Assessing the Consequences of Climate Change for Alaska and the Bering Sea Region

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Cover photos

Upper left: Fishing vessel in Prince William Sound; **Upper right:** Forest near Prince William Sound; **Lower left:** Trans Alaska pipeline north of Atigun Pass (all by D. Coccia, Geophysical Institute, University of Alaska Fairbanks); **Lower right:** Fish rack at fish camp (NPS archive photo, Western Arctic Park Cluster); **Center:** Nesting murre (National Fish & Wildlife Service)

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Preface

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

The assessment covered climate-related consequences on the following sectors:

Fisheries

Effects on fisheries due to climate change have been observed in Alaska where a major international fishery exists in the Bering Sea. These effects, which resulted in increases in catches in some areas and decreases in others, need to be assessed. This assessment needs to also consider fisheries policies, market prices, changes in technology for fish harvesting and utilization, changes in fisheries management and changes in societal needs and preferences.

Forestry

The effects of climate change observed on the Alaska boreal forests include unprecedented insect outbreaks, increased fire frequency and intensity, and the effects of permafrost thawing in changing the landscape. The northward migration of the forests and a lengthened growing season are factors that will become more important to both forestry and agriculture as the climate continues to become warmer.

Infrastructure

Permafrost thawing is occurring throughout Alaska and is already adversely affecting roads, houses, airfields and other infrastructure, as well as slowly changing the boreal forest to bogs and grasslands. As the climate continues to warm, more permafrost will thaw and snow and ice will melt. The resulting impacts will become more serious and will require further monitoring, modeling, and assessment to determine the rates of change, the spatial extent of thawing and melting, and its effects.

Subsistence

Changes in the high-latitude environment, including a reduced sea ice cover, changes in ocean temperatures and snow cover on land, and thawing of permafrost and coastal erosion have influenced the subsistence hunting and fishing practices of Alaska's Native population. The abundance and distribution of fish, marine and land mammals and reduced or altered access to these food resources are all critical factors in assessing future consequences for Alaska Natives.

Wildlife

Seabird populations in Alaska are larger and more diverse than in any similar region in the Northern Hemisphere. They are good indicators of healthy marine ecosystems and can be useful in measuring change in the marine environment. Recent marked shifts in climate have affected entire ecosystems and the continuing study of seabirds is expected to provide vital clues on the health of these ecosystems.

This workshop was part of the U.S. Global Change Research Program's National Assessment of the Potential Consequences of Climate Variability and Change. The Alaska regional assessment was originally begun under the auspices of the International Arctic Science Committee in 1995. This was the fourth annual workshop on this topic held in Alaska. Future workshops are planned to update our assessment of climate change impacts as more information and data become available. The reports published to date are:

- 1996. Preparing for an Uncertain Future: Impacts of Short- and Long-Term Climate Change in Alaska. P. Anderson and G. Weller, eds. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, Alaska, 43 pages.
- 1997. The Impacts of Global Climate Change in the Bering Sea Region. An Assessment Conducted by the International Arctic Science Committee under its Bering Sea Impacts Study (BESIS). Results of a Workshop at Girdwood, Alaska, September 1996. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, Alaska, 40 pages.
- 1998. Implications of Global Change in Alaska and the Bering Sea Region. Proceedings of a Workshop at the University of Alaska Fairbanks on 3–6 June 1997. G. Weller and P.A. Anderson, eds. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, Alaska, 152 pages plus appendices.
- 1999. Assessing the Consequences of Climate Change for Alaska and the Bering Sea Region. Proceedings of a Workshop at the University of Alaska Fairbanks, 29–30 October 1998. G. Weller and P.A. Anderson, eds. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, Fairbanks, Alaska, 94 pages (this volume).

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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]

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[1]1995 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.

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

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

[4]Alaska 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).

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

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

[7] Alaska 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.

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[8] License 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 CO_2 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.

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

[10] Recent 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."

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[11]Kieran 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			
		tons	*year*	tons	*year*	tons	*year*	tons	*year*	Biomass	Catch
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

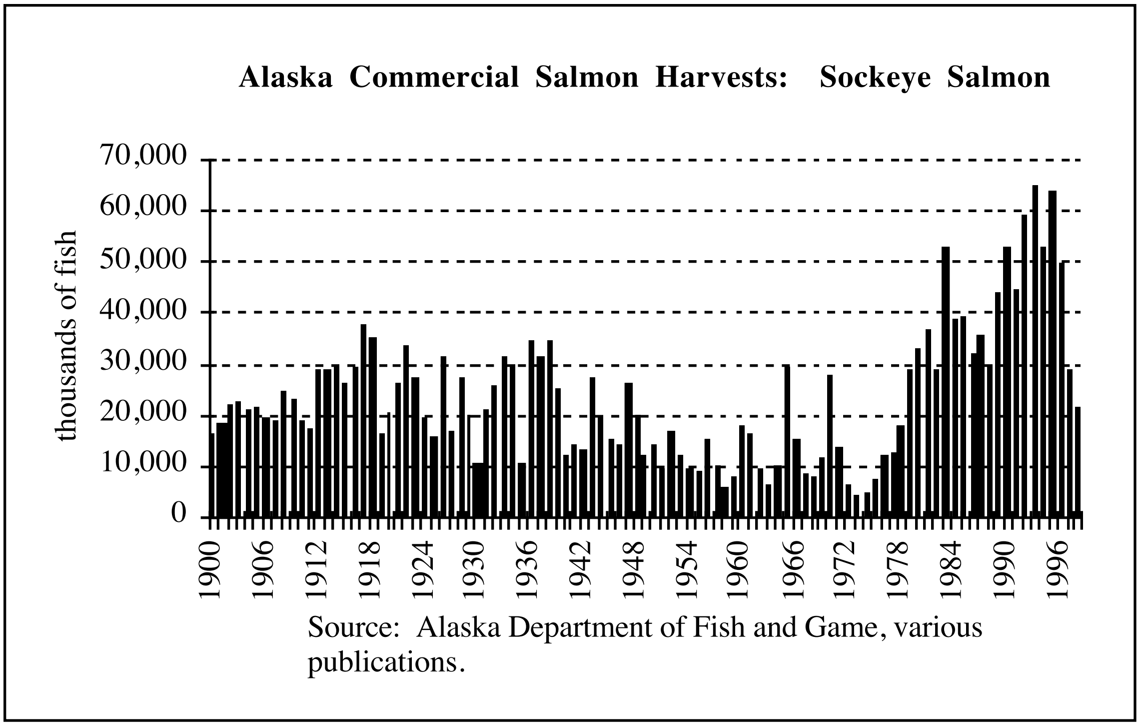


Figure 2

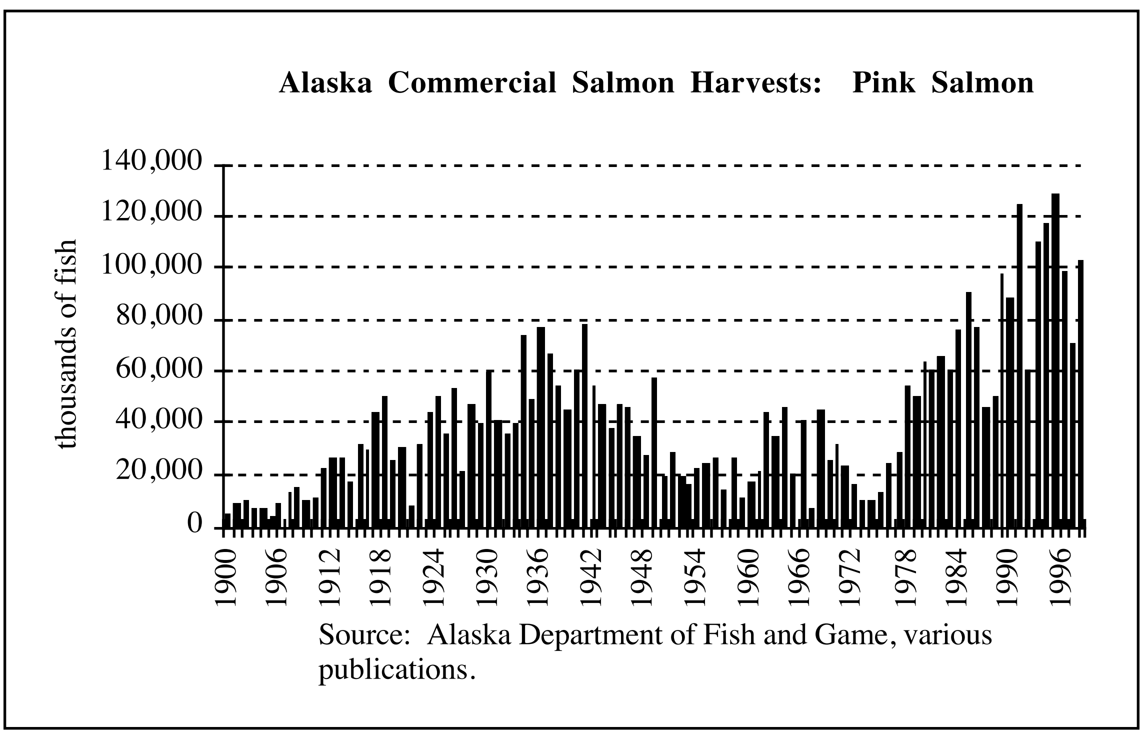
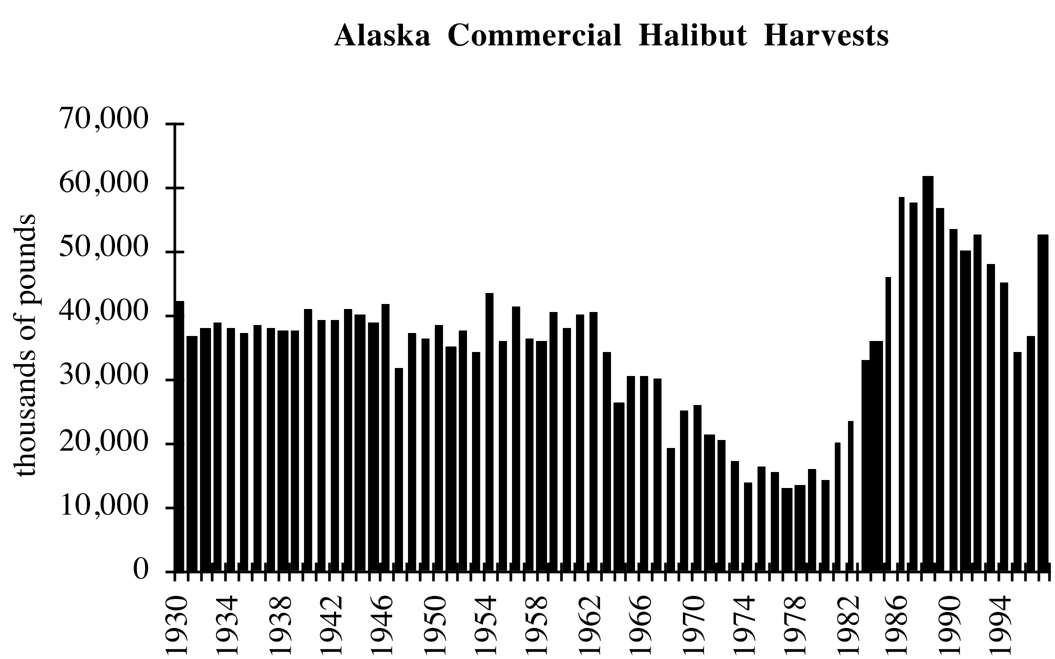


Figure 3



Source: International Pacific Halibut Commission.

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.

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[12]Peter 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.

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[14]Hal 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 institutions. 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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Climate Change and Alaska's Forests: People, Problems, and Policies

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Introduction

Forests cover over one-third of the total land area of Alaska, and forests border the communities in which about 90 percent of Alaska's residents make their homes. Climate change has begun to affect the growth and condition of these forests (Juday et al. 1998). Plausible amounts of additional climate change would likely change both the extent and the character of Alaska's forests (Juday et al. 1998). Alaska residents and public officials would face significant challenges in coping with hypothesized global change effects in its forests. Forest managers face the dilemma of being required to implement often irreversible plans that influence or even produce future forests and yet they must do so amid many uncertainties (Pollard 1991a). Many Alaska forests regenerated today will be experiencing the climate of the year 2100 and well beyond.

This paper discusses potential human effects of climate change on Alaska's forests. It begins with a summary of the role of forests in Alaska's economy, including both commercial and ecosystem values contributed by forests. Next, the paper discusses human dimensions of potential climate effects on forests, focusing on what one needs to know to be able to turn projections of changes in forest ecosystems into flows of impacts to the human environment. Then, it analyzes climate-driven change specifically hypothesized for Alaska forest ecosystems, emphasizing those effects that are likely to have a significant effect on the regional economy and society.

The final section summarizes the most important short-term and long-term regional impacts that emerge from the review of climate effects, and discusses the role of institutions and public policy in reducing costs or increasing benefits of the changes. The paper concludes that hypothesized climate changes on Alaska forests are likely to impose significant short-term costs to the economy and population, and that strategies for mitigating these harmful effects should be considered.

Role of Forests in Alaska's Economy

Alaska contains about 51 million hectares of forest (Figure 1, Table 1), constituting 35.3 percent of the state's total land area (Powell et al. 1993). Approximately 10 percent of Alaska's forest area consists of temperate coastal rainforest and the remaining 90 percent consists of boreal, or interior forest (Labau and van Hees 1990). The federal government is the largest owner of Alaska forest land, followed by the State of Alaska and Alaska Native corporations, and individuals (Table 1). However, average forest productivity is relatively high on most of the national forest and Alaska Native land and parts of the State of Alaska ownership. Much of the non-national forest ownership has low forest productivity. Table 2, the extent of the boreal forest resource, demonstrates that even though millions of acres of productive forest exist in Alaska, a large proportion of forest in Alaska is made up of the marginally productive black spruce type. One measure of the dollar value of forest land is its inherent capability to grow timber, usually expressed as a measure of wood volume per land area per year. Statewide, about 21 million acres or 16.3 percent of total Alaska forest land is classified as

Table 1. Ownership of Alaska Forest Land in Million Hectares (Acres)

Owner	Million Hectares	(Million Acres)	%
State of Alaska	14.17	(35.00)	27.8
Alaska Native	6.11	(15.10)	12.0
State and Native	0.12	(0.30)	0.2
National Forest	4.17	(10.30)	8.2
Other Federal	25.02	(61.80)	49.1
Other Private	1.38	(3.40)	2.7
Total	50.97	(125.90)	100.0

(Source: Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, April 1999)

Table 2. Area of Dominant Forest Cover in the Boreal Forest of Alaska in Million Hectares (Acres)

Forest type	Productive		Marginal		Total		%
Black spruce	0.16	(0.40)	25.26	(62.39)	25.42	(62.79)	55.0
White spruce	2.77	(6.84)	9.33	(23.05)	12.09	(29.86)	26.2
Paper birch	1.35	(3.33)	4.94	(12.20)	6.29	(15.54)	13.6
Aspen	0.64	(1.58)	1.04	(2.57)	1.68	(4.15)	3.6
Balsam poplar	0.32	(0.79)	0.04	(0.10)	0.36	(0.89)	0.8
Black	0.22	(0.54)	0.13	(0.32)	0.35	(0.86)	0.8
All types	5.46	(13.49)	40.74	(100.63)	46.19	(114.09)	100.0

(Source: Labau and Van Hees 1990)

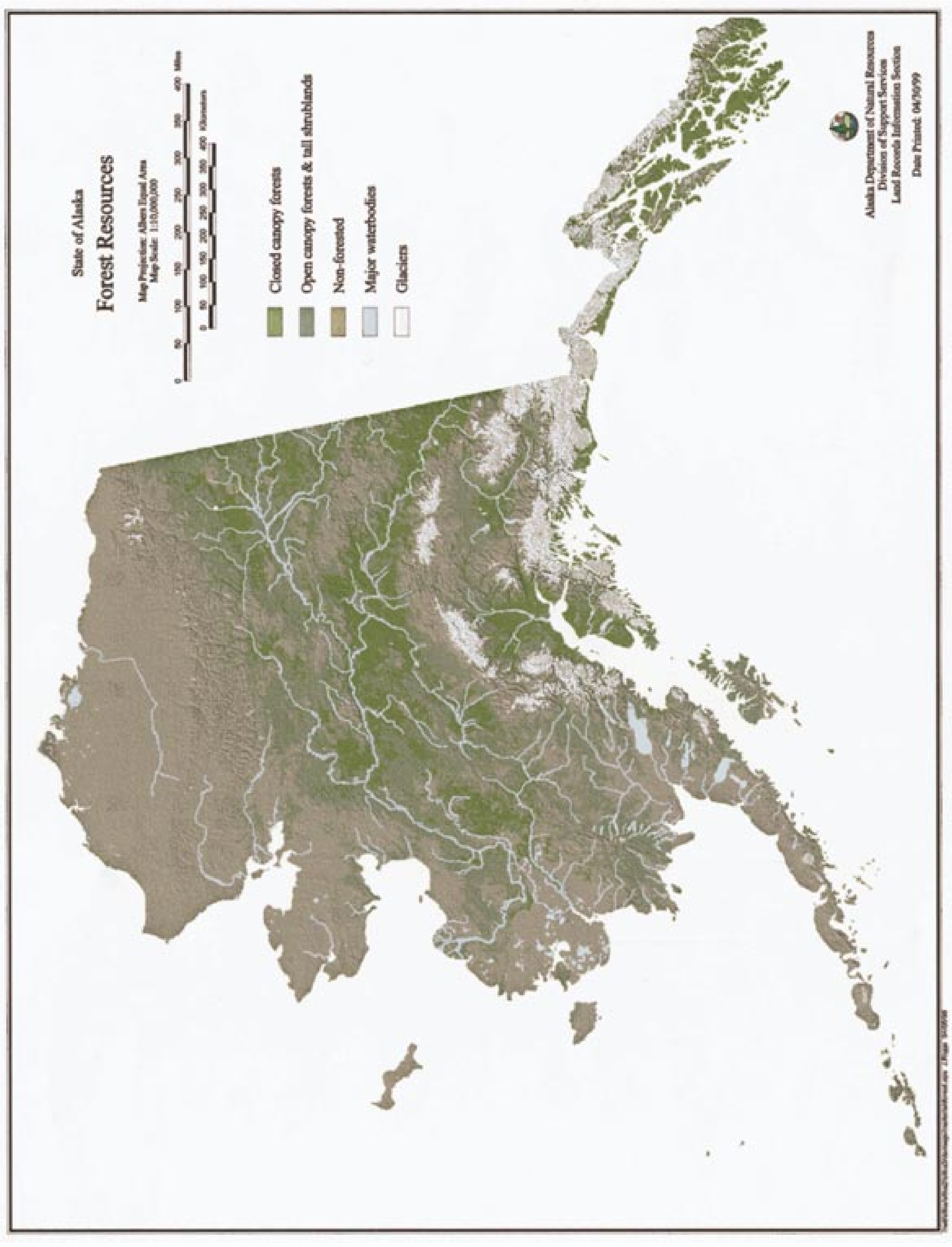

Figure 1. State of Alaska Forest Resources ***(Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, April 1999)***

"productive" forest: that is, land capable of an average growth rate of 20 cubic feet per acre per year (Labau and van Hees 1990).

