

Human Effects of Climate-Related Changes in Alaska Commercial Fisheries

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Abstract

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 effects—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 the nation. In 1995, the ex-vessel value (the value received by fishermen) of Alaska landings exceeded \$1.4 billion, while the first wholesale value (the value after processing in Alaska) was almost \$3.0 billion.

Climate change may have significant effects on Alaska fisheries. Climate change 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 of Alaska 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. These may include:

- Changes in harvests
- Changes in regulations due to effects of climate on other species
- Changes in fishing and processing employment
- Changes in harvesting and processing costs
- Changes in prices
- Changes in market share
- Changes in fishing and processing income and profits
- Changes in income and employment in fisheries support activities
- Changes in local and statewide tax revenues
- “Multiplier” effects of changes in fishing-related income
- Changes in boat, gear, permit and IFQ (individual fishing quota) values
- Changes in fisheries participation
- Social stresses

Political conflict

Changes in costs and opportunities due to changes in weather and ice conditions

Costs of retooling

It is reasonable to assume that climate change could halve or double average harvests of any given species. This suggests that climate change could decrease or increase the total ex-vessel and wholesale value of Alaska harvests of some species by hundreds of millions dollars annually.

The effects of global supply on markets for Alaska fish further complicate the task of assessing the potential effects of climate change on the Alaska fishing industry. It is not sufficient to understand only how fish harvests may be affected in Alaska. To understand potential climate-driven changes in markets, we would also need to understand how climate change might affect harvests of competing species in other parts of the world.

For some regions of Alaska the economic effects of climate change may be highly favorable, for other regions the effects may be highly unfavorable. The fact that many of the economic benefits of Alaska fisheries accrue to non-resident fishermen, processing workers, and processing plant owners reduces the extent to which effects of climate change will be experienced in Alaska. Many of these effects will occur in the Pacific Northwest region.

Potential long-term changes that could affect the significance of climate change for Alaska fisheries include:

Changes in fish prices

Changes in technologies for fish harvesting and utilization

Changes in fisheries management

Changes in Alaska and American society

Potential strategies to mitigate the effects of climate-driven changes in Alaska fisheries include increasing attention to long-term forecasting and planning, and incorporating mechanisms for adjusting to harvest changes in management and political institutions

Introduction

An increasing body of scientific evidence suggests that the world climate is changing and that human activity may contribute to climate change. This has led to increased interest in the implications of climate change. How will climate change affect us? What can or should we try to do about it?

Marine fisheries are very vulnerable to climate change. Marine fish harvests are almost totally dependent on climate-related environmental conditions affecting fish abundance. Even the most responsibly managed fisheries exhibit substantial climate-related variations in harvests over time.

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 effects—of climate-driven changes in fish abundance and commercial harvests. Specifically, the paper examines potential human effects for Alaska and the United States of climate-driven changes in Alaska commercial fisheries and what can be done to mitigate these effects.

Much of this paper is speculation. We have only a limited understanding of the immensely complex systems of global climate, marine ecosystems, and human society and how these systems interrelate over time. All of these systems may affect Alaska fisheries, in part because demand for Alaska seafood is affected by worldwide supply and demand conditions for food. Nevertheless, despite our limited understanding of these systems, thinking about the implications of climate change associated

with Alaska fisheries, and similar attempts to assess other potential implications of climate change in Alaska and elsewhere, is an important first step in identifying the issues we may face as a result of climate change—and in beginning to face them.

This paper is organized in five parts. The first part addresses the importance of Alaska fisheries. The second part briefly reviews what is known about the potential effects of climate change on Alaska fisheries. The third part reviews potential short-term human effects of climate-driven changes in Alaska commercial harvests. The fourth part reviews potential long-run human effects of changes in fish harvests. The fifth part suggests possible ways of mitigating human effects of climate-driven changes in fish harvests.

The Importance of Alaska Fisheries

Table 1 provides data on 1995 Alaska commercial fisheries landings, ex-vessel value, and wholesale value for major commercially harvested species.¹ In 1995, the ex-vessel value (the value received by fishermen) of Alaska landings exceeded \$1.4 billion. The first wholesale value (the value after processing in Alaska) was almost \$3.0 billion.

These are big numbers. *Alaska commercial fisheries are the basis of a major industry of economic significance not only to Alaska but also the nation.*

Here are some additional perspectives on the economic significance of Alaska fisheries:²

- In 1995, Alaska accounted for 54% of the volume of U.S. fisheries landings and 37% of the ex-vessel value of U.S. landings (Table 2).
- If Alaska were an independent country, it would have ranked twelfth in the world in commercial fish harvests in 1995.
- In 1995, Alaska accounted for ten of the top thirty U.S. ports in volume of fishery landings (Dutch Harbor, Kodiak, Naknek, Ketchikan, Petersburg, Cordova, Kenai, Sitka, Valdez, and Seward).
- More than 40,000 people work in fish harvesting in Alaska (although much of this employment is only for part of the year). In 1995, more than 10,000 individuals purchased Alaska commercial fishing permits and more than 30,000 other persons purchased Alaska commercial fishing crew-member licenses.³ At its summer peak, about 20,000 people work in seafood processing in Alaska.⁴

¹1995 is the most recent year for which value data for all Alaska species are conveniently available. Using a different reference year would result in different landed volumes and values for each species, but the same general points would still apply as to the significance of Alaska commercial fisheries.

²In this section, except where otherwise cited, data are from NMFS, *Fisheries of the United States*.

³Number of permit holders is from Gunnar Knapp and Terrence Smith, *The Alaska Seafood Industry: Seafood Sector Report* (1991). Chapter VII.

⁴Alaska Department of Labor, *Employment and Earnings Summary Report, 1995*.

