

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

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

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

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

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

Table 1**Landed Volume and Value of Alaska Commercial Fish Harvests and Production, 1995**

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

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

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

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

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

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

Table 2

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

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

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

File: Significance.

Table 3

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

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

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

File: Commun.xls

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

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

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

Potential Effects of Climate Change on Alaska Fisheries

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

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

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

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

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

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

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

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

Management Responses to Climate Change

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

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

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

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

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

Past Variation in Harvests

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

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

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

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

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

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

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

File: BIOMCAT1.XLS.

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

Figure 1

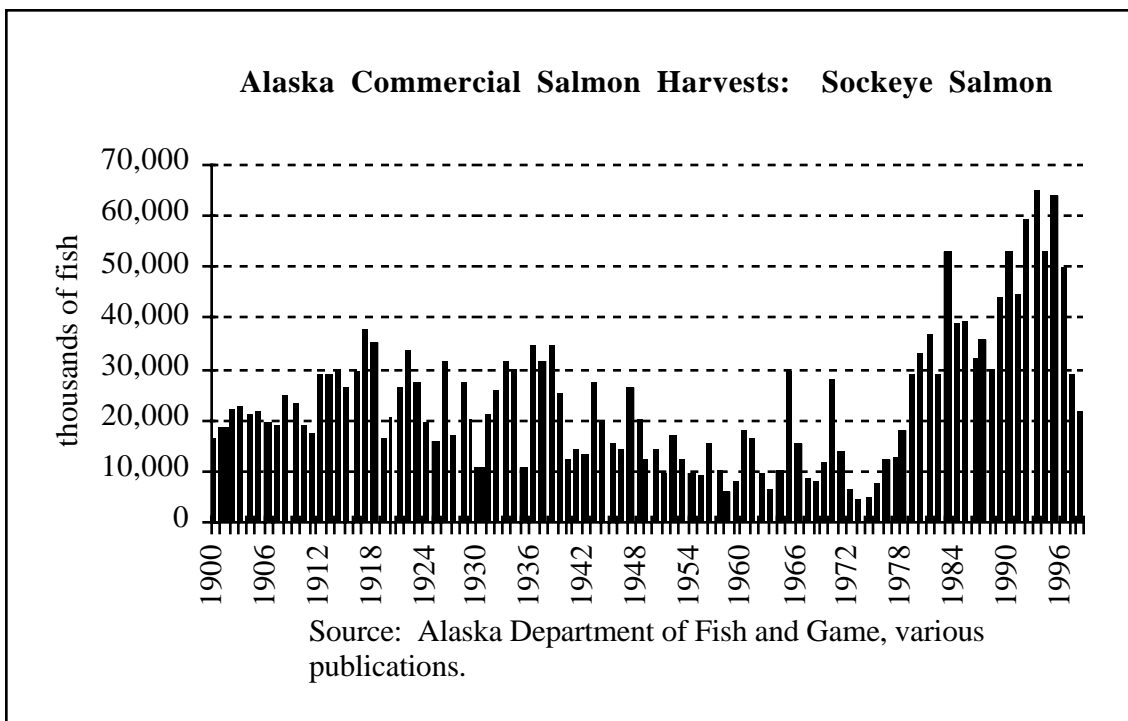


Figure 2

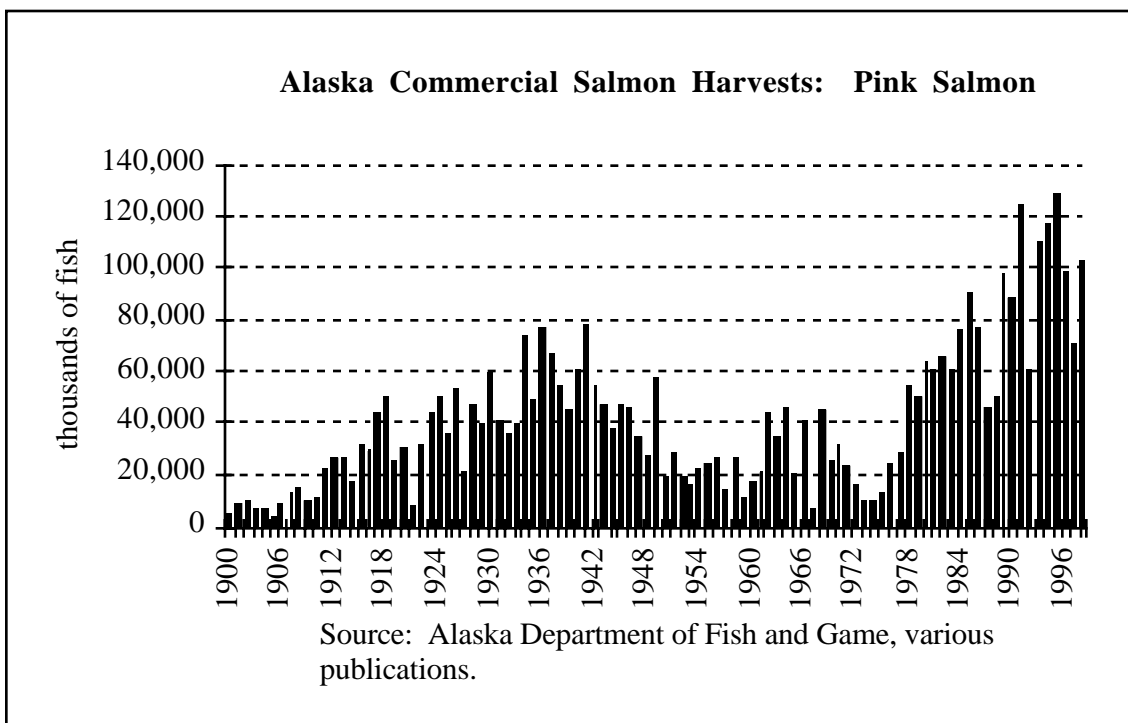
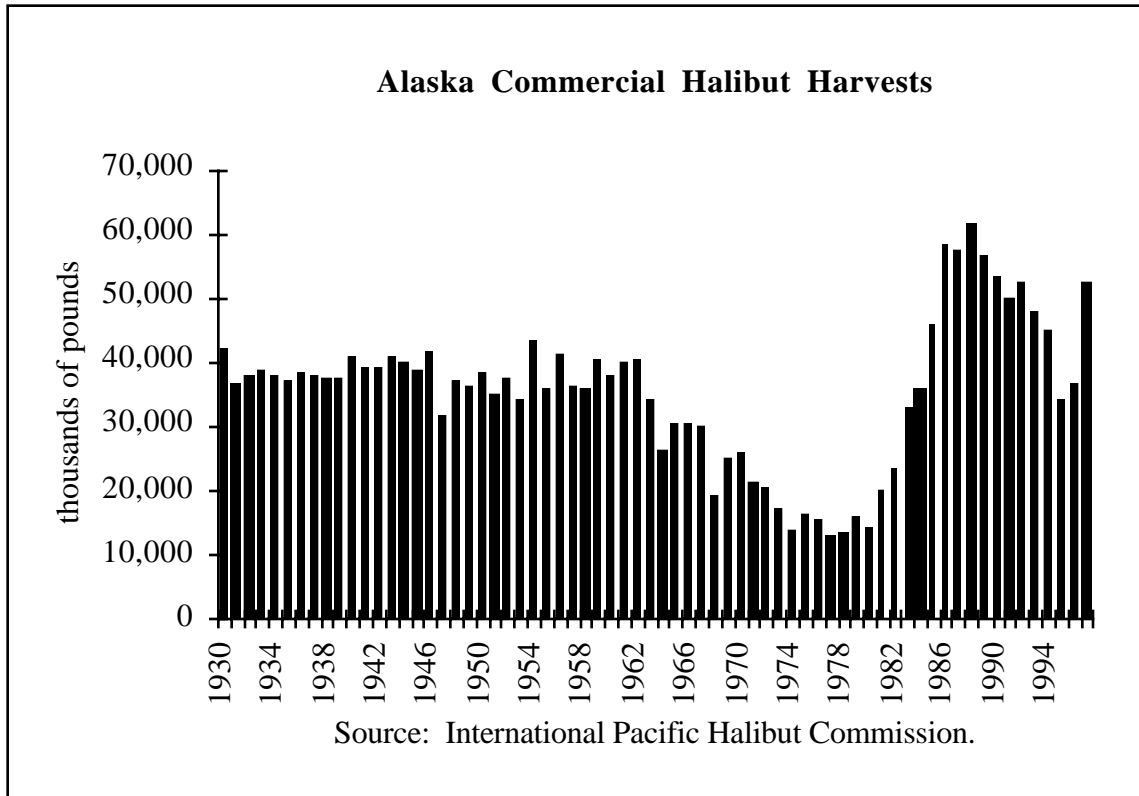