Forests contribute to Alaska's economy directly through commercial and subsistence harvests of timber. Forests also add value to Alaska's economy indirectly through the contribution of forest ecosystems to socially valuable activities. In Alaska, the indirect ecosystem contributions of forests, generally not measured by dollar flows, are very important and may exceed values obtained from commercial timber operations in many parts of the state. Large areas have been permanently devoted to sustaining these uses in Alaska. About 6 million acres or 40% of the productive forest ("timberland") in Alaska is reserved for non-harvest uses (Powell et al. 1993). A larger proportion of the area of Alaska, including productive forests, has been placed into the strictest categories of nature protection than nearly any other similar-sized region in the world (Juday 1996).

However, a substantial area of productive boreal forest in Alaska has not been placed in parks or reserves and could be committed to timber harvest if landowners, especially the public, decided to do so. In the decade of the 1990s, the structure of the forest products industry in the coastal forest of southeast Alaska was fundamentally altered with the closure of the major wood products processing facilities in the region, resulting in a major decline in production and jobs (Brooks and Haynes 1997). There are two sharply divergent perspectives on these fundamental facts about the values of Alaska's forests, and they have clashed for decades. One perspective interprets the lack of expansion of boreal wood products utilization and the decline in the coastal forest products industry as largely the result of public policy obstacles or decisions that add prohibitive costs. The other perspective interprets the lack of or decline in the wood products industry as a reflection of a series of inherent limitations that will tend to keep Alaska wood products values low for the foreseeable future. Analyzing the effects of climate change on the values of Alaska's forests will inevitably be filtered through these perspectives.

A significant amount of economic activity is generated simply by the basic activities of exercising the rights and responsibilities of ownership of Alaska forest land—activities such as forest inventory, monitoring conditions and trends, wildland fire management, administration of access and permits for use. Those administrative activities will occur under any scenario for the future, although they might need to be intensified under certain conditions that could be caused by climate change.

Commercial Timber Operations

Forest management, especially timber removals, usually must bear the costs of building or extending surface transportation routes because Alaska has relatively few roads. Where the productive forest is distributed in scattered small stands across large landscapes, the productive timberland is, with a few exceptions, not economically reachable. Where the productive forest is found in large contiguous blocks in Alaska, commercial forest values may exceed the costs of establishing or expanding the access system, although often only if the scale of harvest is large. But large-scale timber cutting generates determined social/political opposition in Alaska, and a variety of political, legal, and administrative techniques can at least delay if not halt timber cutting operations. This is the dilemma, or often the stalemate, found in managing land for wood products in Alaska.

The amount of forest land in Alaska that can grow timber on a sustained basis with a (current) market stumpage value exceeding the cost of providing new access to the site is smaller than the area that meets the conventional standard of productive (20 cu. ft./ac./yr.) forest. No single wood productivity figure can be used to define the balance between cost of new access and value of wood because dollar values of stumpage depend on a time-specific and site-specific set of variables, including current markets, modes of transportation available (road, railroad, river, marine) and distance to shipping points. But as an example, applying a figure of 50 cu. ft./ac./yr. results in an area of 4.06 million acres (about 3.1 percent of Alaska's forest land), or about 19% of the area that meets the 20 cu. ft./ac./yr.

standard, excluding the 40 percent of productive Alaska timberland that has been reserved in parks and wilderness areas (Powell et al. 1993).

Most of the area with a high enough current productivity to offset new road cost is located in the coastal forest, which constitutes only 10% of Alaska forest area. Of course, if access can be partially or totally paid for from other activities or users then the amount of operable forest land increases. If low-cost forms of access, such as winter roads on frozen terrain, are practical then the area of forest with positive stumpage value also increases. Continued climate warming eventually would expand the productive forest area significantly (Juday et al. 1998, p. 25). On the other hand, a warming climate is decreasing the amount of time when winter access is safe (ice bridges across rivers), and increasing the extent of permafrost thawing, which severely disrupts the ground surface.

Total Alaska timber harvest increased from 618 to 1,100 million board feet between 1986 and 1990, then declined to 685 million board feet by 1996 (Timber Supply and Demand 1996). The policies controlling the timing and level of harvest on public versus private forests in Alaska are quite different. Roughly two-thirds of the wood products harvest in Alaska in recent years has been taken from Native corporation lands and was exported "in the round"—without processing or manufacturing. The Native corporation harvest was not planned to be sustainable, but to convert assets into cash during a time of favorable prices. Exports of round logs in 1996 amounted to 530 million board feet of logs worth about $370 million (Warren 1998). The Asian economic crisis of the late 1990s has dramatically reduced the export price and volume.

National forest timber harvests in Alaska and the rest of the U.S. are required to be at an annual level that can be sustained over time. Until the mid-1990s the level of national forest harvest in Alaska was driven by long-term contracts to supply two pulp mills. The Tongass Land Management Plan Update, conducted from 1988–1998, significantly expanded the land area reserved from timber harvest and substantially reduced the overall level of planned timber cutting. The two pulp mills in Alaska closed operations in the mid-1990s, initiating a restructuring of the industry in the southeast panhandle of Alaska. Factors contributing to this decline included changes in the structure of the Alaska forest sector, changes in markets for Alaska products, changes in conditions faced by Alaska's competitors (Brooks and Haynes 1997), and the increased costs associated with operating on the land base that was made available for timber harvest. Over the period 1990–1996, harvest of national forest timber in Alaska declined by nearly 80 percent.

Average annual employment in Alaska's logging, lumber, and pulp industries has fluctuated between 2,000 and 4,000 over the past four decades. Employment peaked in 1990 at just under 4,000, constituting 1.4 percent of total Alaska employment in that year (U.S. Bureau of Economic Analysis, unpublished data; Goldsmith and Hull 1994). Labor and self-employment income in forest products also peaked in 1990 at about $200 million. Employment and income in the forest products industry declined by about 35 percent between 1990 and 1997, to about 2,500 employees (Warren 1998) and $130 million in wages and self-employment income (U.S. BEA, unpublished data). The two main causes of the decline in the 1990s are the closure of the two dissolving pulp mills in Southeast Alaska and the depletion of Native corporation sawtimber inventories.

Reorganization of the forest processing industry supplied by timber from the Tongass National Forest following closure of the two pulp mills has created room for potential new manufacturing facilities. Total mill capacity in the region in 1990 equaled the equivalent of 745 million board feet in 1990 when both pulp mills were operating. By 1996, Southeast Alaska mill capacity had shrunk to 207 million board feet (Hill and Hull 1997). The potential for expanded production of higher value sawn products has attracted attention from communities affected by job losses and from prospective investors. If investment is made in new processing capacity, manufacture of higher value products could expand significantly from the current depressed level. However, new investment is not likely to happen if access to timber on the Tongass National Forest is subject to the uncertainty typical of the changes in policy that have unfolded over the last two decades. Whatever the short-term changes in markets and policies, forest products industry employment and income derived from forest products are unlikely to achieve the 1990 level again in the next several decades. Projections of demand for Alaska national forest timber over the next decade (1998–2007) range from 113 to 156 million board feet (Brooks and Haynes 1997), well below the 300 to 500 million board feet levels typical of 1970–1990.

About 90 million board feet of dimension lumber are used in construction annually in Alaska and the great majority is imported. Substitution of Alaska manufactured timber for imported products would increase the base level of timber harvest, generate more economic benefits within Alaska than imports, and could easily be accommodated from land already allocated to timber production. Products manufactured from Alaska timber would be suitable to replace 65–70 million board feet of the current volume of wood products imports. Some of the steps necessary to achieve import substitution are relatively simple, such as establishing a lumber grading system and properly drying manufactured wood. Ultimately, new investment in infrastructure and manufacturing processes might be required to produce an Alaska wood product that would compete with some imported products.

If the assumption is made that demand and prices will rise and the public will allow expanded timber cutting under certain circumstances, then the size and economic value of the Alaska forest products sector will likely increase, and thus the risk of harm to it from climate change increases. If the assumption is made that access continues to be expensive (prohibitive), that manufacturing cost disadvantages in Alaska persist, and that public attitudes about expanded timber cutting on the public lands are negative, then the size and economic value of the Alaska forest products sector will likely remain at current (historically depressed) levels, and thus the risk of harm from climate change is not likely to be as relatively large a factor in its future.

Much of recent Alaska forest management has been described as "opportunistic." As inventory data have accumulated, publicly built access systems have expanded, and new scientific insights and data handling tools have become available in Alaska, professional forest managers have anticipated setting and accomplishing goals more systematically. However, the increased uncertainty associated with climate change that has already been experienced in Alaska makes long-term planning and management considerably more difficult.

Ecosystem Contributions

Forest ecosystems play an important role in Alaska's economy through indirect ecosystem effects. The Ecological Society of America defines ecosystem services as "... fundamental life-support services without which human civilizations would cease to thrive." (Daily et al. 1997). Some examples of ecosystem services include:

- Purification of air and water.
- Mitigation of droughts and floods.
- Generation and preservation of soils and renewal of their fertility.
- Cycling and movement of nutrients.
- Protection of coastal shores from erosion by waves.
- Partial stabilization of climate.
- Provision of aesthetic beauty and intellectual stimulation that lift the human spirit.

Alaska forests contribute ecosystem services especially important to the economy through support of subsistence activities, commercial fisheries, sport hunting and fishing, and values of non-consumptive uses of the forest involving tourism, recreation, and enhancement of the quality of life. It is difficult to separate the specific contribution of forests from the contributions of other components of the biosphere in the provision of ecosystem services. Consequently, one may only obtain very rough indicators of the magnitude of the contribution of forest ecosystems on the state economy. Alaska forests also benefit people outside Alaska by helping to regulate global climate, trap atmospheric carbon, and filter air pollutants.

On a global basis, boreal forest cover by itself is a significant factor in determining the amount of energy that is absorbed by the earth's surface and is available to heat the atmosphere (Bonan et al. 1992). In terms of future global climate change, the most important influence of the world boreal forest may be its influence on atmospheric carbon dioxide levels. It has been estimated that a forest managed for maximum sustained yield of timber has a mean lifetime carbon storage about one-third that of a stand maintained at maturity (Cooper 1993). The boreal forest is one of the most intact major vegetation regions of the earth. But not all natural boreal forests in Alaska remain in older age classes; the areas burned or subject to insect-caused tree mortality are very large. Major uncertainties about the influence of the boreal forest on global carbon balance remain, making an economic analysis premature. For example, without detailed regionally based climate scenarios, the balance of uptake versus release of carbon dioxide from the boreal forest cannot be determined. It is not entirely clear whether a slight acceleration of decomposition of wood and forest litter over large areas in a warmer climate would release more carbon dioxide to the atmosphere than an increase in the frequency or size of forest fires caused by climate warming. Accelerated growth of boreal forest vegetation and the expansion of forest into tundra would increase the uptake of atmospheric carbon dioxide, but it is not clear that this would happen in a straightforward way in response to a warmer planet. Finally, the mechanisms to place values on the various carbon transfers are not fully in place. However, if an effective, market-driven system of valuing transfers of carbon is adopted or mandated at an international level, Alaska forests could potentially generate large dollar flows from management treatments designed to store carbon.

Most anadromous fish harvested in Alaska waters spawn and rear in freshwater streams whose water quality and quantity is regulated by forest lands. Alaska commercial salmon harvests in 1997 amounted to 624 million pounds of salmon worth $274 million. Harvest quantities and prices for salmon vary from year to year. In 1994, Alaska commercial fishers harvested 866 million pounds worth $489 million (Alaska Department of Fish and Game, unpublished data). In 1986, the last year for which systematic estimates were made, the commercial salmon fisheries attracted 20,000 participants, generating an average monthly participation of 6,836 (McDowell 1989). In addition to harvesting employment, roughly one-half of the approximately 12,000 annual average seafood processing jobs can be attributed to the salmon fisheries (Goldsmith and Hull 1994).

In 1993, nonresident tourists spent $199 million on sport fishing trips to Alaska, and were willing to pay an additional $72 million for the experience, for a total value of $271 million (Haley et al. 1997). Most of the nonresident anglers targeted salmonids or char either spawned or resident of streams and lakes draining forested watersheds. Approximately 70 percent of Alaska households sport fish at least once every three years, and the estimated value of sport fishing opportunities for residents was $105 million (Haley et al. 1997). Although the contribution of forest ecosystems to creating sport fishing opportunities is substantial, it is impossible to determine an exact percentage of sport fishing values to attribute to forests.

Many of the big game animals most important to hunters depend on forest ecosystems, including Sitka deer, moose, black bear and coastal brown bear. In addition, caribou and mountain goats utilize interior and coastal forests, respectively, for winter range. The most important furbearing mammals are forest residents. It follows, therefore, that forest ecosystems play a critical role in supporting subsistence and sport hunting and trapping activities.

The term "subsistence" in Alaska denotes an economic system based on harvest, non-market distribution, and consumption of local natural resources (Wolfe et al. 1984). Subsistence economies of communities in Southeast, Southcentral, and Interior Alaska are particularly dependent on Alaska's forest ecosystems. In addition to hunting and fishing, subsistence users harvest a variety of plant materials such as wood, berries, and herbs directly from the forest.

In addition to the consumptive use of plants, fish, and wildlife produced by forest ecosystems, many residents and visitors enjoy non-consumptive uses of Alaska's forests. Over one million nonresident tourists visit Alaska annually, and this number continues to grow rapidly (Alaska Division of Tourism, unpublished data). Forests create specific scenic resources for major segments of the tour industry, including cruise ships and state ferry routes up the Inside Passage in Southeast Alaska and in Prince William Sound, and near the rights of way of the Alaska state highway system and the Alaska Railroad. For Alaska residents and visitors alike, forests make an unquantifiable contribution to recreation opportunities and the quality of life.

Assessing Human Dimensions of Climate Change

Suppose we have some projections of climate-driven changes in regional ecosystems. What information would we need about these projected changes in order to assess their potential human impacts?

What Do We Need to Know?

The magnitude of the impact of a potential ecosystem change on economic and social systems depends on the answers to four main questions:

- How certain are we that the effects will indeed occur?
- How large, or widespread will the impact be?
- How costly or valuable is the effect if it occurs?
- When will the effects occur?

Juday et al. (1998) provide information about projected changes in forest ecosystems resulting from hypothesized regional climate change. They discuss the likelihood that various specific changes might occur, and how widespread the changes might be. They also discuss the direction of effects, in terms of whether the resources mentioned are likely to be enhanced or degraded. Juday et al. (1998) do not address specifically how valuable are the resources at stake or how costly the damages might be. They also do not explicitly state how soon they believe the ecosystem changes will begin to affect human activities or values.

The importance of timing cannot be overstated. The cost of damages, in particular, depends greatly on whether the effects are incurred as a gradual shift or as an abrupt (or catastrophic) event. Given enough time, human systems can and probably will adjust to changes in climate regimes with little adverse effect. One needs only to glance at history to understand this point. Although Alaska experienced an abrupt climate shift in the late 1970s (which may or may not persist or intensify), the time scale during which greenhouse-gas climate effects are likely to occur is on the order of one to two centuries. What historical changes have taken place in technology, social relations, and settlement patterns in the past century or two? It is no easier for us to predict what Alaska's economy will look like and how people will live 100 years from now than it would be for Klondike gold-seekers to imagine North Slope oil development and the Trans-Alaska pipeline. We do not know if there will be a global forest products industry in 2100, or what it might look like.

This implies that an assessment of the human dimensions of climate change should consider slowly developing changes in ecosystems differently from more immediate effects. Long-term benefits of ecosystem changes may be substantial, but are likely to be submerged in other changes such as in technology, shifting markets, and global needs, and so they will be little noticed by future generations. Costs of slow ecosystem degradation will be small, since people would be more able to adjust to the new conditions. Near-term events, on the other hand, are likely to be more costly, since the population and economy will have less time to adjust. Sudden events in particular are likely to be much more important than events that we can foresee and plan for.

Three Time Horizons for Viewing Regional Effects of Climate Change

The preceding discussion suggests that it may help to distinguish three time horizons for analyzing the effects of climate-driven change in Alaska's forests, as follows:

1. **Short-term**—likely to occur within the next 10–20 years

2. **Intermediate-term**—may occur during the next half century but not immediately likely

3. **Long-term**—effects generally occurring after 2050

The relevant time horizon refers to the period during which forest ecosystem changes may begin to affect economic and social systems. Some short-term effects are already occurring as a consequence of climate warming since the 1970s (see Juday et al. 1998).

The next section reviews various hypothesized short-term, intermediate-term, and long-term changes in forest ecosystems. The approach to addressing economic and social effects of changes differs, depending on the time horizon during which the effects are likely to begin. Short-term effects that are likely to occur and are large in their projected extent will receive quantitative assessment of the potential economic and social effects. Intermediate-term changes will be discussed in terms of order of magnitude of effects, keeping in mind that changing technology and global needs make any predictions rather speculative. Long-term changes will be discussed only in qualitative terms.

Climate-Driven Changes in Alaska Forest Ecosystems

Juday et al. (1998) review 36 direct potential effects of climate change on forests in Alaska, including 17 potential effects on coastal forests and an additional 19 on interior forests. They classify the potential effects by the authors' confidence that they would actually occur and by whether the effects would tend to enhance or degrade forest resources. The analysis below groups Juday et al.'s 36 potential impacts into two categories on the three time horizons discussed in the previous section. The analysis omits hypothesized changes for which effects on people are unlikely to be significant, especially those for which Juday et al. (1998) are unsure of the sign of effects on resources or have less confidence that they will occur. As mentioned above, the analysis here includes only regional effects of forest ecosystem processes. For example, effects of changes in boreal forest as a regulator of global climate are not considered.

Climate change may directly affect existing forest resources by changing the physical environment. Climate may also create more indirect effects as forest ecosystems adjust to the changes in the physical environment and interact with a changing pattern of human activities. Table 3 summarizes the effects enumerated in Juday et al. (1998) grouped into direct effects of changes in physical environment and indirect effects of ecosystem changes, for each of the three time horizons. While Juday et al. focused on effects on forest resources, the emphasis here is to identify important effects on people.