Table 1

Landed Volume and Value of Alaska Commercial Fish Harvests and Production, 1995

	Landed volume (000 lbs)	Ex-vessel value (\$ 000)	First wholesale value (\$ 000)
Salmon	994,107	\$490,365	\$1,036,835
Sockeye	350,491	\$321,906	\$554,665
Pink	435,455	\$80,030	\$270,374
Other salmon	208,161	\$88,429	\$211,796
Herring	106,471	\$51,288	\$109,879
Shellfish	106,054	\$258,551	\$352,119
Tanner crab (opilio)	74,020	\$174,682	\$234,297
Other crab	32,034	\$83,869	\$117,822
Shrimp & misc. shellfish	11,329	\$11,177	\$19,351
Halibut	33,928	\$68,725	\$75,821
Groundfish	3,869,819	\$585,300	\$1,393,800
Pollock	2,647,550	\$297,100	\$853,400
Pacific cod	611,142	\$111,000	\$216,900
Sablefish	33,511	\$93,700	\$110,500
Other groundfish	577,616	\$83,500	\$213,000
Total	5,121,708	\$1,454,229	\$2,968,454

Sources: Groundfish values: R. K. Kinoshita, A. Grieg, D. Colpo and J. M. Terry, "Economic Status of the Groundfish Fisheries off Alaska, 1995," NOAA Technical Memorandum NMFS-AFSC-72, National Marine Fisheries Service, Alaska Fisheries Science Center, April 1997, Tables 20, 31. All other data: Brian Frenette, Marianne McNair and Herman Savikko. "Catch and Production in Alaska's Commercial Fisheries: 1995 Edition," Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Special Publication No. 11, April 1997, Tables 3, 4 & 5. Note: Salmon wholesale value includes roe products. File: Volume & value.

- Seafood harvesting and processing both account for annual average employment of about 10,000 jobs in Alaska. Together, they account for annual average employment of more than 20,000 jobs, about half again as much as the oil industry.⁵ After accounting for "multiplier" effects on other industries, the seafood industry accounted for about 33,000 jobs in Alaska in 1995 on an annual average basis, or about 11% of total Alaska employment and more than any other private sector activity.⁶
- Seafood processing companies accounted for twelve of the top 100 private sector employers in Alaska in 1997.⁷
- For many Alaska coastal communities, fishing forms the sole private sector basic economic activity bringing income into the community. In some communities fishing and fish processing account for more than half of all jobs (Table 3).

⁵O.S. Goldsmith and Teresa Hull, "Tracking the Structure of the Alaska Economy: The 1994 ISER MAP Economic Database," Table 1.

⁶O.S. Goldsmith, "Structural Analysis of the Alaska Economy: A Perspective from 1997" (August 1997).

⁷Alaska Department of Labor. "The Trends 100: Alaska's Largest Private Employers, 1997," *Alaska Economic Trends*, Volume 18, Number 8 (1998).

Table 2

**National and Global Significance
of Alaska Fisheries, 1995**

	Landed volume (tons)	Landed value (\$)
Alaska	2,401	\$1,396,974,000
United States	4,440	\$3,735,615,000
World	112,910	
Alaska as % of:		
United States	54%	37%
World	2%	

Source: National Marine Fisheries Service, Fisheries of the United States, 1996, pages 4, 86.

File: Significance.

Table 3

**Estimated 1990 Seafood Industry Employment
in Selected Alaska Communities**

	Fishing	Fish processing	Total Seafood	Total employment	Seafood as % of Total
Pelican	29	21	50	120	42%
King Cove	35	119	154	276	56%
Sand Point	76	180	256	438	58%
Akutan	15	378	393	518	76%

Source: 1990 census data from Alaska Department of Community and Regional Affairs website (www.comregaf.state.ak.us). Note: Employment data are based on a sample of households.

File: Commun.xls

The preceding discussion relates to Alaska's commercial fisheries. Sport fishing is also very important to Alaska's economy. In 1997, 180,000 Alaska residents and 250,000 non-residents bought sport-fishing licenses.⁸ Sport anglers support significant and growing charter and guiding industries. In a recent study for the Alaska Department of Fish and Game, the Institute for Social and Economic Research estimated that anglers spent about \$540 million in Alaska for sport fishing in 1993—about \$340 million from Alaska residents and \$200 million from non-residents. These expenditures supported over 9,000 jobs and \$200,000,000 of payroll in Alaska's economy.

Subsistence fishing is also of major economic and cultural importance for a significant part of Alaska's population. Implications of climate change for Alaska subsistence is the subject of a separate paper included in these proceedings.

⁸License data are from the Alaska Department of Fish and Game and may be found at <http://www.state.ak.us/local/akpages/FISH.GAME/admin/license/general/10yrinf.htm>.

Potential Effects of Climate Change on Alaska Fisheries

There is abundant evidence that fisheries are subject to both short-term and long-term climate-induced effects on species abundance. There is a great deal of interest and discussion among scientists, managers and industry about these effects. For example, the annual meeting of the North Pacific Marine Science Organization (PICES), held October 14–25, 1998 in Fairbanks, Alaska, included sessions on “Climate change and carrying capacity of the North Pacific” and “Small pelagic species and climate change in the North Pacific Ocean.” As another example, a session on “Climate Change and Its Effect on the Fisheries” at the November 1998 annual “Fish Expo” industry trade show in Seattle was advertised in the show brochure as follows:

“We have much at stake with respect to potential climate change impacts on freshwater and marine fisheries. Projected changes in water temperatures, water quality, salinity and currents will affect the growth, survival, reproduction, and geographic location of fish species. Climate change will cause fish habitat gains in some locations and losses in others. This session will help you learn how different weather patterns can affect your catch.”

Implications of climate change for Alaska fisheries were reviewed at a previous workshop on “Implications of Global Change in Alaska and the Bering Sea Region” held in 1997.^{9, 10} The extensive literature on this topic may be summarized very briefly as follows:

1. The North Pacific/Bering Sea region is subject to considerable year-to-year variability in climate conditions associated in part with the El Niño–Southern Oscillation (ENSO) cycle. Longer-term multi-decadal climate cycles, known as “regime shifts,” also occur. The effects of “global climate change,” or worldwide warming associated with increasing atmospheric CO₂ concentrations, are superimposed on these short- and medium-term natural cycles of climate variability.
2. Significant correlations have been demonstrated between abundance and/or harvests of various North Pacific/Bering Sea fish species and short-term and long-term climate indicators such as:
 - Ocean temperatures
 - Air temperatures
 - Location and intensity of Aleutian Low
 - The El Niño–Southern Oscillation (ENSO) cycle
 - Percent sea ice cover
3. Although there is a great deal of evidence that climate affects fisheries abundance, the mechanisms by which these effects occur are not well understood. Potential mechanisms for effects of climate on fisheries include:
 - Changes in the velocity and direction of ocean currents affecting the availability of nutrients and the disposition of larval and juvenile organisms.
 - Changes in ocean temperatures which affect abundance of both harvested species as well as predator and prey species.

⁹G. Weller and P.A. Anderson (eds.) “Implications of Global Change in Alaska and the Bering Sea Region. Proceedings of a Workshop,” June 1997.

