(MBIS, 1997). This is because the expected increase in precipitation would be offset by increased evaporation (MBIS, 1997). Similar effects can be expected in Alaska. Changes in the extent of permafrost will affect the rate of infiltration, the moisture content of the active layer, the depth to water, and landforms through thermokarst development.

Coastal Environmental Changes

The coast of Alaska, which exceeds in length the coastlines of the other 49 states, presents special problems (Fig. 11). Tidal amplitudes along the Western coast of Alaska (the Yukon-Kuskokwim delta) can be as large as 15 ft (5 m) between seasonal high and low tides. Large tidal amplitude produces high hydrological energy along the coast and well into large rivers in the area. High hydrological energy associated with much of the coastline of the Y-K delta is associated with high rates of erosion of exposed peats along much of this coastline. This is exacerbated by storm surges (see next paragraph). Aerial photography shows disappearance of up to 1,500 ft (500 m) of coastline in some locations, primarily exposed points, between 1950 and 1984. South of Hooper Bay, 150 ft (50 m) disappeared between 1988 and 1993 (BESIS, 1998). Erosion is also rapid on large former tributaries of the Yukon River. At some points as much as 30 ft (10 m) of river bank have disappeared in a single growing season. Erosion has forced movement of the village of Newtok in the central Y-K delta, and the relocation of other villages including Kivalina and Shishmaref on the Bering Sea coast is being considered. The cost of relocating Kivalina, quoted in the Anchorage Daily News of Nov. 2, 1997 by Orson Smith, Corps of Engineers manager for the Kivalina project, may be up to $50 million.

On the western and northern coast of Alaska sea ice is another problem. Sea ice is present along the Bering Sea coast for half of the year and along the Chukchi and Beaufort Sea coasts in the north for up to 10 months or longer in most years. The presence of ice not only affects the weather and climate of the region, but also restricts all human activities, from fishing to offshore oil exploration. Recent observations have shown a five percent reduction in sea ice extent in the Bering Sea over the last three decades, and the lowest ever sea ice extent has been observed in the Beaufort Sea in the fall of 1998 (BESIS, 1998). With less ice, storm surges have become more severe because the larger open water areas can generate bigger waves. Adding to the resulting erosion is the thawing of permafrost in coastal cliffs. This has led to unprecedented coastal retreat rates that pose serious problems in Native villages along the coast. As the climate continues to warm, these impacts, both positive and negative, can only become more pronounced.

The Gulf of Alaska is ringed by extensive glacier systems, which constitute the fourth-largest glaciated region on Earth (after Antarctica, Greenland and the Canadian islands) and have been identified as major contributors to sea level rise over the last century (see Chapter II). These glaciers are produced by frequent intense storm systems generated by the Aleutian Low, which dump huge snow loads (up to 30 ft or 10 m water equivalent per year), on the coastal mountains. The runoff from these glaciers (over half a million cubic feet per second) produces the Alaskan coastal current with its low-salinity waters that flow westward along the coast and through the passes of the Aleutian Islands into the Bering Sea (Royer, 1981; 1982). Any warming of the climate will intensify this coastal current through increased glacier melting and will in turn affect the weather, climate, fisheries and biota along the entire southern coastline of Alaska.

Impacts on Ecosystems

Ocean ecosystems and fisheries are highly vulnerable to changes in sea temperature and sea ice conditions (NRC, 1996; Brander, 1996; Knapp, 1999). Recent observations of climate-related changes in the Bering Sea showed abnormal conditions during the last two summers. The changes observed include extreme die-off of seabirds, rare algal blooms, abnormally warm water temperatures, and very low numbers of salmon. While some of the changes observed in the 1997 and 1998 summers—warmer than usual ocean temperatures, and altered currents and atmospheric conditions—are quite unusual, the area has