Table 3. Summary of Potential Effects of Climate Change on Alaska's Forests with Important Human Consequences

Time Horizon: Period when significant effects begin	Direct Effects of Changes in Physical Environment	Indirect Ecosystem Effects
Short term: 0-20 years	Increased risk of catastrophic wildfires in settled areas.	Increased defoliator insect and bark beetle epidemics.
	Increased windthrow in coastal forests.	
Intermediate term: 20-50 years	Hydrological changes in forested watersheds—warm stream temperature, lower summer flow from low elevation streams, higher flow from higher elevation streams.	Increased growth rate of young forests, mitigated by appearance of new fungal tree diseases (coastal areas), or moisture stress (interior areas).
	Fires may appear for the first time in coastal forests.	White spruce natural reforestation failures in large disturbed areas.
		Changes in ranges of vertebrate animals; changes in aquatic productivity.
Long term: more than 50 years	Glacial retreat and thawing of permafrost opens new territory for forest colonization.	Changes in range of tree species and ecotypes.
	Interior precipitation deficit increases, increased convective storms.	Increased coastal site productivity allows for greater commercial timber harvests.

(Adapted from Juday et al. 1998)

Short-term Effects

Principal direct effects of changes in physical environment that are already occurring as a result of climate change or are likely to begin within the next two decades include increased incidence and intensity of wildfires in transitional and interior forests, and increased windthrow and blowdown in coastal forests. The main additional ecosystem change that may indirectly result from the effects on the physical environment is an increase in spruce bark beetle and defoliator insect activity. The direct and indirect effects strongly interact with each other, as fire risk may increase in forest stands that have suffered substantial mortality from insects and/or windthrow.

Insect Disturbance. The spruce bark beetle *(Dendroctonus rufipennis),* a primary disturbance agent in Alaska's spruce forests, is responsible for over 2.3 million acres of cumulative tree mortality statewide since 1992 (USDA Forest Service & Alaska DNR Forestry 1997). The area affected is the largest area of tree mortality from a single insect outbreak documented to date in North America (Werner 1996). Climate-warming trends recorded throughout Alaska during the past 15–20 years generally correlate with spruce bark beetle infestation increases during the same period. The extensive tree mortality in this outbreak has come about from rapid increases in spruce bark beetle populations via shortened developmental times, and a general increased susceptibility of the spruce host; both of these contributing factors are temperature-induced responses. Increased mean annual temperatures favor a rapid buildup of spruce bark beetle populations to epidemic levels that essentially overwhelm spruce host tree defenses over extensive areas. At the same time spruce bark beetle activity has increased so has other forest insect activity, primarily in the boreal forests of interior Alaska. Spruce budworm *(Choristoneura fumiferana)*, coneworm (*Dioryctria reniculelloides*), and larch sawfly (*Pristiphora erichsonii*) defoliations mapped throughout interior Alaska have increased significantly, totaling over 800,000 acres of combined infestations in recent years (Holsten and Burnside 1997). As with spruce bark beetle activity trends, the most significant increases in conifer defoliator activity in the boreal forest have occurred during the warmest decade, the 1990s.

Changes in spruce activity trends are most easily illustrated from the Kenai Peninsula spruce bark beetle outbreak, which has expanded from approximately 40,000 acres mapped in 1989 to over 1 million acres of cumulative activity as of the 1997 aerial surveys. An illustration of the rapid expansion of this outbreak is seen in a comparative spruce bark beetle activity map for the period 1993 to 1998 (Figure 2). This map shows the relative expansion of new and ongoing spruce bark beetle activity in relation to older (brown/gray) activity as a means to demonstrate relative expansion of the insect. Another way to quickly demonstrate insect activity patterns in a way that can be correlated with other regions (in this case statewide cumulative spruce bark beetle activity), and possibly climatic trends, is to prepare comparative GIS maps for different periods (see Figure 3). We are just beginning to look at climate trends in relation to spruce bark beetle activity for the Kenai Peninsula outbreak. In this case, mean annual temperature increases of 3–4˚F since about the mid-1970s seem to be correlated generally with “red needle” beetle infestation acreages determined from the annual aerial surveys during the same period (personal communication, Ed Berg, USFWS).

From an economic perspective, the cost of damages caused by insects is measured by the value of timber losses plus the cost of efforts to suppress the attacks or plan land rehabilitation measures. A variety of techniques have been developed for reducing the susceptibility of forests to insect attacks at ordinary levels, including thinning stands, prescribed burning and other silvicultural treatments (Werner 1998). However, only the most costly and intensive measures applied on a tree-to-tree basis have been able to provide effective protection at the extreme spruce bark beetle outbreak levels experienced in southcentral Alaska during the late 1990s. Pesticides and biological control agents are available for spot treatment of beetle-infested trees. Public agencies have not embarked on a pesticide spraying program due to the high cost relative to the value of resources affected and concern over potential environmental effects. On a neighborhood level, however, many home and business owners in Anchorage and other affected communities have used the services of commercial pest control companies to protect individual trees on private property. The cost incurred by private property owners of pesticide spraying to protect their trees against insect attacks should be counted as a cost of climate change. No compilation of these costs is available. Carbaryl and lindane, the two insecticides most widely used by commercial pest control companies to control spruce bark beetles in Alaska, can be toxic to fish and wildlife. If high cumulative levels of insecticide application occurred, or if the insecticides were applied improperly, the resulting costs to fish and wildlife would represent another impact.

During the early phases of the Kenai Peninsula spruce bark beetle outbreak, public sector professional foresters proposed salvage/sanitation logging treatments to reduce the extent and rate of spread of the outbreak, and later to simply capture wood product values that rapidly deteriorate as dead trees stand exposed to the elements. Environmental groups mobilized to resist proposed logging, and wildlife professionals identified risks from logging, especially expanded road systems, to wildlife populations of interest. By one count over 100 public meetings of local residents and the interested Alaska public have taken place since the early 1990s with insect-caused tree mortality as the main subject. In the

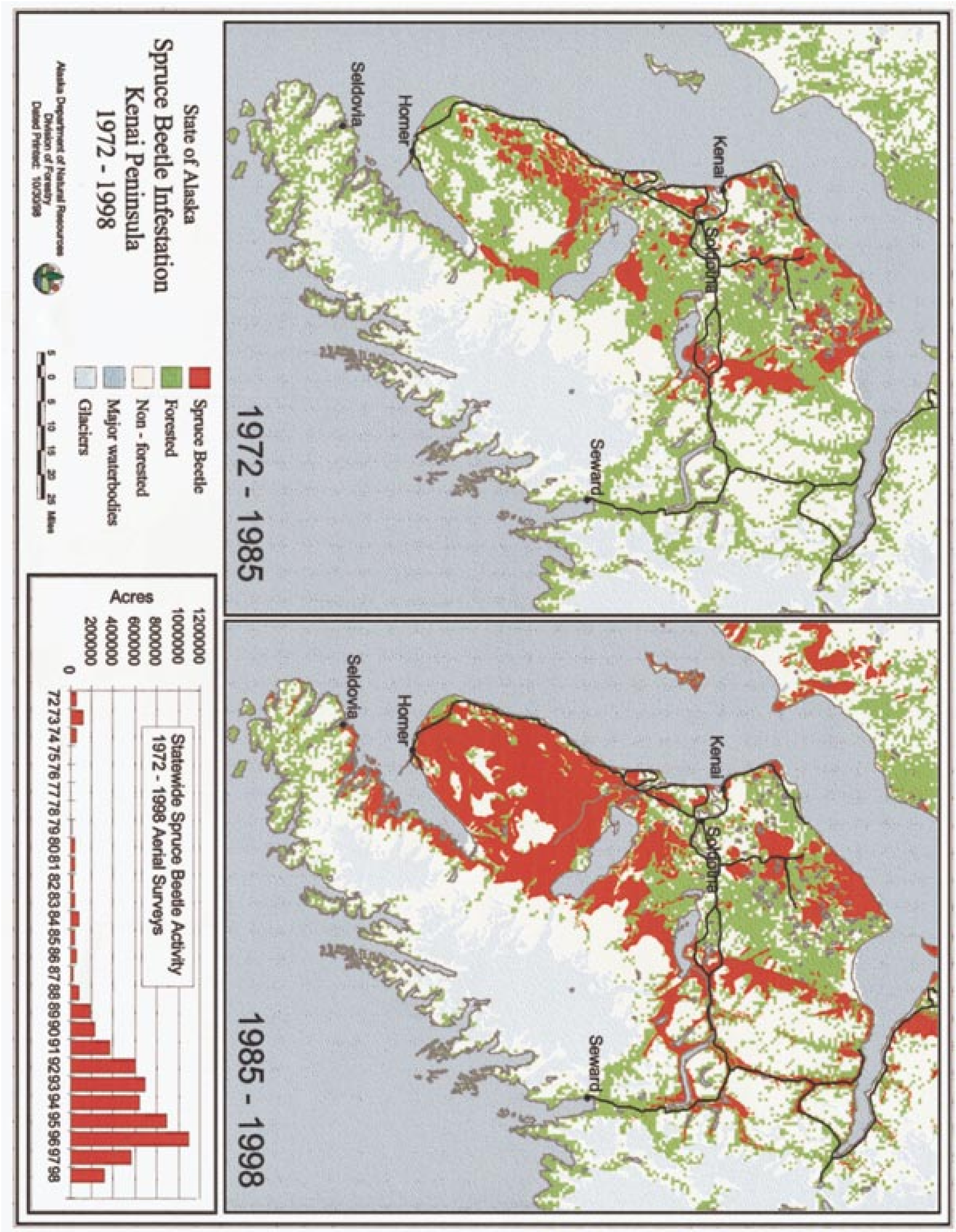

Figure 2. Early and recent total extent of spruce bark beetle infestation on the Kenai Peninsula ***(Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, October 1998)***

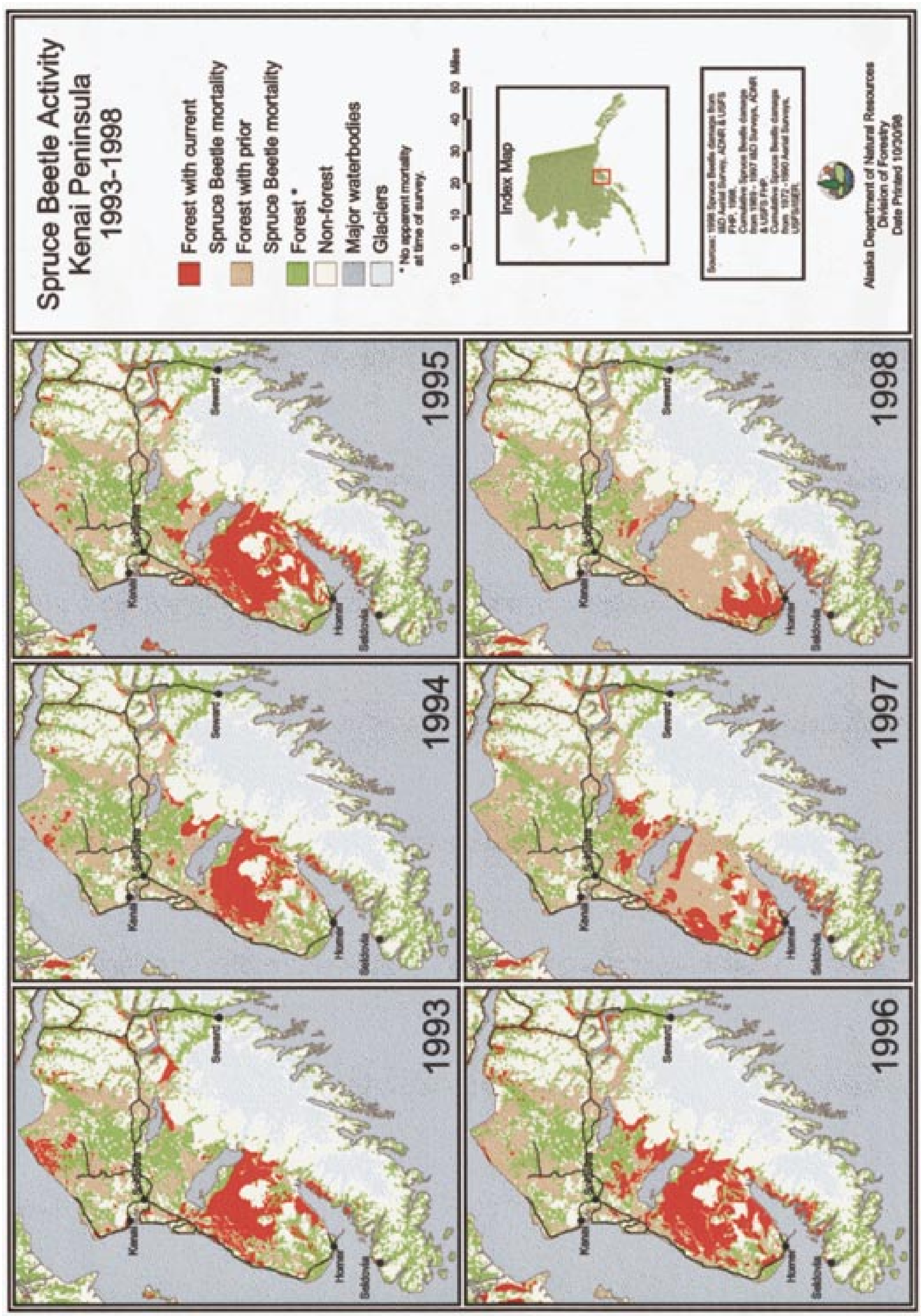

Figure 3. Annual spruce bark beetle activity on the Kenai Peninsula, 1993–1998 ***(Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, October 1998)***

end hardly any salvage logging has taken place on public lands. Both sides of the debate incurred substantial costs to achieve what they both perceive as very little. By the late 1990s, most of the susceptible spruce trees in the beetle outbreak area had been killed. If land management prescriptions to address the effects of spruce bark beetle–caused tree mortality are implemented in Alaska, the sale of salvaged timber might recover costs in some areas treated but would not recover costs of treatment in other areas. The cost of these programs, including social costs, should be counted as an impact of climate change.

Some Alaska private forest owners were confronted with the sudden and complete death by spruce bark beetles of mature trees on land they had planned to harvest gradually. With the need to cut rapidly or lose further value, they have removed the insect-killed trees but have little or no profit to provide for tree regeneration. As a result, a backlog of non-stocked or understocked timberland is another probable result of Alaska's climate-related insect outbreaks.

Even on sites with low commercial timber values that have been affected by insect epidemics, the death of extensive stands of trees may cause a significant loss of aesthetic values (Purcell 1998). Salvage logging either is occurring or is planned in certain areas near human settlements to reduce the risk of catastrophic wildfire and to ensure emergency access and egress from landscapes likely to experience wildfire. For example, the state of Alaska established reduced fuel load buffers around Moose Pass and Cooper Landing on the Kenai Peninsula to reduce the risk of forest fires spreading into these communities. It is probably not feasible to treat all the land necessary to guarantee the safety of all suburban subdivisions within the area at risk. Prescribed fire also could face public opposition, however, and is difficult to impossible to implement in suburban subdivisions. In unpopulated parts of Alaska, prescribed fire at the landscape level is effective in reducing fuel loads in the boreal forest and is one of the least costly land treatments available per unit area. The specific effect of a prescribed fire changes as the fuel and vegetation characteristics of the dead forest stand change, and more needs to be learned about the effects of prescribed fire over time across the large area affected by the spruce beetle outbreak.

Since it is not clear whether any large-scale salvage logging or prescribed burning program will be implemented in Alaska, it would be speculative to attach a dollar figure to the cost of programs to mitigate the damage to aesthetic values and control fire risk in insect-damaged forests.

Wildfire. Wildland fire is a natural disturbance agent in the boreal region of Alaska, and a natural fire regime promotes many aspects of the health, productivity, and biodiversity of the Alaska boreal forest. However, the human consequences of the increased risk of certain kinds of wildfire in a warmer Alaska climate could be enormous. Approximately 80 percent of the population of Alaska lives in communities potentially affected by the increased fire risk. Areas at risk include most areas with dispersed or suburban settlement in the interior and transitional coastal/boreal forests. While professional firefighting organizations defend towns and villages against all but the most catastrophic fires, dispersed settlement and isolated rural cabins are much more difficult and costly to protect. Areas of particular concern include much of the Tanana Valley, the Copper River Basin, the Matanuska-Susitna and Kenai Peninsula Boroughs in Southcentral Alaska, and suburban areas of Anchorage such as Hillside neighborhoods, Eagle River, and Chugiak. In the longer term, coastal forest communities of Southeast and Southcentral Alaska could conceivably be at risk from wildland fire. However, generally lower fire intensities and settlement geography in narrow bands along the coasts would keep risks low, with the possible exception of suburban Haines.

The damages from wildfire and the cost of fire protection are largely determined by the geography of settlement patterns and settlement policy. In Alaska, large-scale dispersed settlement in forest land is a recent phenomenon. Alaska Native groups in Interior, Southcentral, and Southeast Alaska have always lived in or adjacent to the forest, of course, as did trappers and gold prospectors in Territorial days. However, these populations were highly mobile, and tended to concentrate their seasonal homes in villages, or in isolated cabins and camps at very low densities per land area. There was never a high settlement density nor any substantial fixed infrastructure. Consequently, even though wildfires occasionally destroyed property, the total damage from a given fire was generally small.

Since the 1970s, government policies have created a completely new settlement geography. Using federal and state funds, state and local governments have built a network of rural highways and access roads. State and local governments disposed of hundreds of thousands of acres of formerly federal land that was transferred to the state under the Alaska Statehood Act to private ownership (Leask 1985). Most of this newly private land was intended for homesites in forested land. There are no statistics available documenting the number of homes that have been built as a result of these disposals, but it is clear that this set of government policies has completely changed settlement patterns on the Kenai Peninsula, and throughout the Matanuska, Susitna, Copper and Tanana River valleys.

At the same time as major land disposals expanded rural and suburban non-Native settlement in areas of Alaska, another set of federal and state programs transformed Native villages into permanent fixed communities with significant and expensive infrastructure. New schools, community facilities, bulk fuel storage facilities, public utilities, and airports were built in hundreds of communities around the state, including at least 60 small communities surrounded by boreal forests in Interior and South-central Alaska. These infrastructure investments mean that if wildfire does engulf a Native village, the damage will be an order of magnitude greater than it would have been just a generation ago. Where a wildfire may once have burned a few isolated cabins, it might in the future cause catastrophic loss to or of entire communities.

Over the long term, settlement patterns will change. However, absent a major shift in policy toward public provision of transportation and other rural and suburban infrastructure, the change is almost certain to be in the direction of further expansion of dispersed settlement and entrenchment of villages in forested areas at risk from fire. Already settled areas are unlikely to be abandoned even if damaged by wildfire or highly likely to be affected by future fires. The change will almost certainly increase the damages from the typical large wildfire at the same time as the incidence and scale of fires increase.