¹⁰Recent research related to effects of climate change on salmon is summarized in North Pacific Anadromous Fish Commission, *Technical Report: Workshop on Climate Change and Salmon Production* (1998).

- Changes in freshwater stream temperatures, stream flow rates and air temperatures that affect the survival of both freshwater as well as anadromous species in freshwater life-stages, in different ways at different life stages.

These mechanisms are very complex. Climate factors may affect fish species in different ways at different life stages. Climate change may lead to reduced abundance of some species and increased abundance of others. In addition to changes clearly correlated with climate, fisheries are subject to very wide short-term variation in abundance that are not in any obvious way related to climate conditions or to human activity. A given species may be affected by climate change in different ways in different parts of Alaska.

Management Responses to Climate Change

The effects of climate-driven changes in fisheries abundance on harvests depend in part on how fisheries managers respond to climate change. How managers respond depends in part on whether they understand the effects of climate change on the relationship between stock conditions and potential harvests over time. To the extent that climate change brings environmental conditions not previously experienced, past research and harvest experience may provide little guide to potential harvests under a new climate regime.

In a very general sense, as environmental conditions and fishing stocks change, managers will adjust fishing quotas and harvest levels over time. How this is done will determine the extent to which harvests change to accommodate environmental conditions, or instead aggravate the effects of climate change. For example, if we continue to fish with a high quota based on falsely high assumptions of abundance or marine productivity, we may drive stocks lower than if we had adjusted to a lower quota in anticipation of the effects of climate change. The opposite is also possible: we may fail to take economic advantage of the potential for increased harvests of some species arising from improved environmental conditions.¹¹

Managers face vastly different challenges in the management of different species of commercial significance to Alaska. Consider how great the differences are in the life cycles of sockeye salmon, Alaska pollock, and Tanner crab—the three species that contribute the greatest share of ex-vessel to Alaska commercial fisheries. Thus the role of management in how climate change affects fisheries is likely to vary widely between species.

In a very general sense, however, we might suggest that climate change will make it harder for managers to achieve any given definition of “optimal” utilization of fisheries resources, by changing the environmental conditions upon which past research and management experience have been based. The more rapidly climate change occurs, the greater the extent to which purely climate-driven variation in harvests may be amplified by this “sub-optimal management effect.”

¹¹Kieran Kelleher offered the following example of this kind of effect (Personal communication, October 22, 1998): “Inclement climatic conditions tend to reduce the range of pelagic species. This often results in high catch rates as the fish are concentrated into areas restricted by temperature, oxygen, and plankton distribution. The high catch rates tend to send the “wrong” economic signals to investors and rising profits are often channeled to increased investment in catching power or processing. For short-lived species in particular, it may be difficult to project future catches, and the high catch rates are used to “justify” increased TACs and investment. In longer-lived pelagic species, e.g., herring, mackerel, or tuna, a similar situation can occur. The TACs are set in tons—but if climatic conditions become adverse there is less food for the fish. Consequently they don’t grow as expected and the total weight of the stock is less than expected. However the TAC is fully taken—but this represents far more individual fish than originally was expected to be caught.”

Past Variation in Harvests

While we can't predict accurately how climate change may affect future Alaska harvests, the past provides some indication of the potential magnitude of future changes in harvests. As shown in Table 4, both estimated biomass as well as harvests of major Alaska groundfish species varied widely over the period 1978–1998.

Figures 1–3 show historical harvests of three of the species that have been harvested commercially on a large scale for the longest period of time in Alaska: sockeye salmon, pink salmon, and halibut. Salmon harvests exhibit substantial short-term (year-to-year) variation, reflecting the relatively short life span of salmon and the even shorter periods of time spent in several different environments that are subject to year-to-year climate-related variability. Overlying short-term variations in salmon harvests are longer-term, multi-decadal cycles. Periods of record harvests in the 1920s and 1930s were followed by a long period of lower harvests in the 1950s, 1960s and 1970s, which were in turn followed by record harvests in the 1980s and 1990s. Halibut harvests have exhibited much greater short-term stability than salmon, but dramatic long-term variation.

Of course, past variations in Alaska harvests reflect not only changes in climate conditions, but also changes in management, harvesting and processing technology, demand (as reflected in prices), and ocean ranching of salmon. Measurement issues, including the extent to which data account for foreign harvests and bycatch, complicate the problems still further. All of these human-related factors, to varying extents, played a role in the past short-term and long-term variations in Alaska harvests of groundfish, salmon, and halibut shown in Table 4 and Figures 1–3. However, to discuss the role of these different factors is well beyond the scope of this paper.

Table 4
Estimated Alaska Biomass and Catch for Selected Groundfish Species:
Recent Minimums and Maximums (1978-1998)

Area and Species	Biomass measure *	Biomass (tons)				Catch (tons)				Ratio, Maximum to Minimum	
		Minimum		Maximum		Minimum		Maximum		Biomass	Catch
		tons	year	tons	year	tons	year	tons	year		
GULF OF ALASKA											
Walleye pollock	2+ biomass	933,000	1998	3,041,000	1982	50,206	1996	307,000	1984	3.3	6.1
Pacific cod	3+ biomass	605,000	1978	972,000	1987	12,190	1978	80,100	1992	1.6	6.6
Arrowtooth flounder	3+ biomass	542,149	1978	2,071,406	1998					3.8	
Sablefish	4+ biomass	116,000	1979	275,000	1986	8,543	1980	29,903	1988	2.4	3.5
BERING SEA											
Walleye pollock	3+ biomass	2,867,000	1978	11,116,000	1987	913,881	1979	1,384,376	1992	3.9	1.5
Pacific cod	3+ biomass	325,000	1978	2,206,000	1987	33,761	1979	228,496	1995	6.8	6.8
Arrowtooth flounder	1+ biomass	210,176	1978	1,245,159	1996					5.9	
Yellowfin Sole	2+ biomass	2,113,328	1978	3,016,099	1998	80,584	1990	227,107	1985	1.4	2.8
Greenland turbot	1+ biomass	188,391	1998	525,559	1978	1,875	1992	52,921	1981	2.8	28.2
Sablefish	4+ biomass	13,000	1994	89,000	1987	547	1997	4,178	1987	6.8	7.6

* Ages included in the population biomass estimated from the stock assessment model.

SOURCE: Catch and population biomass estimates were obtained from the stock assessment and fishery evaluation reports of the North Pacific Fishery Management Council (NPFMC, 1998a,b).