Figure 3



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

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

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

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

Summary

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

- Climate change may have significant effects on Alaska fisheries.
- Climate change is likely to reduce the abundance of some species while increasing the abundance of others, with resulting reductions or increases in commercial harvests. Some commercial fisheries may disappear; some new fisheries may develop.
- How managers respond to climate change may either amplify or smooth out the effects of climate change on harvests.
- Significant changes in harvests may occur rapidly.
- For a given species, climate change may cause harvests to increase in some parts of Alaska and decline in other parts of Alaska.
- For most species, we can't predict accurately how harvests in a given area may change, or when changes may occur. The farther we look into the future, the greater our uncertainty about potential changes in harvests. Past variation in Alaska harvests reflects short-term and medium-term *climate variability*. Future variation in response to longer-term *global climate change* could be greater than past variation.

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

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

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

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

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

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

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

Types of Short-Term Effects

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

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

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

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

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

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

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

Potential Magnitude of Short-Term Economic Effects

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

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

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

Price Effects of Climate-Driven Changes in Harvests

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

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

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

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

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

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

Regional Differences Within Alaska in Human Effects of Climate Change

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

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

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

Effects Beyond Alaska

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

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

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

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

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

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

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

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

Responding to Climate Change in Alaska Fisheries

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

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

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

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

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

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

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

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

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

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

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

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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:

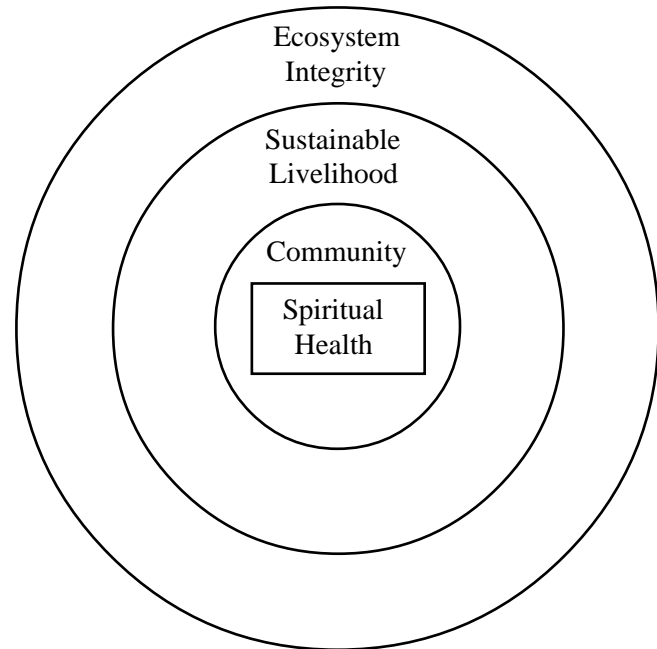
- Establish community-based monitoring projects that incorporated both western science and traditional ecological knowledge (TEK).
- TEK must be at the table when resource management decisions are made, e.g., continued (if not increased) reliance on Regional Advisory Councils in Alaska.
- Carl Jack stressed 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.