Miller's Reach fire example. The Miller's Reach Fire No. 2 of June 1996 provides an example of the magnitude of potential losses from wildfires in settled areas of Alaska. The fire burned approximately 37,000 acres of forest and peatland in a portion of the Matanuska-Susitna Borough with extensive suburban and vacation home development. The blaze was apparently ignited on June 2 by children setting off fireworks. The fire spread quickly though black spruce and peat dried from a spring with abnormally high temperatures and low precipitation. Although no people died from the fire, it destroyed 454 structures, including about 200 homes, before being brought under control on June 15 (Nash and Duffy 1997).

Table 4 summarizes various costs resulting from the Miller's Reach fire. The direct cost of fire suppression efforts totaled $16.5 million. Losses of buildings and personal property were valued at $60 million, not counting any depreciation of land value. In addition, public utility companies lost $1.2 million in facilities and Alaska Native corporation landowners lost about $250,000 in commercial timber (Nash and Duffy 1997). This total direct cost of nearly $80 million must be considered a lower bound to the cost of the fire. In addition to the direct cost of control efforts and property damage, the fire severely disrupted the economy of the Matanuska-Susitna Borough and the lives of its residents. About 4,000 residents were displaced from their homes, and 200 families were left homeless. Businesses in the affected area lost much of their business for several weeks. Productivity of workers throughout the region suffered greatly for the two-week period before the fire was brought under control. These indirect economic costs, as well as the psychological effects of fear and loss, cannot easily be quantified.

Table 4. Social Costs of Miller's Reach Fire, June 1996

Type of Loss	Dollar value if available (million dollars)
Firefighting expense	16.5
Damage to commercial structures	9.2
Loss of residential structures and personal property	51.1
Damage to public utilities	1.2
Loss of commercial timber stumpage	0.3
Total of quantified items	78.3
Loss of productivity and business profits	N.A.
Psychological loss: 200 families homeless, 4,000 people temporarily displaced, fear and anxiety, aesthetic loss, etc.	N.A.

(adapted from Nash and Duffy 1997)

Intermediate-Term Effects

Intermediate-term effects include direct effects of changes in physical environment or indirect ecosystem effects that may begin to affect people between two and five decades from now. One potentially significant direct intermediate-term effect of changes in physical environment might be a set of hydrological changes in forested watersheds in coastal areas. Another physical change for coastal forests might be the appearance of forest fires for the first time in the historical period.

Coastal forest hydrology. Juday et al. (1998) postulate an increase in stream temperature with seasonal low flows in low elevation streams along with higher seasonal flows from higher elevation streams in the coastal forest region. Declines in anadromous and resident fish populations could result from these hydrological changes, including adverse effects on salmonid species important to subsistence, commercial, and sport fisheries.

While the quantitative effects of changes in stream hydrology are speculative, it is possible to gain an idea of the order of magnitude of potential fisheries effects by considering current harvest levels of salmon species in Southeast Alaska. If current fisheries management provides a guide to future decisions, one would hypothesize that the subsistence and sport fisheries would be largely protected from harvest declines, and that most of the conservation burden would fall on the commercial sector. For example, a 25 percent decline in salmon stocks evenly spread among all five harvested species, if absorbed entirely by the commercial harvest (excluding the recreational and subsistence catch) in Southeast Alaska, would reduce the commercial catch by 20 percent. That would mean an annual loss of $20 million in gross earnings, based on the average harvests and prices over the past five years (Alaska Department of Fish and Game, unpublished data).

Coastal forest fires. It is difficult to predict the magnitude of area burned in a region with no historic records of fire. Most fires would probably be small and of low intensity, with negligible effects on commercial timber or other forest values. One might imagine a scenario in which 5,000 acres of coastal forest burned over a period of several decades, causing a reduction of one percent in annual commercial harvests. Based on 1996 figures, a one percent reduction would lead to about a $5 million loss of value added annually, with an associated average annual loss of about 25 jobs.

Intermediate-term ecosystem changes. A variety of indirect ecosystem changes might appear in the 20–50 year intermediate time horizon. Growth rates of young forests would increase with climate warming. The appearance of new fungal tree diseases in coastal areas and increasing moisture stress in interior areas would mitigate or in some cases counteract the increased tree growth, however. In coastal areas, one might hypothesize that the increased growth might increase harvests by one or two percent, approximately offsetting losses due to fire in the intermediate term. Increased growth would not have a larger effect on forest yields in this time horizon since few young growth trees that might benefit from the more favorable climatic conditions would be large enough yet to harvest.

Another effect postulated by Juday et al. (1998) was a potential reduction in frequency of white spruce cone crops, with less effective dispersion into large disturbed areas. Artificial reforestation (either seeding or planting) could compensate for any failure of natural regeneration. Since it is not clear that there would be any significant commercial value to the regenerated white spruce, and other species such as aspen and birch would be able reforest disturbed areas, one should not assume any loss of value for the delayed regeneration of spruce. Juday et al. (1998) also discuss potential changes in range of vertebrate animals and changes in productivity of aquatic ecosystems in forest lands. Since they did not determine a clear direction of these effects, no values need be estimated for them.

Long-Term Effects

Change in extent of forest land. By 2010, increases in temperature and the length of the thaw season would have been large enough and of long enough duration to thaw significant areas of permafrost in Interior Alaska and melt low elevation glaciers in coastal mountains. The length of the growing season would increase, and summer temperatures would rise by as much as 4˚C (Weller et al. 1998). Precipitation increases in the same scenario, although an increase in summer temperature along with increased convective storm activity may increase the frequency of precipitation deficits in portions of the boreal forest.

While these changes in the physical environment merely continue trends that have already begun, it is not until the long-term time horizon that landscape-level changes in vegetative communities would be likely to occur. Hypothesized changes in range of species and ecotypes include all of the following (Juday et al. 1998):

- General treeline advance in elevation and latitude.
- Forest colonization of formerly glaciated or otherwise unsuitable lands.
- Westward expansion of coastal forest on the Alaska Peninsula.
- Westward expansion of boreal forest on the Seward Peninsula.
- Northward expansion of coastal tree species now limited to southern Southeast Alaska.
- Transition to aspen parkland of areas in interior with greatest precipitation deficit, along with expansion of grassland on south-facing slopes.

Increased forest productivity. In the long-term time horizon, effects of already occurring improvement in site productivity will begin to result in substantial increases in timber yields. The Alaska forest industry would likely benefit significantly from an increase in harvest volumes for second growth timber on managed forests. Although growth of young trees may already be beginning to respond to a moderating climate, most of Alaska's second growth forest has regenerated since 1960. Very little of this young growth will be ready for harvest for at least 50 years, even with the faster growth rates.

The timber industry also stands to gain in the long term from transformation to commercial status of a portion of the 97 percent of Alaska's forest land that is currently incapable of producing 50 cubic feet per year. Foresters may be able to hasten changes in range and anticipate changes in productive forest area by regenerating disturbed areas with commercially valuable species likely to flourish in the developing climate regime. For example, the warmest and driest sites in southern Southeast Alaska may become suitable for the commercially valuable and rapidly growing Douglas-fir; lodgepole pine may be planted in some interior sites. Even if these new tree species could survive this plantation range expansion today, the planted trees would not be ready for harvest until late in the 21st century at the earliest.

Conclusion

Summary of Most Important Effects

A given adverse effect on social and economic systems costs more if it occurs sooner and in irregular or catastrophic events. In the short term, by far the most important effect of climate change on Alaska's forests is the risk of catastrophic wildfire in settled areas. The 1996 Miller's Reach fire provides an excellent example of the consequences of such a fire. It destroyed 200 homes and cost $80 million in firefighting cost and losses to property, not counting the disruption to the regional economy during the two weeks the fire burned out of control and the enormous psychological trauma. As many as 200,000 residents of Southcentral and Interior Alaska may be at risk for future fires like Miller's Reach. The number at risk is increasing rapidly as suburban development expands in the Fairbanks, Matanuska-Susitna, and Kenai Peninsula Boroughs.

Short-term effects will continue and possibly become even more pronounced in the intermediate term. In addition, climate effects may result in moderate losses to Southeast Alaska salmon fisheries nurtured by forested watersheds. Coastal forestry losses from possible appearance of forest fires would be offset by increased forest productivity. It would not be until the long term—more than 50 years from now—that changes in extent and composition of forest ecosystems would have significant positive effects on the forest industry.

In general, climate change would have negative effects on social and economic systems in the short to intermediate term as existing ecosystems come under increasing stress. Climate change would have much more positive effects in the long run as ecosystems (as well as humans) adjust to a new climate regime. Human intervention may be able to speed up vegetation changes, but benefits in the form of increased flow of forest products would remain a century or more away.

Role of Institutions and Policy

If climate change continues as projected and settlement patterns continue their current trends, forest fires could periodically impose increasing damage and suffering in Southcentral and Interior Alaska. Whether or not the costs continue to escalate, however, depends critically on how public institutions respond to the challenge. Federal, state and local agencies may implement a variety of policies for reducing the risk. Three alternative strategies, or categories of policies, may be delineated as follows:

Strategy A: public expenditures to reduce public risk. This strategy, advocated by a number of policy makers and stakeholders today, would use taxpayer-supported initiatives to manipulate the forested landscape and increase capacity for fire control. Salvage and sanitation logging would be subsidized by public provision of roads and other infrastructure. Public road networks would be expanded strategically to increase fire suppression capability. Where logging was not feasible, controlled burns would be implemented periodically to create buffers around settled areas. Public fire-control teams would obtain increased funding.

While this strategy may be effective in reducing fire risks in the short term, federal, state, and local taxpayers would be paying to reduce risks to a particular group of residents and businesses that chooses to build in forested areas. It sends the wrong signals to landowners and prospective homeowners about the risks and costs. Thus strategy A may be ineffective in the long term because it hides the true cost of building in areas at risk from fire while it shifts a portion of the cost to others.

Strategy B: incentives to reduce private risk. Strategy B would include a set of policies based on the principle that if a person builds in a risky area, then he or she should pay the cost for society to protect it, rather than assuming that state fire districts and local fire departments (taxpayers) and insurance companies (insurance ratepayers) should pay to protect it. The state or boroughs would create special rural fire protection districts for residents of risky areas that would be supported by a special property tax. The state would require fire insurance providers to assess different rates for rural areas depending on the forest fire risk, not just on whether fire departments could theoretically respond to a house fire. Residents of rural fire-prone areas would be encouraged to form volunteer fire and emergency response cooperatives at their own expense.

Strategy B is a radical departure from historical policies. Nash and Duffy (1997) suggested that homeowners get tax breaks for clearing a defensible space around their homes. This suggestion partially addresses the problem of adverse incentives of strategy A, but would not eliminate them. In particular, it fails to reward citizens who lessen the risk for all by not choosing to build in forested areas in the first place.

Strategy C: settlement policy to reduce cost and risk. The most aggressive strategy for reducing the cost of climate-influenced fire risks would be to rethink the policy on infrastructure for economic development. Most areas now at risk or becoming at risk for damaging forest fires have only recently been settled. Dispersion of settlement has been assisted by public provision of access roads and subsidization of public utility infrastructure for suburban and rural areas, mainly in the Tanana Valley, Susitna Valley, Western Kenai Peninsula, and near Haines. Strategy C involves not only rethinking this conventional infrastructure policy, but reversing it. The conventional policy has increased costs to taxpayers as it has increased the risk of damage to private property. A conscious policy of assisting communities with infrastructure needs only in areas that are already densely settled would at least help to control the spread of dispersed settlement in new areas at risk of fire.

In summary, short-term effects of climate change may cause extensive damage to dispersed settlements in forested areas. Changing from strategy A to strategies B and C can reduce the magnitude of the damage, by more appropriately distributing the costs of making risky investments to those who make those investments.

Longer-term and more general effects of climate change on the forestry sector are especially uncertain. In fact, Pollard (1991b) suggests that the key to coping with future climate change for the forestry sector in British Columbia is meeting uncertainty with broad adaptability of tree genetic material and flexible institutional responses. Enhanced programs of investigation of genetic structure of Alaska tree populations, maintenance of genetic selections in seed orchards, and even possibly some transfer of genes of native tree species to new localities in response to rapid climate change may be additional costs for future forest management in Alaska. Public policy influences on markets will also play a critical role, and several policy options have been suggested for dealing with climate change. For example, if public policy were to provide that owners of forest land would accrue the benefits that *growing* forests provide (fisheries, tourism, carbon sequestration) and if carbon taxes were assessed in proportion to net carbon emission of each country, there would be a large economic benefit to sustaining or expanding boreal forest cover (Chapin and Whiteman 1998). Given the land ownership, population, and current market conditions, these policy changes could become the dominant economic factors in the future of Alaska forest management.

The Major Uncertainties

1. What are the long-term market trends for various timber products and species? We do not know what would happen to the timber industry without climate change, so we can't be sure what the climate impact would be.
2. What is the *interaction* of the risk to forests from insects and fire?
3. The extent of land-use conversions of forests to agriculture (longer term) and settlement (shorter term) induced by climate warming could be a significant effect of a warmer climate. An example is the Peace River region in Canada, where agriculture and settlement, not sustained yield forestry, followed logging.
4. The effects of climate change on forest biodiversity are likely to be much less severe in Alaska than in the lower 48 states because Alaska habitats are not as highly fragmented. Habitat fragmentation multiplies the risk to elements of biodiversity from climate change.
5. Adaptive management is a suitable approach and will be necessary for dealing with uncertainty and change either underway or anticipated in Alaska's forests.

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The Economic Impact and Consequences of Global Climate Change on Alaska's Infrastructure

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Introduction

The purpose of this study is to begin to assess quantitatively the economic impact of and response to global climate change damages to the geography and built environment of the state of Alaska. The events analyzed will include pipeline construction, permafrost thawing and road repair, the engineering of buildings, the impact on power systems and distribution, transportation modes and other examples. It should be noted that much of the damage to infrastructure that we will discuss—roads, transportation, etc.—could be avoided through adequate planning and public policy.

The Importance of Infrastructure

The infrastructure of the state is its built environment. Infrastructure comprises the system of linkages that facilitate and enable the flow of goods and services by the federal and state government, the private sector, and the citizens of Alaska within the state. These linkages include roads, air routes, river systems, and communication lines. It also includes the built and engineered entities within the state: the more than $25B oil-related construction on the North Slope, the factories, buildings, dams, airports and all that comprise the cities and towns: anything that people need in order to live and carry on their business.

Normally, infrastructure is forgotten as an explicit factor in the economic life of the state: it is so pervasive, affects so many of our activities, and shows up in so many different and seemingly unrelated guises that it is difficult to capture, cost or discuss as a single unit. There is no department of infrastructure in state government. But, as will be suggested, infrastructure is critical to the proper functioning of the state economy: it incurs costs to maintain; it can be damaged, removed, or harmed, and must be taken care of for the state to function properly. In this paper we will begin to explore the economic consequences of infrastructure failure.

Examples of Global Climate Change Effects on Alaska's Infrastructure

a) Permafrost [1,2,3,4]

The warming due to global climate change is one of the most obvious influences on the geography of Alaska. Warming affects the roads and structures of a large part of the state because of a single factor: permafrost. Permafrost is a condition of frozen soil and water in various ratios that has a temperature of 32–28˚F. It creates a hazard for any construction or roads, and special engineering precautions must be taken to build on it successfully. Permafrost exists in a continuous or discontinuous layer underground in much of the state, primarily to the north of Anchorage (Figure 1). The Alaska Department of Transportation and Public Facilities (ADOTPF) must solve the problems presented by permafrost in order to maintain roads and facilities, as do Alyeska and other pipeline owners in order to keep their installations intact.

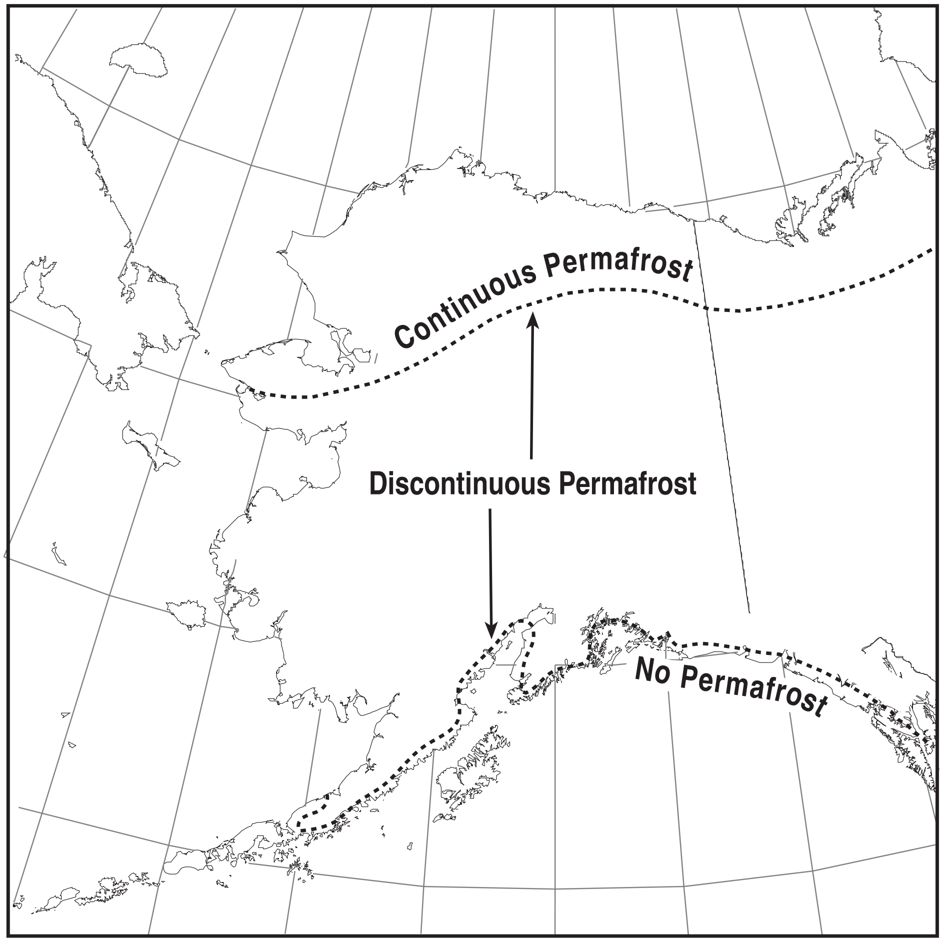

Figure 1. Distribution of continuous and discontinuous permafrost over the Alaskan land mass.