File: BIOMCAT1.XLS.

Put differently, past variations in harvests reflect a combination of climate- and non-climate-related factors that are difficult or impossible to disaggregate. However, climate-related factors have clearly played an important role. We may also reasonably assume that Alaska harvests will continue to fluctuate in response to both climate- and non-climate-related factors. The scale of short-term and long-term variation in past harvests over the period of large-scale commercial exploitation (defined as the period during which resource conditions have represented the primary limiting factor in fish harvests) provides an indication of the potential amplitude of future short-term and long-term variation in harvests.

Figure 1

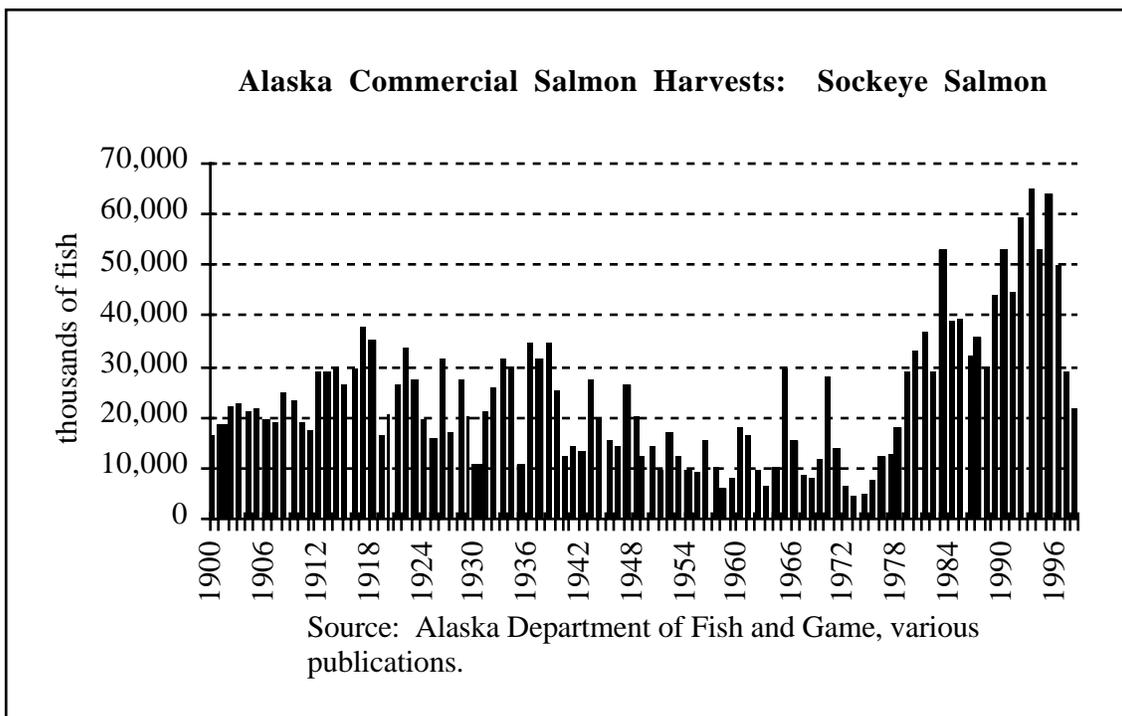


Figure 2

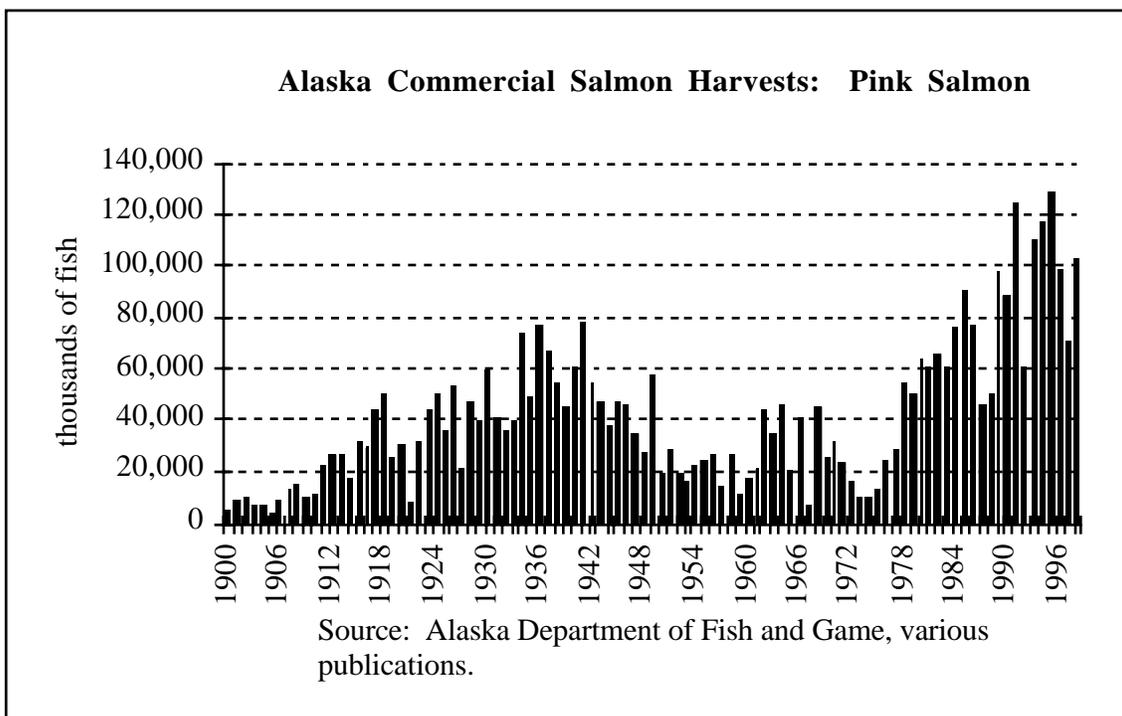
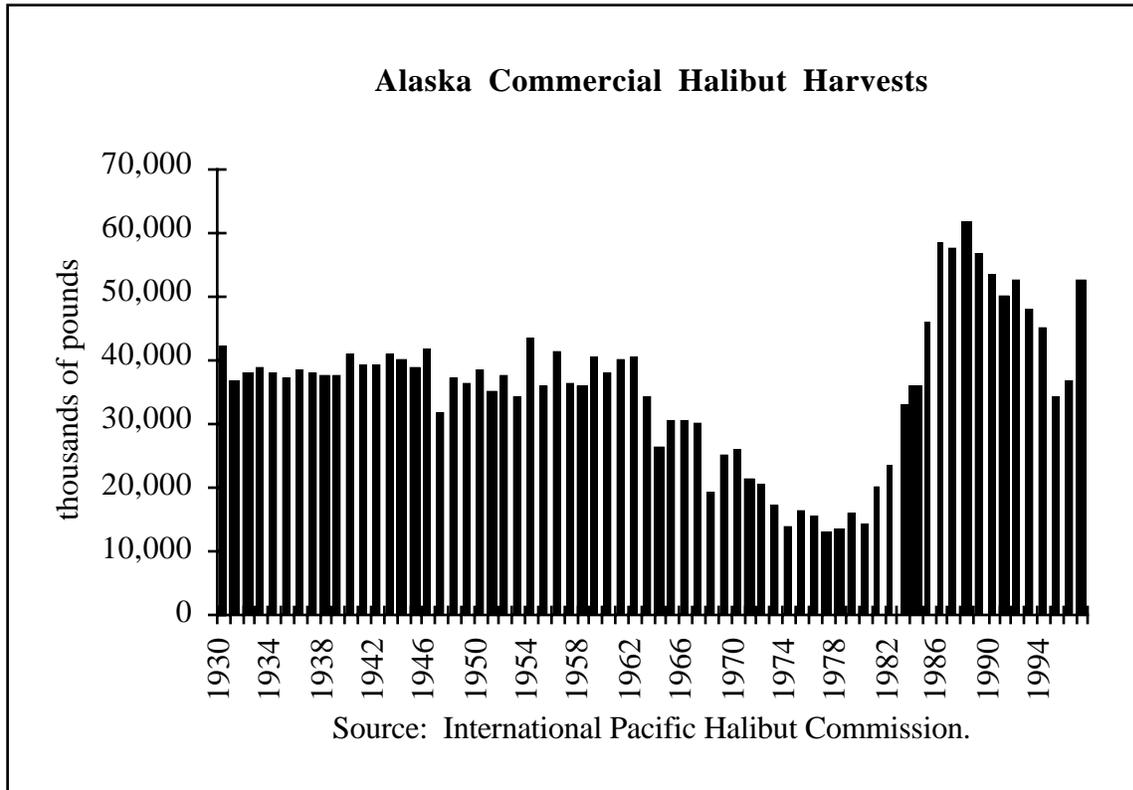