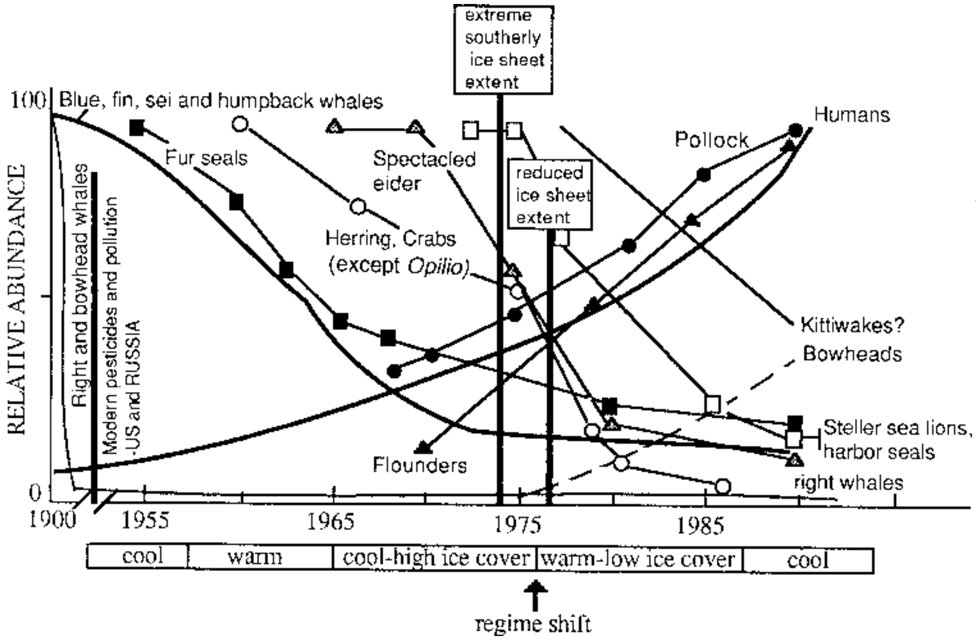

Fig. 12. Schematic temporal change in relative abundance of marine mammals, seabirds, fish, and shellfish in the Bering Sea (from NRC, 1996). Lower bar indicative of changes in sea-surface temperature. Reprinted with permission from the Bering Sea Ecosystem. Copyright 1996 by the National Academy of Sciences. Courtesy of the National Academy Press, Washington, D.C.

been undergoing change on a much longer time scale going back several decades (NRC, 1996; NOAA, 1999; see also Fig. 12).

Over that period the western population of Steller sea lions has declined by between 50% and 80%. Northern fur seal pups on the Pribilof Islands—the major Bering Sea breeding grounds—have declined by half between the 1950s and the 1980s. In parts of the Gulf of Alaska harbor seal numbers are as much as 90% below what they were in the 1970s. There have been significant declines in the populations of some seabird species, including common murres, thick-billed murres, and red- and black-legged kittiwakes (BESIS, 1999). There have also been big variations in the abundance of some fish and shellfish species over the past 30 years. Some have registered large increases (NOAA, 1999).

One of the most striking changes observed involved the appearance in 1997 of large areas of milky, aquamarine water over most of the continental shelf. This was caused by changes in water temperature and atmospheric pressure, which led to a massive bloom of coccolithophores, a type of non-toxic, microscopic marine plant (Fig. 13). The coccolithophores replaced the normal summer plankton and had profound but not well understood effects on the food chain.

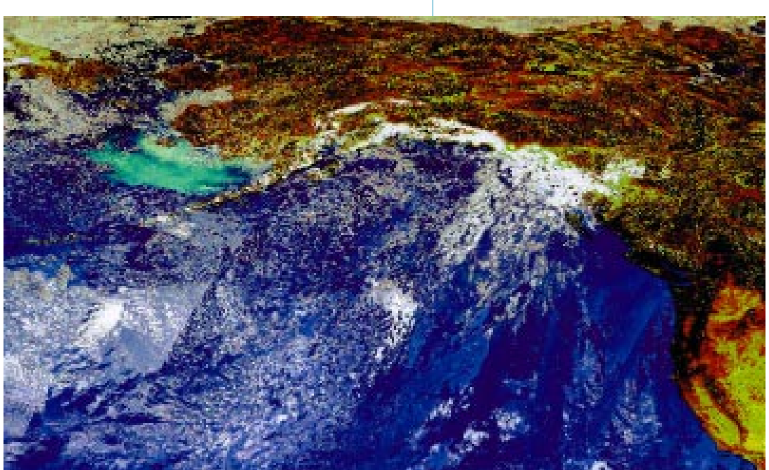

Fig. 13. SeaWifs Composite Image of cocco-lithophore bloom, shown in turquoise, in September 1997 (NOAA Pacific Marine Environmental Laboratory)

Blooms of this sort have never been seen in the Bering Sea for extended periods, and despite different atmospheric conditions in 1998, the bloom returned. Other changes recorded included unprecedented mortality in one seabird species, the short-tailed shearwater, and unsuccessful reproduction rates for another, the kittiwake. The number of returning salmon was far below expected levels, the fish were smaller than average, and their traditional migratory patterns seemed to have been altered. There was also an unusual sighting of Pacific white-sided dolphins in one area, and northern right whales have been seen in the Bering Sea Shelf/Bristol Bay area during recent summers for the first time.