In areas of discontinuous permafrost, a layer of permafrost exists at a depth of about 1 to 50 meters in the ground. Ice or frozen ice lenses in ice-rich permafrost occur in the top of permafrost but the ice can be deeper. The layer of vegetation on the ground serves as a kind of insulation during the summer, preventing extensive thawing of the permafrost. Air temperatures and the depth of snow cover influence the temperature of permafrost. If the depth of the snow cover increases (providing insulation) with no change in air temperature, then permafrost will warm. On the other hand, if there is an increase in the air temperature and the depth of the snow cover is constant, then the warming effects of climate change will be magnified. The thawing of ice-rich permafrost will produce subsidence of the ground surface as the ice volume turns into a slurry. The uneven aspect of the ground as a result of this subsidence produces what is called thermokarst terrain. Thaw settlement has caused problems with human structures being lowered or shifted out of proper alignment.

With warming, the mechanical strength of permafrost decreases, especially in compressive and shear strength, and creep rate increases for frozen ice-rich soils. Adfreeze bond strength between permafrost and piles decreases: if a piling (supporting a pipeline, a bridge or a building) is sitting in permafrost, a change of permafrost temperature from -4 to -1˚C will decrease its load capacity by 70%. Frost heaving may occur because of the thawing of the active layer. The loss of support strength may not occur with thermosyphon supports since they have the capability to freeze the ground in which they are located. But the effective length of a piling will decrease as the frost heave force increases to its maximum. The presence of saline water in the soil, which affects installations near the coast, will decrease the support strength of pilings due to a lower melting temperature for the saline ice.

The active layer lies just below the top surface; it is the soil layer that thaws in summer and freezes again in winter. If the insulating overburden of surface vegetation and underlying organic soil are stripped away during construction, the permafrost will warm by several degrees and the active layer becomes deeper: a talik, or permanently thawed layer, will form. Once a talik forms, the permafrost will thaw continuously from the top down as well as from the bottom upward. If the permafrost in an area or under a road thaws completely and the ice lenses subside, no more change is then able to take place, and the ground will be stable and construction can take place. However, natural thawing of the permafrost layer following surface disturbance is an extremely slow process, often requiring decades to complete unless active thawing is carried out during construction.

Discontinuous permafrost is widespread in Alaska. It stretches from the Yukon River southward, where its temperatures are between 1 and 2˚C. In the continuous permafrost region south of the Brooks Range, the permafrost has warmed by 4˚C and in the discontinuous permafrost region further to the south the warming has been less, 1–2˚C. Some of the continuous permafrost in Alaska has warmed almost continuously since the 1980s. Such warming usually occurs on south-facing slopes where the active layer may thicken. All of AKDOTPF's permafrost research sites along the north-south transect from Prudhoe Bay to Glennallen warmed between the mid-1980s and 1996.

The North Slope of Alaska is an important region of continuous and very deep permafrost that supports billions of dollars of construction for oil production. Changes in thermal characteristics in regions of prospective oil exploration may require changes in engineering practice.

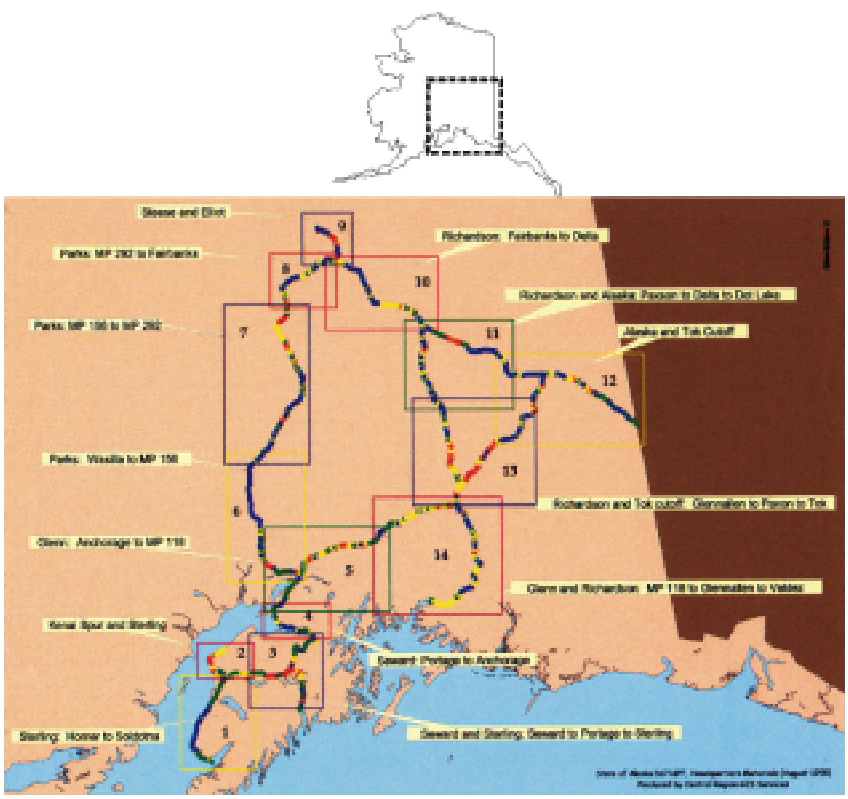

Figure 2. Map of the main surfaced roads in Alaska. The sections in red are at risk due to permafrost; the sections in blue are not.[5]

Effects of Climate Change on Subsistence Communities in Alaska

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Preface: A Consensus Position

Although attaching dollar costs to potential impacts had been a major intent of the workshop, workshop group participants (see Appendix) stressed that the two most important aspects of subsistence, spiritual values and community well being, are not easily monetized.

It is widely recognized that subsistence resources provide basic nutrition and sustenance for isolated rural communities. However, what is not widely understood is that subsistence resources *and the activities associated with the harvest of these resources* provide more than food.

Connected to the physical challenges in harvesting wildlife resources are the sense of accomplishment and the feelings of self-worth associated with the harvest and sharing of wildlife resources within the extended family and with families throughout the community.

Participation in family and community subsistence activities, whether it be clamming, processing fish at a fish camp or seal hunting with a father or brother, provide the most basic memories and values in an individual's life. These activities define and establish the sense of family and community. These activities also teach how a resource can be identified, methods of harvest, efficient and non-wasteful processing of the resource and preparation of the resource as a variety of food items.

The distribution of these resources establishes and promotes the most basic ethical and spiritual values in Native and rural culture—generosity, respect for the knowledge and guidance of elders, self-esteem for the hunter who successfully harvests a resource and family and public appreciation in the distribution of the harvest. No other set of activities provides a similar moral foundation for continuity between generations.

Health

Potential climatic threats to the harvest of wildlife resources elicit fundamental concerns for the health of rural residents. Many Native rural residents believe subsistence foods are healthier for them than are store bought foods. Many subsistence users also believe that wild foods provide a better protection against the cold (Kruse 1983). In addition, the harvesting of wildlife resources takes considerable physical exertion, which contributes to the physical and mental well being of individuals.

Epidemiologists have also linked diet changes with increased morbidity (e.g., diabetes and heart disease). Increased illness is also linked with increased medical care costs.

Alex Whiting, a working group participant, also noted that a warm fall, heavy rains and a lack of shore fast ice impede access to tundra and offshore resources. Many elderly who can no longer participate in more rigorous hunting activities count on being able to pick berries or ice fish. Being stuck in camp and failing to accomplish these activities dramatically affects their quality of life and their personal sense of contributing to the community. In addition, common to all age groups is the spiritual need to feel that one is a productive and contributing individual.

There was also great concern that interruption of subsistence activities may have serious impacts on young men. Already dealing with the considerable problems of adolescence, more free time and diminished community approval (due to their inability to harvest and share resources) could be linked to decreased self-esteem. Both these factors may exacerbate drinking and drug use.

The central theme and basic consensus of working group members was that subsistence activities provide the most basic spiritual and moral activities in their lives. Harvesting resources on the land determines their feelings about themselves, structures the organization of their social relations, contributes to community well being and provides a framework for relating to their environment.

The Political Economy of Subsistence Activities

The ability to carry out subsistence activities and the quality of life in rural Alaskan communities are intrinsically linked to the state's economic and political environment. Etok Edwardsen forcibly argued that cash is an absolute prerequisite for households to engage in subsistence activities. The technologies of subsistence activities (boats, motors, snow machines, guns, ammunition, fuel) are very expensive in these distant communities. A significant proportion of a household's disposable income is often used to pay for these expenses. Some of the events in the state and regional economy that affect cash flows to subsistence include:

- Decreases in state revenues from oil royalties.
- Fewer state programs and decreased funding to existing services.
- Welfare reform.
- Demographic changes in rural areas.

Michael Patkotak and other working group participants emphasized how recent climatic changes have increased the cost and risk of subsistence pursuits. For example, in the last two years the ice pack has retreated a significantly greater distance from land for North Slope hunters. The greater expanse of open water and the increased time and distance needed to access marine mammal resources all add to the risk of these activities. Costs increase from two sources—the greater distances traveled increase fuel and maintenance costs and decrease the use expectancy of the technology. In addition, for safety reasons larger boats with larger engines need to be purchased. Linked to this is the fact that larger parties and more boats are now required and harvests, in terms of manpower and cost, are less efficient.

A detailed analysis of the relationship between income and subsistence activities is provided in later sections. However, as Michael Patkotak notes, the census figures for median income can be very misleading because of the high cost of living (due to shipping costs and low volume), lack of jobs and the high proportion of families below the poverty level. Subsistence foods provide a key mechanism for coping with inconsistent levels of cash income.

Subsistence Integrates Climate Change Issues

As suggested by Joan Eamer, subsistence is a prime example of an integrative issue. All the issues discussed at this workshop, and nearly all those discussed at previous workshops, have direct or substantial indirect impacts on how subsistence users respond to climate change. For example, all the issues at this workshop were identified as having substantial and direct impact on subsistence activities.

- Fishing: decreases in anadromous fish stocks directly affect the economic and dietary well being of subsistence users.
- Wildlife: changes in the distribution and density of wildlife resources will have a direct effect on subsistence harvests.
- Forestry: disturbance of existing habitat and wildlife as the boreal forest intrudes further north will affect subsistence users.
- Transportation: as a higher proportion of limited state budgets go to support urban transportation infrastructure, fewer resources are available to mitigate the dramatic changes impacting small rural subsistence communities.

Also discussed in this paper are the links in the abiotic environment that have direct and secondary effects on subsistence activities:

- Increases in the frequency and ferocity of storm surges in the Bering Sea.
- Accelerated thawing of the discontinuous permafrost.
- Changes in the distribution of sea ice.

As Alex Whiting noted, there also seems to be substantial cultural differences in how climate is evaluated. Kotzebue receives the weather forecast from TV stations in Anchorage. Often times the weather person seems to be rooting for warmer weather and becomes ecstatic when Kotzebue reaches 40 degrees Fahrenheit. People in Kotzebue who depend on early freeze-up to access marine mammals on the ice, to ice fish, or to use snow cover to access terrestrial mammals by snow machine are yelling "No! No!" to 40 degrees. In western culture weather appears to be an inconvenience, whereas expectations about its effects are absolutely integral to subsistence communities.

Multilateral Coordination

As Carl Jack noted, "any initiatives taken by the U.S. cannot succeed in the long run unless the other side [of the Bering Sea] is included in making decisions about monitoring, allocation and pollution." After presentations made by representatives of the Commander Islands at the workshop, it was the strong consensus of the working group that bilateral connections need to be initiated and maintained with the Russian Far East, but especially with the Commander Islands and the communities on the Chukotka Peninsula.

Further discussion and analysis also need to be initiated on issues of "equity." Given finite financial resources, how can one develop a fair and equitable process to address and mitigate the consequences of climate change on human institutions, especially in the critical arena of subsistence?

Comparison with the Mackenzie Basin Impact Study (MBIS)

During the workshop, Stewart Cohen (1997) provided a copy of his article entitled "What If and So What in Northwest Canada: Could Climate Change Make a Difference to the Future of the Mackenzie Basin." This article, which appears in the journal *Arctic*, describes a series of issues raised in the Mackenzie Basin Impact Study with some suggestions on how to mitigate the impacts of climate change. What is interesting is that many of the issues and suggestions elicited from stakeholders in Canada closely overlap similar issues and mitigation measures suggested by members in the subsistence working group.

Pollution. Both groups were concerned that pollution and environmental contaminants would affect the ability of natural resource populations to respond to climate change (e.g., by reducing their resistance to infection). In addition, as Delbert Rexford noted, new circulatory patterns in water and air may bring contaminants, especially from environments in the Russian Far East degraded by decades of industrial and military pollution. Heavy metals such as mercury and cadmium can become concentrated in the food chain and subsistence consumers of marine mammals may be at risk for birth defects and other morbidities.

Construction. While Canadians proposed “a more compatible style of construction, based on local rather than imported materials…Sustainable construction…” (1997:301), Alaskan stakeholders were concerned that human construction and industrial practices, e.g., removing gravel from barrier islands for construction purposes, had the potential to exacerbate climate-induced threats, e.g., storm surges. Such practices need to be identified, modified or eliminated.

Etok Ewardsen detailed an example from the North Slope Borough. Beach gravel removed for an airport runway caused waves to become stronger as the water was now deeper offshore. This in turn led to increased erosion as wave action and currents carried existing beach gravel and sediments 25 miles to the east.

Research. Canadian participants identified the assessment of climate change impacts on wildlife populations and plant communities as a major problem:

> Researchers were hampered in making firm conclusions by lack of long term data, complexity of life cycles, and incomplete information on wildlife responses to previous environmental changes… (1997:297)

Long-term inventory and monitoring issues were also alluded to in the Alaskan workshop, although issues of Traditional Ecological Knowledge (TEK) figured prominently.

Recommendations. For subsistence users, there is a strong concurrence on what kind of institutional response is needed to mitigate fluctuations in natural resources that may be due to climate change stresses. Both groups emphasized the need for improved communication in plain language. Money is needed to keep local communities and regional entities informed about research and possible policy decisions. Significant monetary resources are needed because of the logistical expenses and labor-intensive nature involved in communicating complex issues on a consistent basis to the local level. At the same time, working group participants thought that local input in the form of traditional knowledge and local values must also be accommodated in establishing research priorities and in making resource management and policy decisions.

Both groups (e.g., Cohen 1997:300) heavily emphasized the need to:

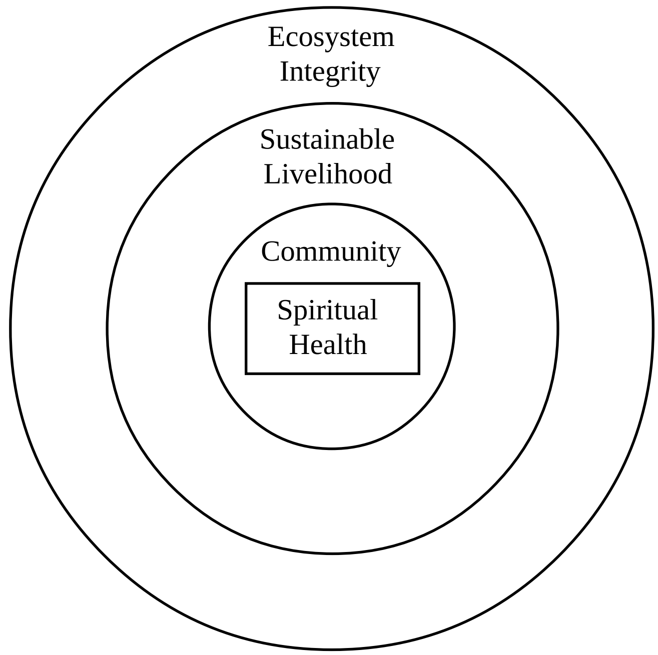
- Establish community-based monitoring projects that incorporated both western science and traditional ecological knowledge (TEK).
- TEK must be at the table when resource management decisions are made, e.g., continued (if not increased) reliance on Regional Advisory Councils in Alaska.
- Carl Jack stressed the need for cooperation among managers and stakeholders and suggested expanding the use of co-management bodies which would include federal, state, local and regional rural representation.
- Institutions and agencies that are responsible for resource management need to adopt strategies that allow for flexibility and rapid response in the setting of seasons and bag limits for subsistence resources.

Space does not permit a detailed consideration of these issues, but see Spaeder, Callaway, Johnson (forthcoming) for an extended discussion (200 pages) of the relationship between co-management, TEK, resource management and the spiritual values associated with subsistence activities.

It should be emphasized that while this paper focuses on the nutritional and economic aspects of wildlife harvests, in fact, it is the spiritual and social relations linked to the harvesting, processing, and sharing of subsistence resources that are of paramount concern to rural Alaska Natives.

Subsistence Working Group Overview

Suzanne Marcy, one of the subsistence working group participants, provided a distilled overview of the two-day session. She noted that during discussions at the workshop, four interdependent relationships emerged. At the core was spiritual health of the individual (see diagram), which has a direct effect on that individual's physical and mental health. This individual's health both influences the community's well being and is supported by the larger community's cultural traditions and values. Individuals and households, interacting, harvesting subsistence resources, sharing, and establishing mutual dependencies provide the means by which a community sustains itself. Finally, all these interactions—spiritual, social, economic and cultural, depend on the health and viability of the natural ecosystems in which they are embedded.



Introduction

Complex climatological processes related to El Niño's impact on the Aleutian Low have the potential for disastrous consequences to the subsistence activities for the 56 communities that border the Eastern Bering Sea. In addition, a possible climate regime shift and its impact on fisheries and habitat will be felt throughout Alaska but especially in the Bering Sea, Yukon/Kuskokwim and Bristol Bay regions. Although our discussion will focus on these regions, other areas within Alaska, notably the interior and southeast sectors, will also be impacted. However, the consequences for these latter regions may be quite different. For example, recent red salmon runs in the Copper River area of the southeast have actually increased, while Kodiak fisheries have experienced a tremendous return of pink salmon.

A different set of repercussions, mediated through a vastly different political economic system, will also occur for a number of communities on the Chukotka Peninsula in the western Bering Sea.

As the Aleutian Low shifts eastward, major changes occur in the circulatory patterns of water and air currents. These changes influence:

- Anadromous fish stocks.
- The distribution of sea ice.

- Existing habitats as the boreal forest intrudes further north.
- Increases in the frequency and ferocity of storm surges in the Bering Sea.
- Accelerated thawing of the discontinuous permafrost.

Each of these changes, which have important implications for subsistence activities, will be discussed in greater detail below. In addition, there are a number of current social, economic and political issues that are linked to the impacts of climate change on subsistence practices. Some of these issues include:

- Decreases in state revenues from oil royalties.
- Fewer state programs and decreased funding to existing services.
- Welfare reform.
- Demographic pressures in rural areas.
- "Dual" management of wildlife resources within the state.

It is beyond our capacity to model the enormously complex interrelationships and feedback loops that exist among the abiotic, biotic and social spheres. In fact, strong skepticism exists about our ability to model even the Bering Sea ecosystem. Therefore, this paper will discuss some of the proximate influences on subsistence from climate change in the context of the existing social and political environment and describe some possible outcomes in Alaska's institutional response to these changes.