Figure 3



Short- and long-term variation in total harvests of individual species is reflected in short- and long-term variation in landings at individual Alaska ports. Table 5 provides an indication of the scale of short-term and long-term variation in total landings for four Alaska ports. For each port, changes in landings reflect, to varying extents, combinations of climate- as well as non-climate-related factors. For example, the dramatic increase in landings in Dutch Harbor reflects primarily the “Americanization” of the Bering Sea groundfish fishery, while the increases in landings in Ketchikan and Petersburg reflect higher salmon landings due to increased ocean survival as well as returns to southeast Alaska salmon hatcheries.

Table 5
Volume of Commercial Landings at Selected Alaska
Ports, 1977-80 and 1994-97 (millions of pounds)

	1977	1978	1979	1980	1994	1995	1996	1997
Dutch Harbor	100.5	125.8	136.8	136.5	699.6	684.6	579.6	587.8
Kodiak	179.6	177.4	150.5	207.4	307.7	362.4	202.7	277.5
Ketchikan	54.8	55.7	22.1	17.3	93.6	116.7	136.8	65.2
Petersburg	33.6	31.0	31.9	32.3	126.3	83.0	105.0	70.1

Source: National Marine Fisheries Service, Fisheries of the United States, various years.
 File: Ports1.xls.

Summary

We may summarize potential effects of climate change on Alaska fish harvests as follows:

- Climate change may have significant effects on Alaska fisheries.
- Climate change is likely to reduce the abundance of some species while increasing the abundance of others, with resulting reductions or increases in commercial harvests. Some commercial fisheries may disappear; some new fisheries may develop.
- How managers respond to climate change may either amplify or smooth out the effects of climate change on harvests.
- Significant changes in harvests may occur rapidly.
- For a given species, climate change may cause harvests to increase in some parts of Alaska 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. Past variation in Alaska harvests reflects short-term and medium-term *climate variability*. Future variation in response to longer-term *global climate change* could be greater than past variation.

Given that there are so many Alaska species of commercial significance, and there is so much uncertainty and complexity associated with the effects of climate change on each species, this paper does not present specific scenarios for how climate change may affect future Alaska harvests of particular species. Instead, the subsequent discussion in this paper is based on the following general assumptions about the effects of climate change:

- Average decadal harvests of some Alaska species will fall to half of current levels, while average harvests of other species will rise to double current levels.
- Changes in harvests will vary between regions. Harvests of a given species will increase in some regions, while decreasing in other regions. Thus the scale of regional variation in harvests may exceed the scale of statewide variation.
- The time scale over which harvest changes occur will vary between species, as will the extent to which changes in harvests are anticipated by managers and industry.

Potential Short-Term Human Effects of Climate-Driven Changes in Alaska Fisheries

The "Short Term" vs. the "Long Term"

What are the "human"—economic, social, and political—effects for Alaska and the nation of climate-driven changes in Alaska fisheries? To address this question, it is useful to distinguish between short-term effects and long-term effects. "Short-term" refers to the period of time during which the economy and society of Alaska and the United States are likely to be fairly similar to that of today—perhaps the next decade or two. It is easier to assess the potential effects of climate change in the short term because we know about the economy and society in which they may occur. But as we try to look farther into the future, it becomes more difficult to assess the potential effects of climate change, because of the greater the potential for other changes in the economy and society that will affect the kind of impacts that climate change may have.

We can speculate with a reasonable degree of confidence what the effects might be if the number of salmon returning to Alaska next year were to decline by half compared with this year. But as we

progress farther into the future, the greater the potential for changes in society that might either magnify or reduce the effects of climate-driven changes in fish harvests. As recently as three decades ago, a dramatic change in Bering Sea pollock stocks would have had little economic impact on Alaska or the United States—because there was minimal American participation in the Bering Sea pollock fishery. As a different example, thirty years from now Alaska wild salmon may be more valuable or far less valuable—magnifying or reducing the losses associated with climate-driven changes in salmon harvests.

