence on the exploitation of one natural resource. Thus, variability regardless of cause in any aspect of the production system (from spawning to landings) would have disruptive effects on the social systems dependent on its exploitation.

In this paper I will discuss briefly current speculation about how a global climate warming might impact living marine resources; the history of the exploitation of Icelandic cod; changes in Icelandic fisheries jurisdiction over time; and post-war Anglo-Icelandic conflicts over extentions of these jurisdictions. I will then focus on the 1972-73 cod war in order to identify and discuss lessons from this case study that might be useful to fishing nations for coping with the impacts of changes in availability or abundance of living marine resources that might accompany a global warming of the atmosphere. A final section will assess the value as well as the limits of including the British-Icelandic Cod Wars as an analogy in the "forecasting by analogy" project.

Pacific (Far Eastern) Sardine

(T. Kawasaki)

The sardine is a species that typically shows a long-term, large-scale fluctuation in abundance. Such a great fluctuation would have been caused by the characteristics of sardine's life histories, i.e., feeding habits and phase variations. The sardine is one of the very rare species that has the ability to take and consume phytoplankton. This fish population has completely changed from a local inshore stock which remained near the southern Japanese coasts (around 1965) to a highly migratory one which, since the 1980s, predominates over the Pacific as far as 174°W as if it had become a different species. This is why the abundance of sardine has skyrocketed recently.

There are three populations of the sardine, *Sardinops sagax*, in the Pacific, each being distributed in the Far East, along the west coast of North America, and also along the west coast of South America. They have shown fluctuation patterns in abundance quite in phase with one another. These patterns are highly related to the secular changes in surface temperature, implying that the fluctuation in sardine stocks in the Pacific may have been caused by a common, global climatic change. Sardine catch accounts for a quarter of the total catch in the Pacific recently, and its ups and downs has had in the past and will continue to have in the future great effect on society as well as on the fisheries.

The Collapse of California's Sardine Fishery

(A.D. MacCall and E. Ueber)

Historical Overview

The California sardine (*Sardinops sagax caeruleus*) fishery of the northeastern Pacific Ocean ranged from British Columbia in the north to Baja California in the south. Annual landings from 1926-1951 averaged 430,000 tons, ranging from almost 800,000 tons to 130,000 tons. During the peak of the fishery, the majority of these landings was converted into fishmeal for poultry feed. However, as sardine availability declined, the higher prices received for sport fishing bait and canning made continued fishing profitable.

Sardine abundance and landings continued to decline through the mid-1960s, with nearly total loss of the associated economy. Surplus capital equipment was readily transferred to other parts of the world and contributed to rapid development of substitute fisheries. The society and culture associated with the California fishery was readily transferred to famous novels by John Steinbeck.

In 1967 the California legislature suspended all commercial landing of sardines. After 20 years of protection, the abundance of sardines recovered somewhat, and a 1,000-ton quota was authorized. This small fishery is again providing sardines for fresh fish products, and for dead and live bait. The re-establishment of markets for a canned product and the economic viability of the associated processing industry are not yet clear.

Lessons and Analogies

This study will assess the local, state, national and international ramifications of this fishery collapse. In addition to a review and analysis of the documented history of the fishery, we will interview local people who transferred their skills and equipment to other areas of the world (e.g., Peru and South Africa) and stimulated other fishmeal fisheries. We will assess how people in California and elsewhere coped with dislocation and major lifestyle alterations.

It is likely that global warming will produce collapses of some fisheries and expansions of others. Likelihood of collapse may be aggravated by inadequate management due to insufficient authority, willingness to act, or knowledge. The technical knowledge, substitutional opportunities and dynamics, and institutional constraints which affect the risk of local or global fishery-related disruption will be considered.

Pacific Northwest Salmon
(K. Miller and D. Fluharty)

The Pacific Northwest salmon fishery exploits five species of salmon which migrate throughout the northern Pacific Ocean. The most important species spawning in Washington, Oregon and California are Chinook and Coho. During the 1982–1983 El Niño event, Coho salmon experienced significantly increased adult mortality, decreased body size, poor body condition and reduced fecundity. Chinook salmon were also affected, with those stocks which remain in the south showing greater effects than those migrating northward. The presumed causes of these problems are related to reduced regional upwelling and decreased primary productivity which support salmon survival and growth. To understand the effects of El Niño events on salmon, it is necessary to place those effects in the context of long-term trends in the fishery, and in management measures.

Possible social and economic effects of variations in marine conditions on Coho and Chinook include impacts on harvesters, management and scientific research. Questions related to these impacts will be investigated in this study. For example:

1. Have there been impacts on the allocation of salmon among different users – Indian and non-Indian troll, gillnet, purse seine and sport fisheries?
2. What was done by fishery managers to adjust regulations and management measures to El Niño conditions?
3. Were scientists able to predict the effects of the El Niño and other variations in marine conditions on salmon production?

From this investigation it may be possible to assess society's ability to respond to the effects of short-term environmental fluctuations on salmon fisheries. This may help to identify effective ways to manage salmon in response to environmental variability. In addition, the investigation may indicate gaps in knowledge and useful directions for research.