Components of the Alaska marine ecosystem appear to react to many different environmental variables in the atmosphere and the ocean, but overall, climatedriven variability in the Bering Sea ecosystem is significant. It appears that climate has caused relatively rapid shifts in the organization of this marine ecosystem, most recently in the late 1970s, and that changes over periods of decades may have larger effects than those over yearly periods (NRC, 1996). The recent observations of climate-related changes in the Bering Sea showed abnormal conditions during the 1997 and 1998 summers. These impacts may be amplified if the climate continues to warm.

Unlike marine ecosystems, where impacts may be observable on very short time scales, changes in terrestrial ecosystems may take much more time. Ecological models predict major shifts in vegetation, with forests expanding into tundra regions, and coastal forests shifting from conifers to mixed broadleaf and conifers, but these changes occur on time scales of hundreds of years as shown. On the Seward Peninsula in Alaska this slow transition from tundra to forest is illustrated in Fig. 14 (Rupp et al., 1999).

Other effects already observable on land include thawing permafrost beginning to modify landscapes by changing forests to grasslands and bogs and increasing slope instabilities. The tundra, in previous decades a sink for carbon dioxide, has now become a source (Oechel et al., 1993). Continued warming and thawing of permafrost would extend and magnify these effects.

Social Impacts on Native Communities

There is no universal model of "Native response" to climate change, as northern communities are not all the same. They have highly diversified subsistence-based economies and they do not respond to environmental trends in the same standard way as do vegetation, permafrost, and sea ice. Social, economic, and political differences may obscure local responses. Also, Native (indigenous) people are only a part of the arctic resident population. As such, they are preoccupied with the various issues, political and economic,