Types of Short-Term Effects

In the short term, the direct effects of climate change would occur as a result of changes in species abundance. Changes in species abundance may have a variety of direct and indirect economic and social effects.

The history of commercial fishing in Alaska and elsewhere offers numerous examples of the economic and social consequences of changes in fisheries abundance. We need look no further than Bristol Bay or western Alaska in 1998 to be reminded of short-term economic and social effects of lower salmon runs. We also have no shortage of examples of the effects of large harvests, ranging from the western Alaska king crab boom of the late 1970s to the (very different) 1991 pink salmon season in Prince William Sound, when large volumes of unmarketable pink salmon were dumped at sea. We can look to the east coast of Canada to see the widespread economic and social consequences of a collapse in groundfish stocks on a region where fishing had been a way of life for hundreds of years.

These many examples show that the short-term human effects of climate-driven changes in fisheries can be both significant and varied. Potential effects may include the following:

- ***Changes in harvests.*** As the abundance of a species changes, fishermen will catch more or fewer fish—either because managers change quotas or because it becomes easier or more difficult to catch fish.
- ***Changes in regulations due to effects of climate on other species.*** Climate-related stresses on the populations of other species, including sea birds and marine mammals, may cause managers to curtail commercial fisheries harvests or change how these fisheries are prosecuted. For example, potentially climate-related declines in Steller Sea Lion populations led to proposals for significant restrictions on the Alaska pollock fishery in 1998.
- ***Changes in fishing and processing employment.*** Changes in harvests affect employment opportunities in fish harvesting and processing. Typically, however, relative short-term changes in employment will be less than changes in harvests.
- ***Changes in harvesting and processing costs.*** As the abundance of a given species changes, harvesting and processing costs per pound change.
- ***Changes in prices.*** Fisheries markets are highly sensitive to supply. Changes in Alaska harvests tend to have opposite effects on prices, thus partially (or sometimes fully) offsetting the effects on harvest value of changes in harvest volume. Prices paid in Alaska fisheries are also directly affected by harvests in other parts of the world. Climate-driven changes in Russian salmon harvests or Norwegian cod harvests directly affect prices paid for Alaska salmon or cod.
- ***Changes in market share.*** Higher or lower Alaska harvests affect short-term market shares for Alaska and competing fish producers. This may have longer-term effects on markets for Alaska fish products even if harvests subsequently revert to previous levels.

- ***Changes in fishing and processing income and profits.*** Changes in harvest volumes, prices and costs combine to affect Alaska income and profits earned in both fish harvesting and fish processing.
- ***Changes in income and employment in fisheries support activities.*** Many support industries, ranging from transportation to boat building to banking, depend upon the Alaska commercial fishing industry. Changes in Alaska harvests and prices directly affect sales, income and employment in these industries.
- ***Changes in local and statewide tax revenues.*** Fisheries business taxes, aquaculture enhancement taxes, and fisheries marketing assessments are directly tied to the ex-vessel value of harvests. As the ex-vessel value of harvests change, collections from these taxes and assessments also change. For some fishing communities, shared fisheries taxes represent an important share of revenues.
- ***“Multiplier” effects of changes in fishing-related income.*** Income earned directly in fish harvesting, processing, and associated support activities is “multiplied” as it circulates through the local and statewide economy. As “direct” income changes, “indirect” income from this multiplier effect also changes. In relative terms, this effect is more important the greater the extent to which communities are dependent on fisheries (for example, Dillingham) and less important in communities which have more diversified economies (for example, Seward).
- ***Changes in boat, gear, permit and IFQ values.*** Changes in harvest levels and prices affect expectations for the value of boats, gear, limited entry permits and individual fishing quotas (IFQ) which may be needed to participate in Alaska fisheries. Changes in boat, gear, permit and IFQ values can greatly magnify the financial impacts for fishermen of higher or lower harvests in a particular year.
- ***Changes in fisheries participation.*** Changes in fishing employment and income opportunities affect who participates in those fisheries. Changes in harvest values may affect the extent to which Alaska fisheries attract participants from outside Alaska, and the extent to which limited entry permits and IFQ are owned by Alaskans or residents of other states. Climate-associated changes in fisheries in other parts of the world can also affect the extent to which fishermen and processors from other areas seek out opportunities in Alaska.
- ***Social stresses.*** Changes, particularly reductions, in income and employment may contribute to a wide variety of family and community stresses, with symptoms such as divorce and substance abuse. These may be particularly important in isolated fishing communities where there are few alternative sources of income. Loss of economic opportunities in fishing may have greater social effects than other kinds of economic decline because few other occupations offer the independence of commercial fishing. Put differently, it may be more difficult for fishermen to adjust to working for wages than it would be for people already working for wages in one industry to work for wages in another industry.
- ***Political conflict.*** Changing relative harvest levels can upset the political balance in agreements over allocation of mixed-stock fisheries and transregional or transnational fisheries. Formal or informal harvest allocation agreements that have worked in the past may not work as well if climate change affects harvests in different regions in different ways.
- ***Changes in costs and opportunities due to changes in weather and ice conditions.*** Changes in the physical environment, such as weather and ice conditions, may affect where and when fishing is physically possible as well as the costs of fishing.

- **Costs of retooling.** Even if lower harvests of one species can be offset by higher harvests of another species, there may be significant costs of changes in boats and equipment needed to harvest and process different species—and different people may enjoy the benefits.¹²

Alaska sport-fishing–related industries, such as charter services, are subject to many of the same short-term human effects of climate change as those listed above for commercial fisheries. However, the economic benefits of sport fisheries are not as directly tied to harvest levels as for commercial fisheries (one extreme example is provided by catch and release fisheries). Economic effects may derive not only from climate-related changes in abundance of sport fish species in Alaska. Demand for Alaska sport fishing opportunities may also be positively or negatively affected by climate-related changes in sport fishing opportunities in other parts of the United States or other countries.

Potential Magnitude of Short-Term Economic Effects

In the short term, to the extent that changes in harvests are not offset by changes in prices, the value of current harvests, shown in Table 1, provides an indicator of the potential magnitude of economic effects of climate change on Alaska fisheries.

The possibility that average harvests of any given species may be halved or doubled by climate change suggests that the total ex-vessel and wholesale value of Alaska harvests of some species could increase or decrease by hundreds of millions of dollars annually.