The Sea Lamprey in the Upper Great Lakes:
A Case Study
(H.A. Regier and J.L. Goodies)

The sea lamprey irrupted sequentially in the Upper Great Lakes in the period 1935–55. The invasion by sea lamprey was facilitated by ship canals and ships themselves. Shipping interests were never held directly accountable for this consequence. The preferred prey of lamprey included salmonids, both salmonines and coregonines, which are also preferred by fisheries—whether commercial, recreation, or artisanal. Salmonids are ecologically sensitive species and were already stressed by many adverse cultural influences, including a fishery practiced with an intensity that bordered on biological overfishing. When the sea lamprey began competing with fishermen for their preferred fish, fishermen did not temper the intensity of fishing to compensate for the new stress exerted by lamprey. Many relatively discrete stocks of salmonids were extinguished altogether as a result of the combination of several stresses in which sea lamprey predation played a predominant role.

During the decades that the sea lamprey irrupted sequentially in the Upper Lakes, fishery politics were in turmoil with respect to a number of difficult issues. Irruption of sea lamprey as an issue did not become politicized in the sense that any jurisdiction or group of stakeholders was blamed for it, not even the shipping interests. Control of sea lamprey provided an appropriate focus for joint interjurisdictional action and became the beachhead for expanding interjurisdictional governance of fishing issues in the Great Lakes.

Many small fisheries and fishing communities succumbed as a result of the new sea lamprey stress imposed on an ecosystem that was already experiencing moderate cultural stresses throughout and some intense stresses locally. Many small fisheries ceased operations in ways reminiscent of how farming ceases in marginal areas during hard times—the young left for the cities and towns, and the old used up their "capital" in part-time fishing in a life of relative poverty. Some larger fisheries consolidated their operations, diversified fishing practices, diversified their businesses to include non-fishing enterprises and survived for the two decades until some preferred species returned as a result of lamprey control and other rehabilitative reforms.

In 1989 the sea lamprey is under partial control in most parts of the Great Lakes; in large rivers and their mouths the sea lamprey is not under control because available control techniques are not cost-effective in those waters. Where sea lamprey have been partially controlled, and because other rehabilitative reforms are also under way in these ecosystems, fisheries are again thriving.

Development of the Western Indian Ocean Tuna Fishery: Rapid Social Response to New Opportunity

(G.D. Sharp)

A review of the evolution over a ten-year period of the Western Indian Ocean Tuna Fishery, since its initial identification as a viable opportunity, provides a lesson in the variety of social and political responses that result from major changes in fishery activities. The sort of problems faced include "discovery phase" explorations, determination of localized interests in regard to both ownership and access to the resources as these vary over time and space, and the development of infrastructure to optimize product and fishing economic returns.

The consequences of the evolution of this fishery include: (1) major changes in the Atlantic tuna management situation; (2) major economic developments in the Seychelles social milieu from new support infrastructure; (3) the development of a tuna processing industry in Thailand which in 5 years brought that nation from noninvolvement to the top of the list of canned tuna product exports; (4) lowered global prices for fish products, due to the shift of emphasis from U.S. and Japanese products to Thai products; (5) the development of an Indian Ocean observational capability and better knowledge of the inter-annual climate/ocean variability in a region that had previously not been well understood.

King Crab Deposed
(W.S. Wooster)

The king crab stock in the eastern north Pacific (eastern Bering Sea and Gulf of Alaska) has varied nearly ten-fold in abundance in the last 25 years (Hayes 1983). From the late 1960s, the fishery has been the second most valuable Alaska seafood industry, exceeded in value only by the combined value of all six salmonid species harvested in Alaska (Hanson 1987).

In 1981 the stock reached very low levels and has recovered only very slowly since then (Fig. 1). Stocks of other king crabs (blue, brown) also declined as did Tanner crabs. The reasons for this collapse have not been established although various explanations have been offered, including overfishing, predation and disease. It is entirely possible (see later) that the cause was some sort of environmental change (and, presumably, with further change, abundance will again increase). Overfishing seems an unlikely cause, given the conservative nature of management for this fishery.

The short term economic impact of the collapse was large – between 1980 and 1983, revenues to fishermen dropped by about $93 M; processor sales by $178 M; wholesalers sales by $304 M (Hanson 1987). Comparable losses were presumably felt by associated industries (e.g., shipyards, lending institutions).

As the abundance of king crab declined sharply, the industry shifted to other resources, first to other crabs until they too were depleted, and then to groundfish (among other changes, some of the large crabbers were converted to trawlers). The domestic groundfish fishery grew rapidly in response to the extension of U.S. jurisdiction over fisheries (and the MFCMA) which in effect provided a new resource, the groundfish that had previously been taken by foreigners.

The history of many fisheries includes eras of unusually high or low abundance. Some species are more variable than others. It has been traditional to blame overfishing, but while exploitation undeniably reduces stock size, it is much less clear to what extent it controls stock replacement. While several (many?) processes interact to yield strong (or weak) year classes, the system as a whole is probably modulated by changes in the abiotic environment.

Although the major changes in abundance of most stocks are probably environmentally driven, they cannot as yet be predicted from environmental data. A consequence of climate change, whether anthropogenic or otherwise, is likely to be change in the distribution and abundance of many fish stocks. It is less clear that there will be any large scale change in ocean productivity.

Such changes must be accommodated by fisheries. Fishermen will have to be prepared to respond flexibly to the likely changes in fish stocks. Likewise, consumers of fish products will have to be flexible in their demands, as the availability of seafood shifts from stock to stock.