Climate Change Effects

Climate Change Effects on Subsistence/Commercial Fishing

Currents responsible for the rich nutrient upwelling over the continental shelf move westward to deeper water with a drastic decline in anadromous fish stocks in the Bering Sea and Bristol Bay regions.

a) As Figure 1 shows, approximately 60% of the 43 million pounds of wildlife resources that rural residents harvest in Alaska comes from fish. This means about 26 million pounds of fish were harvested per year for subsistence purposes during the mid-1990's.

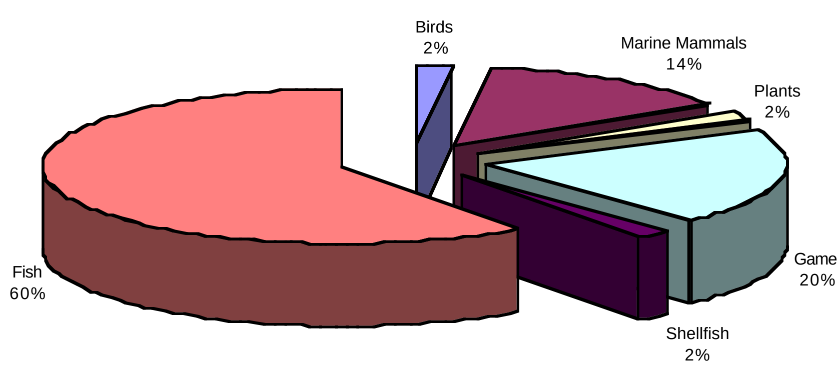


Figure 1. Composition of wildlife harvests by rural Alaskan households, 1990s.

Climate change, whether it is attributed to the short-term effects of El Niño or a longer-term regime shift, has important implications for subsistence harvests and its intimate links to commercial fishing.

Commercial fishing is intrinsically linked to subsistence fishing in that subsistence fish are often taken during commercial fishing activities and the profits from commercial fishing often help to pay for the technology (boats, outboard motors, guns, snow machines, ATV's) necessary to perform subsistence activities.

A variety of limitations (lack of available data, time and space constraints) preclude a thorough consideration of the relationship between commercial fishing and subsistence activities. However, three sources (Jorgensen 1990; Wolfe 1984; and a recent Alaska Department of Fish and Game data set associated with communities affected by the *Exxon Valdez* oil spill) provide some insight into this relationship. For example, Jorgensen (1990:198) notes that:

> The benefits for subsistence uses of equipment purchased for commercial fishing are very important, and the availability of loans, the extension of payback dates, and the support of the village and regional corporations make commercial fishing possible. Subsistence pursuits are benefited by the availability of loans for commercial fishing, even if a fisherman spends more than he makes.

For Unalakleet in 1982, where naturally occurring resources comprise about 75 percent of the local diet, the primary source of income for about 115 Natives was commercial fishing. While the average household income was $20,100 per year, the average household equipment and trip expenses for subsistence purposes might run $10,000, or nearly half the total household income.

Wolfe (1984:176), using a sample of 88 households from six communities in the lower Yukon region, provides detailed information on the proportion of the commercial catch retained for subsistence purposes. He states that:

> On average the sampled households sold 91 percent by weight of the salmon harvest (10,477 lbs.) and retained 9 percent for subsistence use… However, the Stebbins sample sold 66 percent by weight of their herring catch and retained 34 percent for home use.

Both authors underscore the importance of sharing, not only as a cultural ethic but also as an adaptation to fluctuations in resource populations. Jorgensen (1990:127) notes that:

> When, in 1982, late breakup and very high water destroyed the salmon fishing for Yukon River villages, Unalakleet families connected to families along the Yukon River through marriage packed and shipped huge quantities of fish, caribou, and moose to their affines.

In considering the impacts that climate change may bring to these small rural communities, one must also be cognizant of traditional strategies that have evolved to mitigate uncertainty. How much flexibility exists when region-wide fluctuations occur is difficult to assess.

b) Fish provide the most substantial contribution to subsistence diets throughout rural Alaska. However, this "averaged" data masks a lot of inter-regional variation. Rural communities in the northern part of the state are more dependent on marine mammals than they are on fish and many interior communities are more dependent on game (primarily large land mammals), whereas communities in western Alaska are heavily fish dependent.

Recent changes attributed, at least in part, to climate shifts, have differential effects on existing fish stocks. For example, the total number of commercial salmon harvested was about 131 million in the summer of 1998, close to the 20-year average but about 10% less than forecast. However, as the Anchorage Daily News points out (09/06/98), the "catch is far less valuable than the $400 million average of the previous five years. It's also less than half the value of the 1992 harvest, in which fishermen caught a comparable number of fish." The difference in revenue is attributable to the composition of the harvest. Red salmon, the real money maker ($1.00–$1.20/lb in 1998), had a pre–dicted catch of 20 million in the Bristol Bay region. However, for the second year in a row the actual harvest had a shortfall of 10 million fish. In contrast, Kodiak had a huge run (4x the forecast) of pink salmon. In addition to abundance, individual fish (@ 12–15 cents/lb) were larger than average.

The Yukon and Kuskokwim Rivers sustained drastically low runs and the state designated communities in those areas as economic disasters. In contrast, the Copper River in southeast Alaska had a strong red salmon run of 1.7 million fish. This strong run may be linked to the fact that these stocks are independent from Bristol Bay and Bering Sea stocks.

Climate Change Effects on Sea Ice

Changes in air currents and temperature gradients impact the distribution of sea ice.

There is a wealth of testimony in *Answers from the Ice Edge* (1998) on the impacts of the changes in sea ice conditions on subsistence. Traditional observers have noted that during the last three years, the sea ice was much thinner, breakup occurred much earlier, formation of shore fast ice came later, and the extent of the ice pack decreased. These phenomena have a variety of outcomes, which when taken in balance, indicate a dramatic reduction in access to sea mammals.

Gibson Moto (Deering) notes:

> It's harder to hunt for some sea mammals that can't get on the ice. For some odd reason the ugruks that we hunt are further out there. There's lots of clean ice and there's no ugruks or seals on it. (p. 19)

Benjamin Neakok (Point Lay) observes:

> It makes it hard to hunt in fall time when the ice starts forming. It's kind of dangerous to be out. It's not really sturdy. And after it freezes there's always some open spots. Sometimes it doesn't freeze up until January. (p. 19)

There is also some concern about marine mammal productivity. Benjamin Pungowiyi (Savoonga) notes that "A lot of senior captains were saying the ice conditions weren't really good for the little baby walrus and seals." (p. 18)

Changing ice conditions can also bring increased risk for hunters, as York Mendenhall (Kotzebue) cautions:

> Freeze up is so slow. If it does start to freeze up and you get a layer of snow before it really freezes then you have to be really careful. Because the snow insulates the ice and it takes a lot longer to freeze… (p. 17)

To some extent hunters adjust to changing conditions. Pete Schaeffer (Kotzebue) notes:

> What that means for sea mammal hunting here is that hunting patterns have had to accommodate that change. Hunting actually occurs much earlier than before, maybe in part due to advancing technology, and using larger boats. (p. 16)

In addition, linked to changes in sea ice are noticeable changes in snow cover. Many traditional hunters mentioned difficulty in gaining access to land mammals (e.g., caribou) because lack of sufficient snow prevented reasonable use of snow machines. Perceptively, Gilbert Barr (Deering) notes:

> It seems to me that winters are not as cold as they used to be. Maybe that's due to the lack of precipitation. I've been involved with the City Council off and on for the last twenty or so years, and I guess a good indication would be our financial report for the public road maintenance that we do. Normally that program was always running into the red because of snow removal. For the last couple of years—and I don't know if this is good or bad—we've been operating in the black. It's good for the finances of the city, but not for hunting. Last year there were more caribou than I've ever seen or heard of in my life here, but the guys couldn't go out hunting due to lack of snow. I guess it probably could be done. If you wanted to really hurt your snow machine. But you'd have to weigh whether the cost of parts for your snow machine would be worth the effort of getting the caribou while they're this close to us.

Naturally there are also economic limits to some of the logistical fixes (bigger boats, travel further) for marine mammal hunting and these adjustments will be of little help if there are widespread decreases in resource populations. Recent surveys seem to indicate dramatic decreases in recruitment for walrus populations as the proportion of juveniles and pups has dropped precipitously.

Decreasing the area of the pack ice margin has important implications for productivity. The ice-edge bloom depended upon by many organisms, including marine mammals, has been decreasing as increased solar heat stratifies the water column, impeding vertical mixing and decreasing nutrient availability.

Walrus and bearded seals require a special mix of sea ice conditions. For example, walrus require sea ice strong enough to support their weight but over water shallow enough that they can reach the bottom to feed. As *Answers from the Ice Edge* (1998:18) notes, “A retreat of pack ice to deep waters would be disastrous for both these marine mammals.”

Climate Change Effects on Existing Habitats

Another consequence of this changing weather pattern is a northward migration of the boreal forest and other habitat changes throughout the state. Linked to these shifts in habitat are changes in the distribution and density of a number of wildlife species.

Careful consideration of the manifold implications of these habitat changes is beyond the scope of this paper. However, a useful overview can be found in chapter 5, “Wildlife and Reindeer,” from *Implications of Global Change in Alaska and the Bering Sea Region* by Babcock, Juday and Douglas (Weller and Anderson, eds., 1998)

Climate Change Effects on Storm Surges, Rainfall and Snow

Within the last couple of years enormous storm surges have occurred on the western coast of Alaska altering the protection of barrier islands, changing habitat and battering the infrastructure of some coastal communities, e.g., Shishmaref.

In October of 1997, 55 mph winds and 30 ft waves pounded the barrier island on which Shishmaref, a small Native community of some 500 people, is located. Shishmaref, some 125 miles north of Nome, is about 95% Inupiat and heavily dependent on wildlife resources, especially marine mammals. Storms are common every year for Shishmaref, but not since the early 1980’s had storm surges eroded so much of the limited land base. Twenty years ago a housing project was situated 60 feet away from the ocean bluffs; today these same homes are in jeopardy of falling into the sea.

In this storm surge a number of families lost their winter supply of food. Walrus meat, fish, seal and seal oil, which had been stored under sand but on top of permafrost, was lost to the sea (Daily News, 10/05/97). Village spokesman Chuck Newberg said that “Millions of dollars have been spent on erosion control, which has not been effective in battling the elements.” In addition to food caches, two homes had their foundations cut to the point where they were hanging over the bluff, one house had been moved, and eleven families had to be evacuated because their homes were at risk of tumbling into the ocean. Only 4 of those 11 houses could be saved by relocation. Other threatened buildings included school housing, the tannery, a warehouse for the local store, a tank farm and the National Guard Armory.

This year’s storms eroded 30 feet of bluff and exposed underlying permafrost to the sea. Concerns about erosion are not new. In 1974, after a large storm caused widespread damage all along the Chukchi Sea coast, the village of Shishmaref voted to relocate to a site on the mainland called Five Mile Bluff. About five miles from the current community location, this site would have provided continuing access to subsistence resources. But as a Daily News article noted (10/12/97):

> When scientists came in to study the Five Mile Bluff area, they found shallow dirt covering thick layers of ice and a lack of gravel for use as fill. Nayokpuk recalled one of the engineers saying "it would be cheaper for Shishmaref to move to Juneau."

Given these cost estimates, the relocation effort was shelved.

In 1996, a study by the Alaska Department of Natural Resources recommended that the best solution to the erosion problem was to move the village. Unfortunately, current cost estimates of moving the village to another location exceed $50 million dollars, exceeding the estimates for relocating another village in similar circumstances—Kivalina. Engineers and scientists have suggested several other locations on nearby islands or on the mainland. However, all have problems relating to access, geology or proximity to subsistence resources.

For example, most of the land near the current village is low-lying marshy ground. Some of the relocation scenarios involve moving north to an area that the village currently uses as a catch basin for its water supply. Community members fear a relocation to this area would threaten their water supply.

In contrast to these relocation efforts, it would cost $4–6 million dollars to build a sea wall from shield rock that might last 10–15 years. However, there are no funds currently available to accomplish this construction and the community is working with Senator Ted Stevens to obtain grants, possibly from the Economic Development Agency.

Everyone acknowledges that the sea wall is only an interim solution. Communities like Shishmaref and Kivalina are built on barrier islands, sparsely vegetated peninsulas that extend parallel to the coastline and enclose sheltered lagoons. However, the geological processes that create these "islands" are constantly in action. "Gradually, the barrier islands all over the world have a tendency to migrate shoreward" (Orson Smith, Anchorage Daily News 11/02/97).

Climate Change Effects on Thawing of the Discontinuous Permafrost

Documented widespread thawing of the discontinuous permafrost has occurred. This thawing has implications for habitat change (e.g., thermokarsts) but more importantly for the physical infrastructure of communities as buildings sink and roads disappear.

Shishmaref, Kivalina, and Little Diomede form only a small fraction of the class of communities that are currently affected by recent climate shifts. Other communities facing erosion problems may become increasingly vulnerable to climatic shifts that induce increased storm surges, changes in snowfall or greater rainfall. Inhabitants of riverine communities such as Bethel rely on sea walls to protect them from the shifting boundaries of the Kuskokwim River as it cuts into their community. For example, the cost of moving the community of Allakaket after the 1994 floods was nearly $50 million dollars.

Thawing of the discontinuous permafrost has similar impacts on community infrastructure as buildings sink, tank farms are threatened or food caches destroyed. Particularly costly is damage to highways in metropolitan areas or in the stretches of roads between road-connected communities.

All of these climate-induced challenges to the infrastructures of small communities or the larger metropolitan areas such as Fairbanks must be mediated through our state and federal political institutions. The considerable costs to mitigate these problems must be considered in the current social, political and economic context of the entire region. It is impossible to detail the conflicting accusations regarding urban/rural appropriations within the Alaska legislature. A Daily News article (5/03/98) discusses this urban/rural tension and notes:

One explanation offered by Republicans in Juneau for this year's battles is that Alaska is starting a long and difficult debate over the future of the Bush. To some urban lawmakers, that means raising tough questions about the costs of "subsidizing" schools, airports and water systems in villages with no more than a few hundred residents. "I really don't think it's the government's role to prop up a part of Alaska, especially with tax dollars," said Kohring of Wasilla. Rep. Con Bunde, a Republican from South Anchorage, said rural Alaskans must learn to accept the disadvantages of rural life along with the advantages and not expect the same educational opportunities or other services. Communities that can't support themselves may ultimately be forced to consolidate or move, he said.

Social, Economic and Political Factors

- There are continuing decreases in state revenues from oil royalties in Prudhoe Bay. Income from oil depletion and royalties currently account for about 85% of the revenues in the state budget. As revenues decrease, allocation of scarce dollars tends to go to urban areas.
- Fewer state programs (including decreases in funding for education) lead to fewer services and less employment in rural communities.
- Welfare reform, initiated at the federal level, provides less public assistance to rural communities that suffer from substantial proportions of discouraged workers and high unemployment (near 50%).
- Compounding these potential difficulties are demographic shifts in rural communities resulting from families returning to their natal, rural communities from urban areas during periods of economic downturn. In addition, high birth rates within communities increase demand for services (e.g., education), employment and consumption of wildlife resources. It is unclear what role emigration from rural communities to urban areas plays in these processes.
- Divided management of wildlife resources between federal and state agencies, different mandates among the federal land managing agencies, and the policies and objectives of a variety of environmental groups all make the goal of "ecosystem management" difficult to attain.

The Importance of Subsistence Resources in Rural Alaska

Figure 2 shows the high dependency on wildlife resources for regions within Alaska.

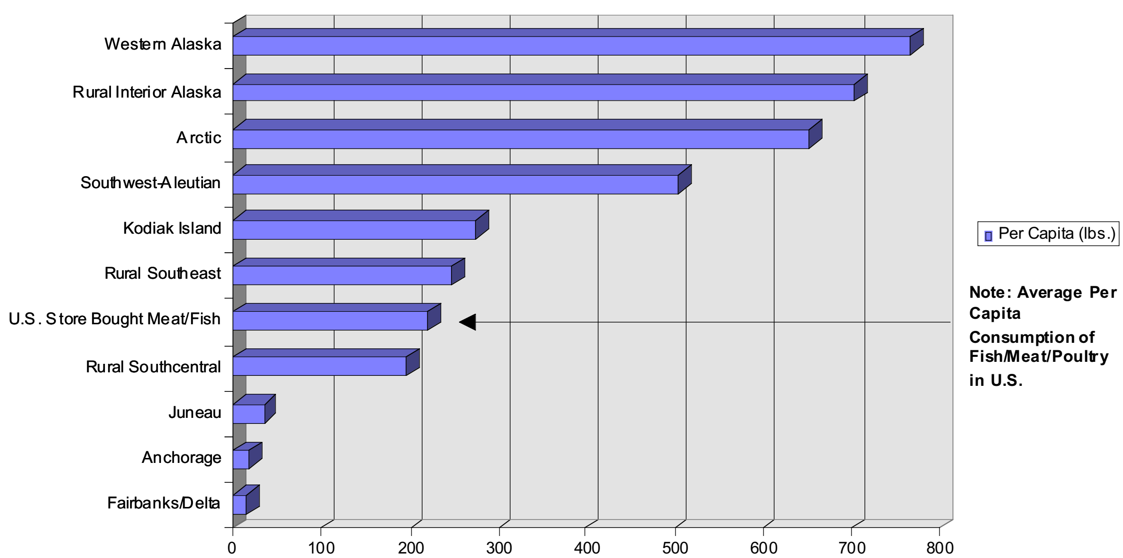


Figure 2. Per capita wild resource harvest (lbs) for selected Alaska regions.

The Arctic Region (of which the Northwest Arctic is a part) averages about 650 pounds per person per year in the consumption of wildlife resources. Although conversion factors for marine mammals may skew the results slightly, it is apparent that the most substantial part of an individual's diet comes from subsistence products. This contrast is more dramatically underscored when we realize the average U.S. per capita consumption of fish, poultry and meat is 222 pounds per person per year.

In addition, rural Northwest Arctic communities are accessible only by air. Bulk items such as food are extremely expensive to transport. For example, in 1995 groceries in Anchorage cost about 25% more than a similar market basket in Portland, Oregon. However, the University of Alaska Cooperative Extension Service (in conjunction with USDA) calculates that while a family of four will spend $93.22 a week for food in Anchorage, this same amount of food will cost $217.96 in Stebbins, a community in rural Alaska.

For the Arctic Region (which includes both the Northwest Arctic, North Slope and Calista regions), Wolfe and Bosworth (1994) estimate an annual harvest of 10.5 million pounds of wildlife products per year. They point out that:

> Attaching a dollar value to subsistence uses is difficult, as subsistence products generally do not circulate in markets. However, if families did not have subsistence foods, substitutes would have to be imported and purchased. If one assumes a replacement expense of $3–5 per pound, the simple replacement costs of the wild food harvests....