Because changes in climate are likely to increase harvests of some species while reducing harvests of other species, it is unlikely that the relative magnitude of the change in total Alaska ex-vessel or wholesale value, as well as other economic effects, would be as great as the relative magnitude of the change in value for individual species.

Price Effects of Climate-Driven Changes in Harvests

To the extent that changes in harvests affect prices, relative changes in harvest value may not be as great as relative changes in harvests. Economists express the sensitivity of prices to harvests in terms of “elasticity of demand.” The more “elastic” demand is, the less sensitive prices are to changes in harvests. The more “inelastic” demand is, the more sensitive prices are to changes in harvests.

Some econometric studies suggest that short-term elasticity of demand for many Alaska species may be inelastic, which would imply that the relative effects of climate change on the value of Alaska fish harvests might be less than, or even opposite from, the relative changes in harvest volumes.¹³ However, care should be taken in interpreting the results of such studies.

¹²Peter Koeller, an east-coast Canadian fisheries manager, offered the following comment (Personal communication, October 21, 1998): “The big issue on the east coast of course is the decline of the groundfisheries (both overfishing and climate have been implicated) and the resulting change to invertebrates, including lobsters (always a staple diet for the fishery here), shrimp, snow crab, sea urchins, etc. In fact landed value is higher than ever, but the turmoil as the industry “retools” has been enormous.”

¹³“The economic effects on commercial fisheries of changes in fish populations depend on the elasticity of demand for fish.... Increases in catch result in increased revenue where demand is elastic, but result in decreased revenue where demand is inelastic. Fisheries for Pacific halibut and Pacific salmon have been shown...to operate in the inelastic region of their demand curves thus increased landings will fail to increase revenues unless total demand expands. Although the current ex-vessel demand for walleye pollock is elastic, modest increases would cause demand to become inelastic.... Whenever costs are an upward sloping function of catches, profit maximizing harvest levels will be even smaller than revenue maximizing harvest levels. Although formal demand systems have not been estimated for other region fisheries, it is likely that the demand for most of the remaining groundfish stocks is inelastic (or nearly so). The likely exceptions to this generalization are sablefish and commercial targeted crabs, high valued species with depressed harvests.” (K. Criddle et al., “Marine Biological Resources,” Chapter 7 in G. Weller and P.A. Anderson (eds.) *Implications of Global Change in Alaska and the Bering Sea Region* (1998)).

Given the increasingly global nature of seafood markets, prices paid for Alaska fish products increasingly reflect worldwide supply. For any given species, climate-driven changes in Alaska harvests will be offset by changes in prices only if Alaska accounts for a large share of world harvests, and/or similar climate-driven changes in harvests occur in the rest of the world. For example, if climate change causes crab harvests to decline in Alaska but rise in other parts of the world then Alaska prices might not rise in response to lower harvests.

The effects of global supply on markets for Alaska fish further complicate the task of assessing the potential effects of climate change on the Alaska fishing industry. It is not sufficient to understand only how fish harvests may be affected in Alaska. To understand potential climate-driven changes in markets, we would also need to understand how climate change might affect harvests of competing species in other parts of the world.

Regional Differences Within Alaska in Human Effects of Climate Change

Commercial fishing of different species is not evenly distributed across Alaska. Particular regions are often highly dependent on just a few species. For example, Bristol Bay is highly dependent on harvests of sockeye salmon, while Dutch Harbor is highly dependent on the pollock and crab fisheries. For this reason, as harvests of different species change in different ways, the relative effects of climate change on different regions may vary widely.

To the extent that climate has different effects on harvests of the same species in different regions of Alaska, climate-driven changes in prices may offset the effects of changes in harvests in some regions while amplifying these effects in other regions. For example, in 1998 lower Bristol Bay sockeye salmon harvests helped drive up prices for sockeye salmon. As a result, fishermen in Kodiak, where sockeye harvests were higher than average, experienced both higher harvests *and* higher prices.

For some regions of Alaska the economic effects of climate change may be highly favorable, for other regions the effects may be highly unfavorable.

Effects Beyond Alaska

Many of the economic effects of changes in Alaska fisheries may be experienced outside of Alaska. The regional distribution of economic effects depends in part on where fishermen and processing workers live and in part where the support activities for fisheries are based. Many of the participants in Alaska fish harvesting and processing live outside of Alaska, and much of the support activity for the industry is based in the Pacific Northwest. A significant share of the processing industry is foreign owned.

The fact that a large part of the benefits of the Alaska fishing industry are captured by non-residents has long been a sore spot in Alaska. However, this fact somewhat mitigates the economic effects of climate change in Alaska. Just as Alaska does not derive all the benefits when harvests go up, Alaska doesn't suffer all of the losses when harvests go down. From a national perspective, however, the full effects are what matter.

The fact that many of the economic benefits of Alaska fisheries accrue to non-resident fishermen, processing workers, and processing plant owners reduces the extent to which effects of climate change will be experienced in Alaska. Many of these effects will occur in the Pacific Northwest region.

Long-Term Human Effects of Climate-Driven Changes in Alaska Fisheries

The general nature of human effects of climate-driven changes in Alaska fisheries may be similar in the long run as in the short run. However, it is far more difficult to quantify these effects or how significant they may be. Several factors that may affect the significance of climate change for Alaska fisheries in the long run are briefly reviewed below:

- ***Changes in fish prices.*** Future trends in fish prices will directly affect the economic effects associated with changes in harvests. For some Alaska species, prices could be substantially higher in the future, increasing the importance of climate change. For other species, prices could fall—ironically reducing the importance of climate change. Factors that could tend to raise Alaska fish prices over time include growing world demand, increased consumer health consciousness, and the potential for climate-related disruptions to world food production. Factors that could tend to lower prices include the development of aquaculture—as demonstrated by the rapid erosion of markets for Alaska salmon over the past two decades by growing farmed salmon production.
- ***Changes in technologies for harvesting and utilization of Alaska fisheries.*** Current technology and markets in the Alaska fishing industry reflect the fishing opportunities that have existed in the past in Alaska. To the extent that climate change affects the fisheries resources found in Alaska’s waters, we may not be able at first to take advantage of increased abundance of some resources which have not been exploited previously. Over time, however, we may develop new technology and markets in response to new opportunities—thus mitigating the effects of climate change.¹⁴
- ***Changes in fisheries management.*** The past three decades have seen dramatic changes in the management of Alaska fisheries, including the adoption of limited entry in the salmon and herring fisheries; the adoption of Individual Fishing Quota (IFQ) management in the halibut and sablefish fisheries; the Magnuson Act and the subsequent Americanization of the groundfish fisheries; and the Community Development Quota (CDQ) program, which has brought economic benefits of offshore fisheries to western Alaska coastal communities. These management changes have dramatically affected who participates in and benefits from Alaska fisheries. More changes to management are likely to occur in the future. If the past is any guide, future changes will further reduce the number of individuals and boats participating in Alaska fisheries. Thus the long-term effects of climate change—both good and bad—may directly affect fewer people.