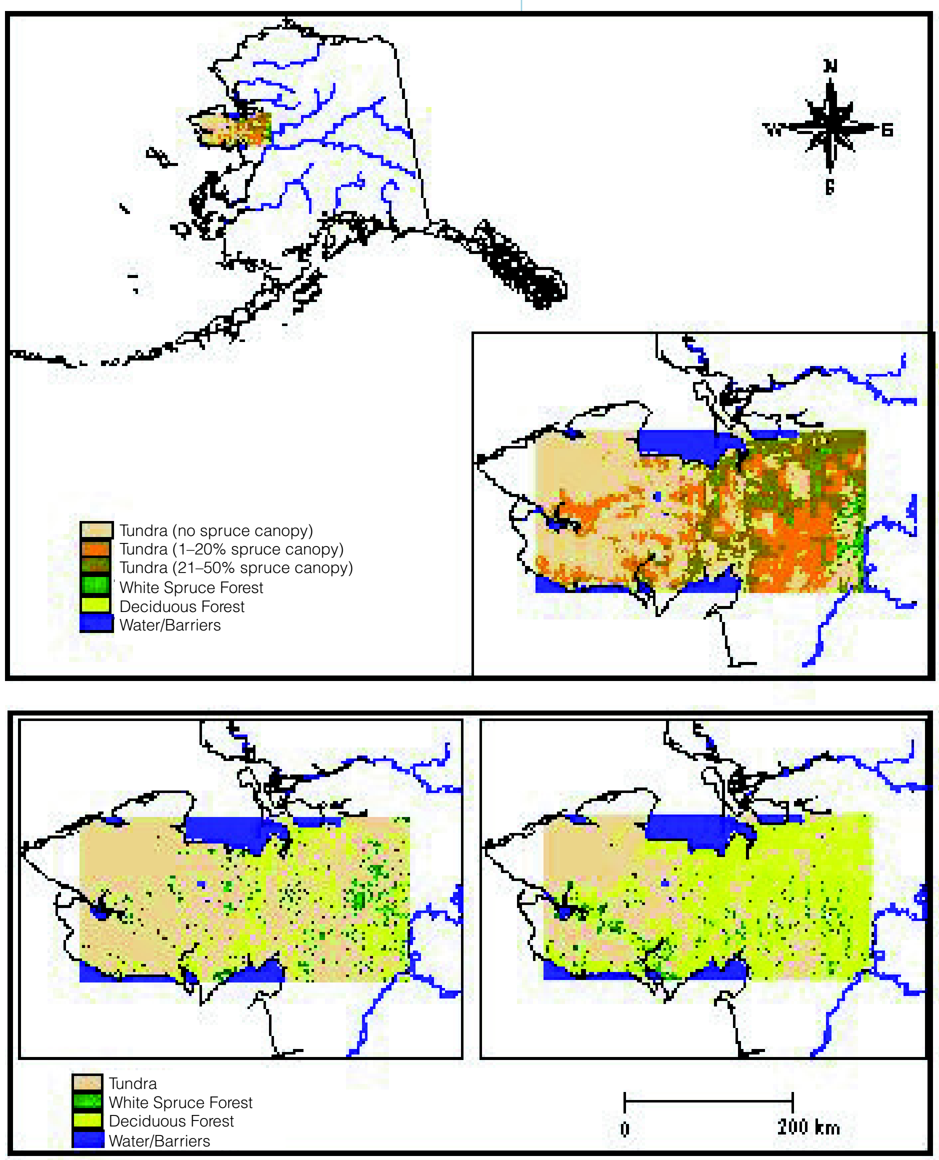

Fig. 14. Vegetation changes on the Seward Peninsula, Alaska, at present and after 100 and 200 years, following an intantaneous temperature rise of 7°F (4°C). Rupp et al., 1999

that are of critical importance in their respective areas. For many indigenous people, climate change may not be a top priority. In many northern areas debates about the ongoing (or forthcoming) climate trends may look like a "luxury," compared to the acute social and economic problems they face on a daily level. Scientists have to be aware that they may well be indoctrinating Native residents with their anxieties about climate change and other related topics (Weller and Lange, 1999).

In trying to assess scientific versus "Native" perspectives on climate change, a key issue is the meaning of "uncertainty" and the differences in understanding "uncertainty" and in living with it between scientists and Native communities. Under the scientific approach, the key strategy is to identify the "uncertainty" (in this case future climate change), target it aggressively, evaluate potential causes and damages, and to turn it into "certainty," that is, into a model or into an analyzed and stratified phenomenon, at the least. Most of the scientific projects related to the study of climate change are organized in this way. The Native perspective, however, is to live with the uncertainty and to try to cope with it. While scientists often view "change" as a short-term and rapid phenomenon, Native residents can live with it long-term because they see it as existential. These differences are to be acknowledged in any attempt at building a model of human response and at collecting data on climate change among the Native residents.

The operational framework for assessing the social consequences of climate change include the following parameters:

- Sensitivity—predisposition to be affected by an internal impact; in this regard every community is sensitive to climate change.
- Adaptability—potential to react in a way to mitigate negative change; here various communities differ in the strategies and effectiveness of their adaptability. Traditionally, Native communities have a high degree of adaptability, and they share a highly valuable pool of strategies for adapting to arctic environmental change.
- Vulnerability—beyond one's ability to adapt. In general, modernization increases the communities' vulnerability as it makes people more dependent on modern life-support networks and technologies, including electricity, sewage, heating, construction on permafrost, etc., which are highly vulnerable to climate change.

There are many examples of successful Native adaptations to climate change across the arctic region, both in pre-history and in modern times. Factors that enhanced Native adaptability and decreased vulnerabilities to climate change include:

Loading dogsled with butchered caribou, Anaktuvuk Pass, 1950

- “Being on the land.” This facilitates advance warning and opens local strategies in using alternate resources in case of any environmental change.
- Maintaining a diverse economy (usually a combination of hunting, both marine and land game, fishing, herding and trapping).
- “Always being ready.” A product of high mobility and existential attitude to climate change.
- Relying on long-term observations and generationally transmitted local knowledge about numerous components of the ecosystem.

Modern factors constraining adaptability and increasing vulnerability of arctic Native communities to climate change include:

- Current strong dependence on village and urban lifestyle and related employment.
- Continuing population growth and high concentration of people in modern residential communities that are often built in areas of low (or no) ecological sustainability.
- Dependence on outside inputs and infrastructure and the risk of its shortfall and even failure (as is now happening in the Russian Arctic).
- Rigid or non-responsive bureaucratic and governmental forms now in control of Native life via economic and welfare policies, hunting regulations, and restraints on mobility.
- Openness to outside messages, agendas and anxieties (e.g., environmental quality, contamination, game regulation regimes).

Native communities remain very sensitive to environmental trends. However, as modernization progresses, their pattern of response to climate change is shifting from a Sensitivity = Adaptability to a Sensitivity = Vulnerability model (Weller and Lange, 1999).

Nunamiut hunter and caribou in winter.