In the Arctic Region this replacement cost would be $31.5–$52 million.

Table 1 and Figure 3 put this into context. With per capita incomes ranging from $5,000 to $14,000, the total replacement cost of wildlife resources, in the four communities for which we have detailed harvest data, range from 13% to 77% of the **total income for that community**.

Table 1. Replacement cost of subsistence products @ $3 & $5/lb.

	Kotzebue	Deering	Noatak	Kivalina
Per Capita Income—1990 Census	$13,906	$7,272	$7,089	$4,968
Replacement Cost $3/lb	$1,779	$2,016	$1,383	$2,283
Replacement Cost $5/lb	$2,965	$3,360	$2,305	$3,805

It is clear that subsistence plays an integral and essential role in the economic life of these Northwest Alaska rural communities.

Kivalina, a Community Profile

Kivalina, with a total population of about 300 people (95% Inupiat), provides a representative snapshot of the economic difficulties faced by rural communities in this region (and in Alaska). According to the Department of Community and Regional Affairs (DCRA), Community Information Summary (CIS), Kivalina had an estimated 48 available jobs in 1990. Those 48 jobs must sustain the 168 people over the age of 16 (and below retirement age) who need wage income to support their families. In actuality, only about 108 out of the 168 were employed or had actively sought employment during the reference year. About 35% (60 individuals) of this group are not in the labor force either because of family reasons or because competition and demand for the limited number of jobs available have discouraged their participation. The CIS indicates an unemployment rate of 56% and notes that 71% of all adults were unemployed. Despite a median household income of $28,000, nearly a third of the community residents were below the poverty line.

It is startling to realize that in Kivalina, households average more than five people per household, with median household income at around $28,000 (in 1990). At current levels of payout from the Alaska Permanent Fund, dividend payments could account for about one-fifth (20%) of a household's total income.

Figure 3 illustrates the relative contribution of income from various sources for the community of Kivalina. Keep in mind two factors related to this chart. First, although income from wages is clearly the predominant source of income for a household, per capita wage income, as we have already demonstrated, is quite low. That is, although the wage income slice in the pie diagram seems large, these are slices from a very small pie. Secondly, because it is a very small pie, even small slices like public assistance play a very crucial role in the household's ability to cope. Also keep in mind, during the discussion of subsistence activities below, the crucial role all income plays in purchasing technology to participate in these activities.

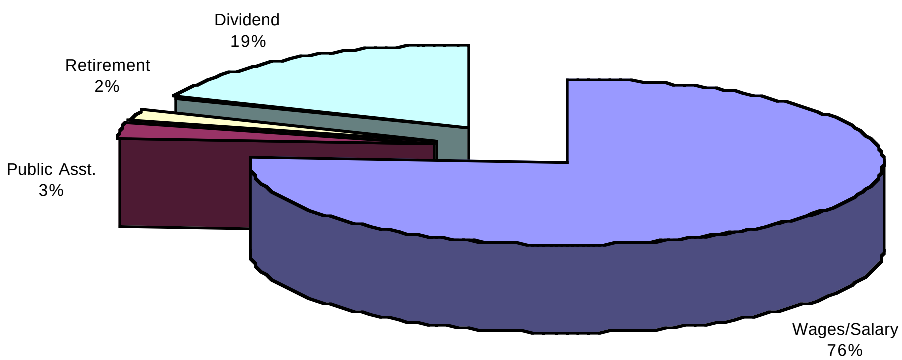


Figure 3. Kivalina: total household income by source

With the exception of Kotzebue, rural communities in this region have:

- High unemployment.
- High proportions of discouraged workers.
- Few jobs available in the community.
- More than half their jobs in the government sector.
- High dependence on public assistance and transfer income.
- Modest infrastructures.
- A high reliance on subsistence harvests.

Further Assessment of the Impact of Climate Change on Subsistence Practices in Rural Alaskan Communities

A detailed financial assessment of the effects of climate change on subsistence practices will require careful analysis of a number of topics:

Existing Secondary Data Sources

- Modeling of state revenues from oil production at Prudhoe Bay (currently 85% of total state revenue).
- Careful analysis of the state budgetary process with special note taken of revenues allocated to transportation and differentials in urban/rural construction and service programs.
- Monitoring and modeling of changes in habitat. A northerly intrusion of the boreal forest and numerous other habitat changes will affect forage and plant species, which will in turn affect the distribution of keystone subsistence species, e.g., land mammals. [See "Climate Change and Alaska's Forests: People, Problems and Policies," this volume.]
- Models and assessments of fish productivity, commercial fishing revenues to communities and revenues from community fish quotas (CFQ's). [See "Human Effects of Climate-Related Changes in Alaska Commercial Fisheries," this volume.]
- Monitoring of the social, economic and subsistence environment. Some of this can be taken from secondary sources, e.g., regional employment by sector, demographic shifts and state and federal transfers to communities.

New Data Collection Initiatives

While much information can be gleaned from existing sources, one should note that only five out of the 50 or so communities in the BESIS region have current demographic, income or subsistence harvest data at the community level. There exists a need for a carefully designed sampling initiative that monitors harvest consumption practices and also collects basic household demographic and income data. This social, demographic and cultural data can then be linked to proposed projects that inventory, monitor and model changing resource populations in the area (at both the species and ecosystem level).

Summary

- Sharp decreases in fish stocks, which comprise 60% of subsistence resources, have created a dietary and economic hardship for many rural Alaska communities.
- A decline in commercial fisheries is causing economic hardship and steep declines in income in rural communities. Income from commercial fishing is used to purchase the technology used in subsistence activities. This income is also crucial in purchasing store-bought food during periods of natural resource scarcity.
- Sharp decreases in access to marine mammals, due to variations in the pack ice coverage, have been attributed to climate change. Marine mammals are a stable food source in many coastal communities.

The recent severe declines in fish and access to marine mammals in the Bering Strait, when combined with declining income and increased human populations, all lead to dramatically increased pressures on households to make ends meet. Rural households find themselves in the bind of having access to fewer traditional resources while at the same time declining employment, commercial fishing income, and public assistance prevent purchase of very expensive store-bought goods.

Simultaneous with these declines in household income and the proportion of natural resources in their diet, rural communities are suffering a decline in their quality of life as funding for services such as education, water, sewer and electricity are reduced. Opportunities to replace houses, schools, generators, etc., damaged by storm surges are also becoming more limited.

Thawing of the discontinuous permafrost also affects the physical structure of these communities. Additional difficulties occur when state funds, once distributed to remedy these difficulties, decline. The state legislature, dominated by urban interests, is now more likely to divert scarce revenues to remedy urban infrastructure problems.

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Implications of Climate Change for Alaska's Seabirds

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Introduction

Seabirds are prominent and highly visible components of marine ecosystems that will be affected by global climate change. The Bering Sea region is particularly important to seabirds; populations there are larger and more diverse than in any similar region in North America—over 90% of seabirds breeding in the continental United States are found in this region. Seabirds, so named because they spend at least 80% of their lives at sea, are dependent upon marine resources for food. As prey availability changes in response to climatically driven factors such as surface sea temperature and extent of sea ice, so will populations of seabirds be affected.

Seabirds are valued as indicators of healthy marine ecosystems and provide a "vicarious use value" or existence value—people appreciate and value seabirds simply because they are there and enjoy them through venues such as pictures, nature programs, and written accounts without ever directly observing seabirds in their native environment. A direct measure of this value is demonstrated by Federal legislation that established specific national wildlife refuges to protect seabirds and international treaty obligations that provide additional protection for seabirds. Seabirds are also an important subsistence resource for many who live within the Bering Sea region. Furthermore, the rich knowledge base about seabirds makes them a valuable resource as indicator species for measurement of change in the marine environment. Understanding this latter relationship is particularly important for seabirds as they can be dramatically affected by development-related activities (e.g., oil spills, fishing); understanding the population effects due to climatic change is critical to interpreting the actual effects of specific human activities or events.

Why Seabirds?

Overview of Alaskan Seabirds

Populations of seabirds in Alaska are larger and more diverse than any similar region in the Northern Hemisphere. The extensive coastal estuaries and offshore waters of Alaska provide breeding, feeding and migrating habitats for 66 species of seabirds. At least 38 species of seabirds, over 50 million individuals, breed in Alaska. Eight Alaskan species breed only here and in adjacent Siberia. Five additional species range through the North Pacific, but their populations are concentrated in Alaska. In addition to breeding grounds, Alaskan waters also provide important wintering habitat for birds that breed in Canada and Eurasia. Shearwaters, which breed in the southern hemisphere, are the most numerous species in Alaskan waters during the summer (U.S. Fish and Wildlife Service 1992).

The most abundant breeding species in Alaska are northern fulmars, storm-petrels, kittiwakes, murres, auklets and puffins. These species also form the largest colonies. Fulmars, storm-petrels and kittiwakes are surface feeders, picking their prey from the surface or just below the surface; murres, auklets, and puffins dive for their food. Fulmars nest primarily on island groups in and around the

Bering Sea. They take a wide variety of prey (e.g., fish, squid, zooplankton, jellyfish) from the surface or just below the surface. Storm-petrels are strictly nocturnal and nest below ground in either burrows or crevices between rocks. They forage on zooplankton and squid; in some areas they are dependent upon small fish such as capelin and sand lance caught at the surface. Black-legged kittiwakes are widespread throughout Alaska, Canada and Eurasia while red-legged kittiwakes are found only in the Bering Sea region. Both are surface feeders although black-legged kittiwakes feed primarily on small fish and forage over the continental shelf and shelf break; red-legged kittiwakes feed primarily on myctophids and will forage beyond the shelf break. Murres nest on cliffs around the coast of Alaska, forming large colonies. They forage over the continental shelf and will dive up to 300 feet for prey (primarily fish during the breeding season and zooplankton during the winter). Six species of auklets nest in Alaska, four of which (Least, Crested, Whiskered and Parakeet) nest only in the Bering Sea region. Least auklets are the most abundant breeding seabird in Alaska; approximately one-fifth of the State's total breeding seabirds.

Figure 1. Nesting murre.

Auklets forage across the continental shelf; however, they are attracted to "fronts" between water masses where food is concentrated. They feed on zooplankton, usually diving to moderate depths but can dive up to 250 feet. Puffins breed throughout Alaska, where their populations are concentrated. Puffins generally forage near their breeding colonies and while their diet is broad over the course of the year, puffins depend upon fish to feed their young.

Habitat changes associated with projected shifts in climate will clearly affect seabirds through changes to their habitat—some species will be favored, others will not. Distributions will shift and relative abundances will change. For seabirds, their fate depends upon available, high quality prey and adequate nest sites. Direct mortality due to predation and storms are primary factors in shaping populations. For seabirds, habitat at sea is characterized by physical characteristics of water (e.g., temperature, salinity, turbidity, currents, nutrients and depth). Many marine organisms have fairly narrow temperature ranges that favor them, and directly or indirectly, temperature and salinity are the main physical indicators of different communities.

Intrinsic Value of Wildlife

Seabirds are an integral and quite visible part of the Bering Sea area and therefore valued simply for their existence. The Bering Sea region is generally an extreme environment and receives minimal recreational or tourism use in comparison to other coastal and marine environments. The existence of the region, however, is important and valued. Existence value relates to the appreciation and therefore value ascribed to wildlife and wilderness areas by individuals even though most would not visit the areas or directly view the wildlife (Krutilla 1967). Appreciation is gained instead through vicarious enjoyment of nature programs, books, art, and programs about unique areas (Randall 1992). The audiences to be considered in recognizing this type of value include Alaskan residents from outside the region and non-Alaskan residents (both national and international) (Thomas et al. 1992; McCollum and Bergstrom 1992).

Legal Framework

The intrinsic values of seabirds are demonstrated by specific legislation and land designations for the protection of seabirds. Early in the century, several national wildlife refuges were established primarily to protect seabird nesting habitats. These were ultimately combined into the Alaska Maritime National Wildlife Refuge, which was established as part of the Alaska National Interests Lands Conservation Act (ANILCA). The purposes of the refuge are, as outlined in Title III - National Wildlife Refuge System, Section 303 (B):

> "(i) to conserve fish and wildlife populations and habitats in their natural diversity including, but not limited to marine mammals, marine birds and other migratory birds, the marine resources upon which they rely, bears, caribou and other mammals;
>
> (ii) to fulfill the international treaty obligations of the United States with respect to fish and wildlife and their habitats;
>
> (iii) to provide, in a manner consistent with the purposes set forth in subparagraphs (i) and (ii), the opportunity for continued subsistence uses by local residents;
>
> (iv) to provide, in a manner consistent with subparagraphs (i) and (ii), a program of national and international scientific research on marine resources; . . ."

The intrinsic value associated with wildlife is further recognized and acknowledged in the International Treaty obligations contained in the Migratory Bird Treaty Act. The treaties speak to the protection of migratory bird populations and their habitats. A further consideration relates to the Endangered Species Act—it is easier and cheaper to manage a species to prevent it from being listed under the Act than to manage it as an Endangered Species. A recent example is the potential for closure of the longline fishery due to mortality of the endangered short-tailed albatross.

Monitoring

Seabirds are a valuable indicator of the function and integrity of marine ecosystems (integrity being equivalent to "completeness" or "wholeness"). As marine systems shift in response to climate change, so will the numbers and composition of seabirds. Due to their dependence on different portions of the marine environment, seabirds are also a useful group of species to monitor how climate change affects marine ecosystems. Proceedings of earlier workshops on global change in Alaska sponsored by the International Arctic Science Committee have listed a number of implications of climate change on marine ecosystems (e.g., Weller and Anderson 1998). Seabirds, because they feed primarily on marine organisms, are good indicators of change in different parts of the marine food web (Montevecchi 1993) because their prey is directly affected by changes in sea temperatures, extent of sea ice, primary productivity in the ocean, and other physical and biological characteristics (e.g., Divoky 1978, Iverson et al. 1979, Cairns 1987, Murphy et al. 1991, Hamer et al. 1991, Springer 1991, Decker et al. 1995, Ohtani and Azumaya 1995, Springer et al. 1996). Furthermore, changes in sea level or increases in the frequency and intensity of storms could directly impact birds at nesting sites (Byrd and Tobish 1978) or contribute to die-offs in winter (Bailey and Davenport 1972). By monitoring parameters like reproductive success, timing of nesting events, and prey preferences of species indicative of various foraging guilds (e.g., surface feeding planktivores, diving planktivores, surface feeding piscivores, etc.), it is possible to see responses to annual changes in the marine environment. Parameters like survival rates and population trends reflect decadal-scale responses.

In addition to their utility as indicator species, it is important to understand the relationships between climate change and seabird distribution and abundance. Seabirds can be dramatically affected by other anthropogenic changes related to fishing or industrial development. Oil spills can result in dramatic impacts; over 36,000 dead birds were collected as a result of the *Exxon Valdez* spill in the

Gulf of Alaska in 1989. The effects of climate change need to be understood in order to clearly understand the effects of these other activities.

Subsistence

Subsistence, living off the land, is an important way of life for many residents in rural Alaska. The value transcends the economics associated with putting food on the table. As an elder from Fairbanks put it: “Subsistence tells us who we are and what we are worth, and without it, we would be lost.” Subsistence harvest of seabirds is conducted by residents of coastal villages throughout the Bering Sea region. These villages are remote and have limited employment opportunities; consequently, many residents rely on subsistence resources. The relative use of seabirds depends in part on proximity to the resource; a study of bird hunting in Savoonga and Gambell over the course of a year found that nearly all households used birds (Wohl et al. 1995) (Table l)

Table 1. Subsistence Use of Birds, Savoonga and Gambell

	Households using seabirds	Total number of birds	Primary species
Gambell	92.8%	16,174 (estimated)	Crested Auklet, Common Murre, Pelagic Cormorant
Savoonga	100%	5,730 (estimated)	Common Murre, Pelagic Cormorant, Crested Auklet

Seabirds and their eggs, while a small portion of the overall subsistence diet, provide variety, particularly in the spring. Seabirds may also provide an important food resource in years when other resources are limited. Seabird hunting and egg gathering are activities generally done in family groups. These activities help to maintain family ties and provide cultural identity. Furthermore, the gathering activities are viewed both as food gathering and essentially as social and recreational activities (Wohl et al. 1995). The use of seabird resources extends beyond the region, as trade and barter are integral parts of the subsistence lifestyle; consequently, resources specific to certain regions or areas are used to trade for other resources that are not available locally.

Economic Values

While tourism activities directly related to seabirds may be minimal in the region, they can be important locally. Annually, many groups visit the Pribilof Islands to enjoy the spectacle of large and diverse seabird populations. This tourism is important to the local economy. In addition, the local Native corporation, in cooperation with the Fish and Wildlife Service, supports a science camp for young people to learn from their elders and others about the local environment. The camp, while being of great educational value, also provides income to the local area and important diversity to the local economy.

The Bering Sea region is a unique environment, particularly for seabirds as measured by their diversity and populations within the region. This uniqueness contributes to science and educational products and outputs—one of the last “wilderness” laboratories (McCollum and Bergstrom 1992). Use by scientists and resource managers provides distinct economic values related to the employment of people who study and manage seabirds and all the related goods and services they need. Factors that need to be considered in evaluating the economic value of this aspect include the logistics required by scientists to pursue onsite studies, and then support for data analyses and report preparations back at their respective home bases. Resource managers are supported for a variety of activities from scientific studies to public education and outreach (Hoehn 1992).

Available Information

Distribution and Relative Abundance at Breeding Colonies

Two programs largely were responsible for initial inventories of seabird breeding colonies in Alaska: 1) the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which was associated with offshore oil leasing in Alaska beginning in the mid-1970s, and 2) surveys associated with Wilderness Area designation in the Aleutian Islands National Wildlife Refuge in the early 1970s (Sekora et al. 1979). Results of these descriptive surveys were used to publish "Catalog of Alaskan Seabird Colonies" (Sowls et al. 1978), which mapped the distribution of seabird breeding colonies, provided a list of breeding species, and included approximate counts of individuals present. Since the objective for these surveys was to delineate important seabird concentrations, initial inventories were crude for most colonies, providing data useful for determining relative abundance of species but adequate for measuring only very large population changes in the future. The U.S. Fish and Wildlife Service's Division of Migratory Bird Management in Anchorage developed, and has maintained, a computer data base on seabird breeding colonies which is updated as new information is received. An updated version of the 1978 catalog was produced in 1996 (Mendenhall and Stephensen 1996), and the database has been expanded to include colony surveys on the Russian side of the Bering Sea.