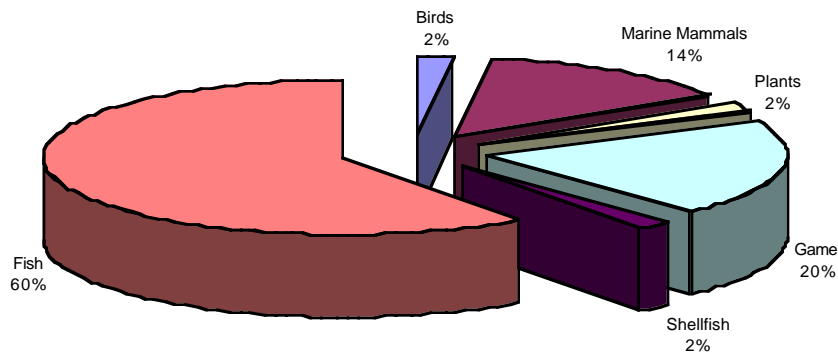


Figure 1. Composition of wildlife harvests by rural Alaskan households, 1990s.

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 predicted 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 Diomedes 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.

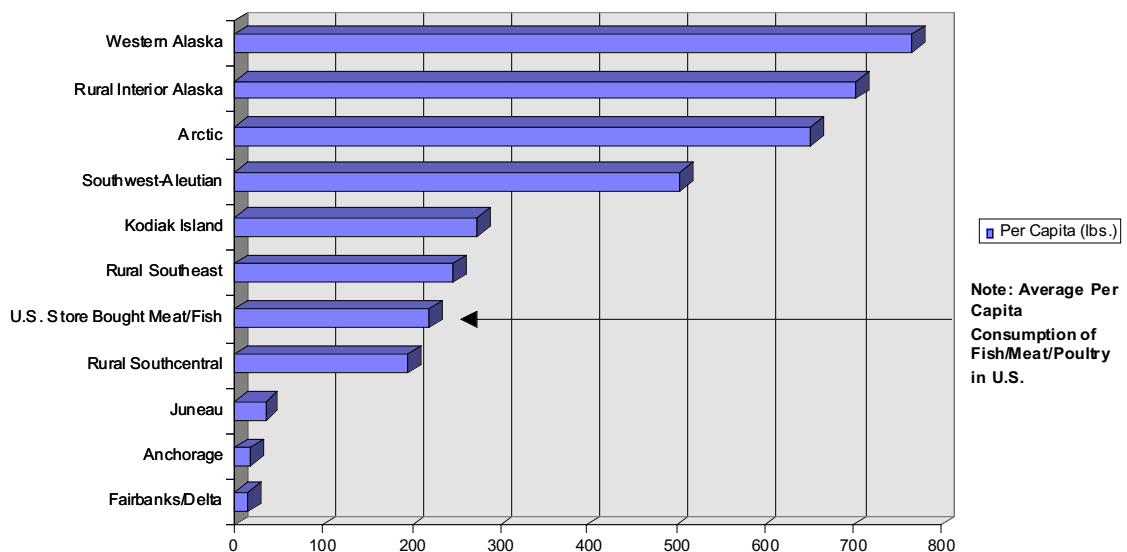


Figure 2. Per capita wild resource harvest (lbs) for selected Alaska regions.

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.

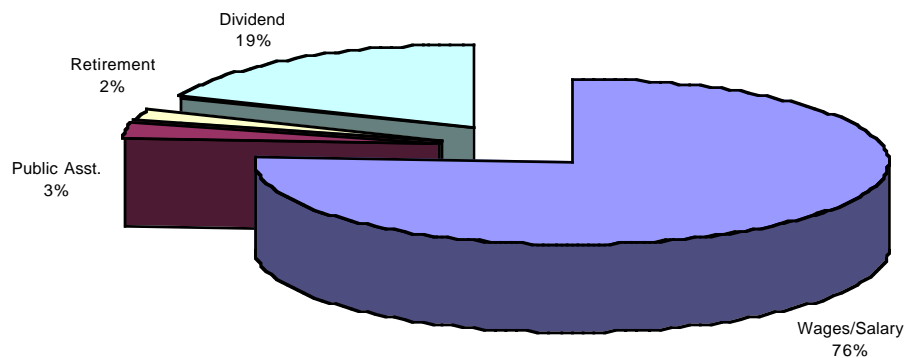


Figure 3. Kivalina: total household income by source

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, murre, 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; murre, 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 long-line 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 1)

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 (*Cephus 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 murre 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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