¹⁴Hal Weeks of Oregon State University’s Sea Grant extension program offered the following comment (Personal communication, October 21, 1998): “The warming of waters off the west coast due to last year’s El Niño events substantially changed the distribution (to the north) of many warmer water species.... In 1997, this was noted through substantially increased incidental catch of jack mackerel and chub (Pacific) mackerel in the Pacific whiting fishery.... This imposed several types of costs on the industry. For fishers, the mackerel competed for net/hold space with the desired whiting: mackerel were weighbacks and not paid for by processors.... For processors, there were costs imposed in terms of disposition of these species. However, there was also some limited opportunity here. For example, there is a reduction plant here in Newport which presumably benefited. However, being an apparently transient phenomenon, market development... doesn’t seem to have developed, and therefore neither has a large target fishery.... On a broader time scale, what we now understand to be a substantial oceanic regime shift in the mid/late 1970s *seems* to have favored arrowtooth flounder at the “expense” of Greenland turbot. Greenland turbot is highly desired by markets, while arrowtooth is not. However, the apparently sustained increase in abundance in arrowtooth has led to efforts by some (for example, the Fishery Industrial Technology Center in Kodiak) to develop market products using arrowtooth flounder. So the economic effects from changes in fish abundance due to climatic shifts may include short-term costs (for avoidance/disposal of unwanted species) and perhaps longer-term benefits as processing technology and markets develop for some of these previously unwanted critters.”

- ***Changes in Alaska.*** In the short run, climate-driven changes in Alaska fisheries may have very significant economic and social effects because the economy and society of many parts of Alaska are very dependent on commercial fishing. Over time, Alaska may become less dependent on fisheries, not only due to changes in the fisheries themselves, but also because of other changes in society. We cannot at present guess what these changes may be, but it is not impossible that they could eclipse the economic activities that are presently important in Alaska, including commercial fishing. There is no reason why economic change in Alaska over the next three decades may not be as dramatic as it has been over the past three decades—which have seen a transformation of Alaska society brought about by the discovery and development of North Slope oil.

Responding to Climate Change in Alaska Fisheries

What, if anything, can or should we try to do in order to mitigate the effects of climate-driven changes in Alaska fisheries? The following are suggestions for adapting to future climate-driven changes in fisheries abundance.

Long-term forecasting and planning. The greater the extent to which managers and industry can anticipate longer-term changes that may occur in fisheries as a result of climate change, the more we may be able to plan for and adjust to harvest changes. Most harvest forecasting in Alaska is focused on the immediate future—only one season ahead. There are few specific predictions of longer-term harvest trends.

Yet it is the longer-term harvest outlook that should drive longer-term investment decisions of individuals and companies with respect to boats, gear, processing facilities, limited entry permits and individual fishing quota. At present, many of these important decisions may be based on very simplistic assumptions about the future.

If global climate change is indeed likely to lead to significant changes in harvests, then it is important for scientists to study these potential changes—and to convey to industry and managers the best available information about the nature of changes that are likely to occur. Even though long-term harvest forecasts may be highly uncertain, they may still be valuable—just as the knowledge that there is a possibility of hurricanes in the Caribbean in the fall may be useful in planning a vacation. Industry and managers, in turn, need to be aware of and make use of available information.

Incorporating mechanisms for adjusting to harvest changes in management and political institutions. It is highly likely that climate change will cause significant changes in harvests in the future—although we can't predict what those changes may be. How we design our management institutions will affect the nature and scale of the economic and social disruptions caused by future harvest variations.

For example, political agreements over fisheries allocation, whether they are between local gear groups or between countries (such as the United States and Canada), should recognize that significant future changes in harvest levels are not only possible but likely. These agreements should incorporate adjustment mechanisms so that they continue to be politically acceptable even as stock conditions change. As a basic principle, to the extent possible, harvest allocations should be based on shares of total harvests rather than numbers or pounds of fish.

Designing management institutions to be flexible in response to future harvest changes is not easy. The choices we face in responding to change reflect fundamental choices that we face as a society. One such choice is between economic efficiency and the social benefits derived from opportunities to participate in fishing. The economic efficiency (and profitability) of fishing is affected by flexibility in the use of gear and fishermen in response to changing stock and harvest levels. Varying degrees of flexibility in response to harvest changes are built into current Alaska fisheries management institu-

tions. For example, it is easier to increase or reduce the number of fishing boats and fishermen in response to changes in harvests under the halibut IFQ management system than under the salmon limited entry system. A challenge for managers is that management institutions that are more economically efficient in responding to harvest changes may also be more socially disruptive. Fewer fishermen may be the most efficient response to the fewer fish—but it may have a greater social impact than a system that spreads the effects of lower harvests over more fishermen. Access limitations that benefit fishermen in one fishery reduce the options of fishermen in other fisheries for responding to short-term or long-term changes in harvest abundance.

Similar conflicts arise with respect to the mobility of persons and equipment involved in the harvesting and processing of Alaska fishery resources. Most Alaskans would argue in favor of harvesting and processing by local residents in onshore facilities. However, these strategies tend to increase the vulnerability of Alaska fisheries to economic and social disruption as a result of climate change. The greater the geographic mobility of fishermen and processing facilities, the greater the extent to which fishermen and processing workers can adjust to climate-driven changes in harvests.

A more general issue relates to the broader response of government to short-term and long-term changes in fisheries abundance and harvests. To what extent, and in what ways, should government provide short-term or long-term assistance to individuals or communities when fisheries fail? As was apparent in the wake of successive salmon run failures in Bristol Bay in 1997 and 1998, there was no consensus or plan as to how to respond. If similar harvest failures are to be expected in the future for other fisheries, it makes sense to think in advance about how we should respond.

As noted earlier, climate change may also create new opportunities for profitable commercial fisheries where none previously existed. It is also important to develop management mechanisms to allow and encourage fishermen to take advantage of these new opportunities.

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