Breeding Ecology

Also as part of the OCSEAP program, studies of breeding ecology of common species of seabirds at selected colonies were undertaken. Study sites were scattered along most of Alaska's coastline to cover all the potential oil leasing areas. Some of these studies continued for several years and information was gathered on timing of nesting events, reproductive success, and prey preferences. Furthermore, research was conducted on sources of variability involved in monitoring population trends. The data gathered during these and subsequent studies provided the basis for a seabird monitoring program designed to document patterns of change.

Distribution at Sea

Opportunistic and directed transect surveys of potential marine oil lease sites and other areas were conducted using standard methods during the OCSEAP studies, and these data were entered into a "Pelagic Seabird Database" maintained by the U.S. Fish and Wildlife Service. Over the past two decades, additional survey information has accumulated, but the database has not been completely updated. Currently there is a need for funding to enter data and to make the database more user-friendly.

Monitoring

As indicated above, baseline data on breeding seabirds began to accumulate in the mid-1970s due to OCSEAP studies and continuing work sponsored primarily by the Minerals Management Service and the U.S. Fish and Wildlife Service. After the Alaska National Interests Lands Conservation Act of 1980 established the Alaska Maritime National Wildlife Refuge, with a purpose of conserving marine bird populations, a more formal monitoring program began.

The stated objectives of the existing monitoring program are to provide long-term, time-series data from which: 1) biologically significant changes may be detected, and 2) hypotheses about cause of changes may be tested. Since it was impractical to monitor every breeding parameter for every species at every site annually, choices had to be made about the most appropriate approach. The idea was to detect signals of change in the marine ecosystem using seabirds as indicators. From the standpoint of conservation of seabirds, changes in population levels are of paramount interest, but populations of these long-lived birds would more likely respond to changes of a decadal rather than annual time scale. Reproductive success, timing of nesting events, prey preferences, and adult survival rates were deemed to be more sensitive to annual changes in the environment.

Different species of seabirds use different portions of the marine food web, so the group of species selected for monitoring included both piscivores and planktivores. Within these groups, species were included that are able to forage in the water column (down to 100 m) along with species that are restricted to feeding on the surface of the sea. In addition, both inshore and offshore feeders were included. This mixture of species provides a basis for evaluating the extent of impacts of perturbations in the marine ecosystem.

The geographic coverage of the monitoring system is statewide, but the density of sites is low. A total of 12 sites have been designated for annual monitoring by the U.S. Fish and Wildlife Service (Alaska Seabird Inventory and Monitoring Plan, U.S. Fish and Wildlife Service, Anchorage). Besides the annual sites, data are being gathered opportunistically at other sites visited less frequently. Supplementary information is also provided through research projects like those funded by the *Exxon Valdez* Oil Spill Trustee Council and monitoring sponsored by the Minerals Management Service.

Most of the data being gathered annually are being entered into the "Pacific Seabird Monitoring Database," a project coordinated by the Pacific Seabird Group and initially funded by the U.S. Geological Survey, Biological Resources Division. Furthermore, annual reports of monitoring results are being distributed by the U.S. Fish and Wildlife Service (e.g., Byrd and Dragoo 1997, Byrd et al. 1998).

Relationship to Environment

Colony Locations/Breeding Habitat

Collectively seabirds use a wide range of coastal habitats for nesting, but common characteristics of all nesting habitats are safety from mammalian predators and availability of marine prey near nesting colonies. Colonies are distributed along the entire coastline of Alaska. Most seabirds nest on offshore islands or mainland coastal cliffs, with some species nesting on the ground, some nesting in earthen burrows, others nesting in rock crevices, and some species using cliff ledges. The availability of habitat in spring following snow melt is a factor that can affect timing of nesting events and ultimately reproductive success at more northerly colonies (Sealy 1975). Abnormally high rainfall can affect survival of chicks in earthen burrows, and incidence of big storms with high winds during the chick-rearing period can cause mortality for chicks of species nesting on cliff-ledges (Byrd and Tobish 1978).

At-sea Distribution in Summer

Most species of seabirds nesting in Alaska feed within 50 km of breeding colonies. The practical distance for foraging is limited by the time it takes to capture and transport food to chicks frequently enough for adequate growth. The relative abundance and distribution (in time and space) of prey is affected by ocean dynamics including climate and physical factors (e.g., Piatt and Anderson 1996). Changes in the availability of prey can cause reproductive failures (Ainley et al. 1996).

Feeding Guilds

Ashmole (1971) described foraging strategies used by different groups of seabirds. Since species exploit identifiable parts of the food web, seabirds as a group offer opportunities to compare responses of different portions of the marine ecosystem to perturbations like climate change. For example, species that feed on organisms at the surface of the sea may be more sensitive to changes in distribution of prey than those that are able to pursue prey deep into the water column. Furthermore, species that feed on plankton may respond differently than forage-fish feeders to change in the marine environment.

Wintering Habitat

Relatively little is known about the winter ecology of seabirds nesting in Alaska. Few surveys have been made at sea during the winter, and it is virtually unknown where seabirds from any particular breeding colony winter. Nevertheless, it is known that some species (e.g., murres) remain as far north as there is open water in winter, and concentrations of several species of seabirds are associated with the sea ice edge. Clearly, the extent and duration of ice cover has a major impact on the amount of winter habitat available in the Arctic Ocean and Bering Sea.

Potential Effects of Climate Change—Case Studies

Long-term Changes in the Gulf of Alaska Marine Ecosystem on Marine Birds and Mammals

Abrupt changes in marine fish communities in the northern Gulf of Alaska are reflected in the diets and population biology of many marine birds and mammals. Capelin were the dominant prey of seabirds in the late 1970s, but were absent or much reduced in seabird diets in the late 1980s and early 1990s. Capelin were replaced by sandlance (*Ammodytes hexapterus*) and pollock. Likewise, diets of northern fur seals (*Callorhinus ursinus*), Steller sea lions (*Eumetopias jubatus*) and harbor seals (*Phoca vitulina*) collected in the 1970s were rich in fatty forage fish such as capelin and herring (Pitcher 1980, 1981; Castellini 1993). These prey were rare in stomachs of fur seals and Steller sea lions collected in the 1980s (Alverson 1992; Castellini 1993; R. Merrick, pers. comm.).

Coupled with these changes in diet, and probably because of them (Castellini 1993, Springer 1993), there have been marked changes in the population ecology of several marine bird and mammal species in the Gulf of Alaska. For example, breeding success of black-legged kittiwakes (*Rissa tridactyla*) at colonies in the Gulf of Alaska declined dramatically through the 1980s (Hatch and Piatt *in press*). Kittiwake populations have declined (ca. 50%) at Middleton Island since about 1980. Common murre populations have declined by up to 90% at many colonies both inside and outside the *Exxon Valdez* oil spill zone and were declining at some affected colonies before the spill occurred. Prince William Sound boat surveys conducted in 1989–1991 suggest that there have been major declines (50–95%) in populations of 15 different coastal and marine bird species since surveys conducted in 1972–1973 (Klosiewski and Laing 1994). Species that have declined significantly include cormorants (-95%), Larus gulls (-69%), kittiwakes (-57%), pigeon guillemots (*Cepphus columba*, -75%), marbled and Kittlitz's murrelets (*Brachyramphus* spp., -68%), and horned puffins (*Fratercula corniculata*, -65%). Similarly, analysis of Christmas Bird Count data suggests that marbled murrelet populations throughout the Gulf of Alaska have declined by over 50% since the early 1970s (Piatt and Naslund 1995).

As another indication that food has been limiting in recent years, several large-scale die-offs of seabirds, mostly surface-feeding species, have been observed in the Gulf of Alaska during the last decade, most notably in 1983, 1989, and 1993 (Nysewander and Trapp 1984; Hatch 1987; Piatt 1990; USFWS unpubl. data). In March of 1993, an estimated 100,000 common murres died throughout an area spanning southeast Alaska to the Alaska Peninsula. Starvation was determined to be the proximate cause of death. In contrast, there were no reported die-offs in the 1970s since Bailey and Davenport's (1972) report of a massive murre die-off along the Bering Sea side of the Alaska Peninsula in 1970.

Marine mammals have exhibited similar signs of food stress in recent years. Harbor seals at Tugidak Island in the Gulf of Alaska declined by about 85% between 1976 and 1988 (Pitcher 1990). Steller sea lion populations declined by 36% in the Gulf of Alaska between 1977 and 1985 (Merrick et al. 1987), and by another 59% between 1985 and 1990 (Castellini 1993). Northern fur seals declined about 35% by 1986 from their average numbers in the 1970s, although numbers had rebounded somewhat (20%) by 1990 (Castellini 1993). Associated with the declines in Steller sea lions are declines in birth rate, fewer breeding females, fewer pups, decreased adult body condition, decreased juvenile survival, and a change in population age structure (Merrick et al. 1987; Loughlin et al. 1992). Declines in marine mammal populations may be due in part to harvest, incidental catch in fishing gear, and disease, but the consensus among researchers is that changing food availability (lower quality or biomass) is the most likely cause of recent declines (Castellini 1993).

Conclusions. A variety of independent data point to an abrupt shift in the marine ecosystem of the Gulf of Alaska during the past 20 years. This shift has been manifested by marked changes in the composition of marine fish communities, reduced forage fish biomass, and dramatic changes in the population ecology of higher vertebrates that depend on those fish populations. Unlike short-term phenomena such as the El Niño, which may disrupt marine food-webs and diminish seabird productivity for 1- to 2-year periods (Ainley and Boekelheide 1990), this shift represents a more pervasive and persistent change in the ecosystem.

It appears that a "change of state" was initiated in 1976, when atmospheric circulation in the North Pacific shifted, and remained that way until the late 1980s (Trenberth 1990; Kerr 1992). Effects of this climate shift were evident in a host of environmental variables measured throughout the eastern North Pacific between 1968 and 1984 (Kerr 1992). It may have taken 3–5 years for this change of state to be manifested by changes in water temperatures, fish populations and seabird demography in Alaska. Atmospheric and ocean climate conditions may now be returning to those observed prior to 1976 (Royer 1993; Trenberth 1990).

Although they do not appear to be synchronized with events in the Gulf of Alaska, similar temporal relationships between water temperatures, fish stocks, seabirds and marine mammals have been observed in the Bering Sea (Alverson 1992; Springer 1992; Decker et al. 1995). Productivity of seabirds nesting on the Pribilof Islands started declining in about 1978, as water temperatures rose above average and an unusually large year-class of pollock appeared. Seabird productivity remained low through the 1980s, while pollock stocks increased dramatically. Diet composition of murres and kittiwakes changed significantly, and indicator species such as capelin and hyperiid amphipods largely disappeared from diets in the 1980s (Decker et al. 1994). By the late 1980s, seabird productivity was increasing again as pollock stocks declined. As in the Gulf of Alaska (above), a strong negative relationship between pollock biomass and kittiwake production may be an indication that predators compete for forage fish and that food-webs are regulated by "top-down" interactions (Springer 1992). Alternatively, forage fish, pollock, kittiwakes and other predators may all be responding in their own fashion to changing oceanographic conditions and primary production ("bottom-up" control; Springer 1992).

Whatever the mechanism, natural long-term cycles in marine productivity may account for much of the variation observed in seabird population parameters. For example, Aebischer et al. (1990) demonstrated a remarkable similarity between long-term (33-year) trends in wind patterns, the abundance of phytoplankton, zooplankton, and herring (*Clupea harengus*), and kittiwake clutch size, phenology, and chick production in the North Sea. All these measures of biological production declined from about 1955 to the late 1970s, and have been increasing since that time.

Black Guillemots in Arctic Alaska

The anticipated changes in air temperature associated with global climate change will have the most immediate effects on the distribution and biology of arctic seabirds. The response of snow and ice cover to elevated temperatures from global change will be immediate and pronounced. While snow and ice influence the life histories of most subarctic and many temperate birds, their influence on arctic species is most pronounced. Arctic seabirds have evolved a range of life history characteristics in response to the temporal and spatial patterns of snow and ice cover in the region. Seabird species most dependent on, or constrained by, the presence or amount of ice and snow would be expected to be among the first affected by warming.

There is increasing evidence of ongoing climate warming in the Arctic in general (Overpeck et al. 1997; Cavalieri et al. 1997) and northern Alaska in particular (e.g., Foster 1989; Foster et al. 1991; Sharratt 1992). While the consequences of the predicted warming on arctic species have been the subject of much speculation (Brown 1991; Peters and Lovejoy 1992), little has been done to monitor or document recent or ongoing effects (Jarvinen 1995). One of the few examples of contemporary climate change on Alaskan arctic seabirds is demonstrated by the distribution and abundance of the black guillemot (*Cepphus grylle*) in northern Alaska. The black guillemot is a circumpolar arctic seabird typically associated with snow and sea ice habitats for the entire year. In the western Arctic this species breeds north of the Bering Strait in coastal locations (Sowls et al. 1978), which are typically snow-covered for approximately nine months each year (Brower et al. 1977). They nest in cavities and require a minimum of 80 days from first occupation of the cavity to chick fledging, an atypically long period for an arctic nesting species. Successful reproduction in the Arctic is dependent on early occupation of a nest site shortly after cavities become snow-free, and on fledging chicks before snow again accumulates in late summer or early autumn.

Studies at a northern Alaska black guillemot colony over the last two decades (Divoky 1998) show that black guillemot breeding chronology and success are sensitive to snow melt and accumulation. Ovulation by females occurs only after they can occupy a nesting cavity. Initial occupation of the colony in the spring and breeding initiation are dependent on the timing of snowmelt. During the study period, black guillemot breeding chronology, as measured by dates of colony occupation and clutch initiation, was correlated with snowmelt at the colony and advanced 4.5 days per decade in response to climate amelioration. Snow accumulation in late summer and early fall had the potential of decreasing breeding success. In 1988, when the period between spring snowmelt and fall snow accumulation was <80 days, chicks were trapped in nesting cavities, reducing fledging success and post-fledging survival.

While black guillemots were commonly recorded at Point Barrow since the late 1800s (Bailey 1948), the first breeding record was obtained in 1966 (Maclean and Verbeek 1968). Prior to that time, snow conditions may have prevented successful breeding. Examination of historic weather records dating back to the 1940s indicates that the snow-free period in arctic Alaska has regularly exceeded 80 days only since the mid-1960s. The observed warming temperatures at Barrow are part of a long-term warming trend that began in the region early this century after approximately three centuries of cooler summer temperatures (Overpeck et al. 1997). The recent establishment and growth of black guillemot colonies in northern Alaska may be the result of the century-long warming trend in the region.

Other bird species may be responding to the increased snow-free summer period in arctic Alaska. Horned puffins (*Fratercula corniculata*), a subarctic species whose breeding range extends as far north as the central Chukchi Sea, have prospected potential breeding sites in the Barrow area since at least 1972 (Divoky 1982 and unpubl.), and the first breeding record occurred in 1986 when a pair bred successfully in a nest box on Cooper Island (Divoky unpubl.). Horned puffins have a longer nesting period than the black guillemot, requiring about 90 days from the onset of egg formation to chick fledging. Snow-free periods <90 days occurred regularly until the 1980s, and like that of the black guillemot, the first record of a horned puffin nesting in arctic Alaska may have been related to the increasing snow-free period.

Warming temperatures have allowed guillemots to breed in the Barrow area, but continued warming may be creating conditions unfavorable for the persistence of a regional population. The reliance on the pack ice as a foraging habitat through most of the year makes black guillemots sensitive to changes in the extent and nature of pack ice. In northern Alaska annual variation in guillemot breeding success is inversely correlated with the distance of the pack ice from the shore in August due to the abundance of arctic cod (*Boreogadus saida*) at the ice edge and a lack of alternative prey in ice-free nearshore waters (Divoky unpubl.). In the eastern Canadian Arctic, changes in breeding distributions and abundance of black guillemots are associated with annual variation in distribution of sea ice (Prach and Smith 1992). If temperature increases in the arctic are as high as predicted, the Beaufort Sea pack ice may regularly retreat >100 km from mainland Alaska (McGillivray et al. 1993), far greater than the foraging range of guillemots (typically <15 km).

While anticipated changes in the Beaufort Sea would affect the productivity of the Cooper Island colony, recent reductions in sea ice extent may already be contributing to the colony's decline. From 1989 to 1997 the colony decreased from 225 to 110 pairs, primarily due to decreases in immigration and annual survival of adults. Both decreases may be due to alterations in sea ice cover resulting in decreased prey abundance or availability. Winter sea ice has been decreasing throughout the Arctic over the past 20 years (Johannessen et al. 1995), and summer sea ice extent decreased 9% in 1990–1995 compared with the previous ten years. Some of the greatest reductions in summer ice extent have been in the eastern Siberian Sea (Maslanik et al. 1996). Guillemot colonies from that location may be in the same metapopulation as the northern Alaskan colonies (Divoky 1998).

Future Research

Besides identifying trends, time series data on seabirds can be used to test hypotheses about effects of climate change. The wildlife group at the workshop developed, as examples, some predictions that could be tested given various responses of the marine environment to climate change, particularly warming. The group decided that less emphasis needs to be placed on economics; while there are modeling techniques available to determine estimated dollar values of seabirds, the importance of seabirds relates to their utility for monitoring. The following topics describe how seabirds may be affected by changes in climatically driven variables. From these relationships, specific hypotheses for testing can be developed.

Extent of Sea Ice. If warming continues, the extent of sea ice will continue to decline. Some species of seabirds may benefit (increased productivity, range extensions) by being able to feed in open water near nesting areas earlier in spring and fledge young before fall freeze-up. Nevertheless, reduced sea ice may adversely affect species dependent on feeding at the ice edge. More open water could increase severity of rough seas, potentially causing increased winter mortality of birds at sea.

Surface Sea Temperature. If sea temperatures change substantially, the distribution of seabird prey will shift. For some species and sites, the shift may be beneficial (e.g., species that feed on prey that local conditions now favor), but for others it could be detrimental (e.g., surface feeders whose prey has been driven too deep for them to access). Initially, productivity of seabirds would be affected and ultimately population change would occur.

Spring Snow Melt. If warming continues, snow melt in spring will make nesting sites available earlier. This could be beneficial for some species at locations where productivity, particularly survival of young, has been reduced due to the shortness of the available nesting period. In contrast, it is possible that enhanced vegetation growth during extended growing seasons could cover crevices used by auklets.

Air Temperature. If average spring air temperatures continue to increase, coastal permafrost could thaw, potentially making new areas available to burrow-nesting seabirds.

Storm Intensity. If warming causes increased storminess (duration and/or frequency), mortality of seabird chicks at nest sites could occur and adult mortality in winter might also result due to rough seas interfering with feeding and dispersing prey.

Precipitation. If warming causes increased precipitation in summer, burrow nesting seabirds may experience increased chick mortality from flooding.

Sea Level. If warming causes significant increases in sea level, low-lying nest sites on barrier islands and nearshore scree nesters might be lost.

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