# Climate Change and Alaska's Forests: People, Problems, and Policies

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## Introduction

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

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

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

## Role of Forests in Alaska's Economy

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

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

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

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

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

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

*(Source: Labau and Van Hees 1990)*

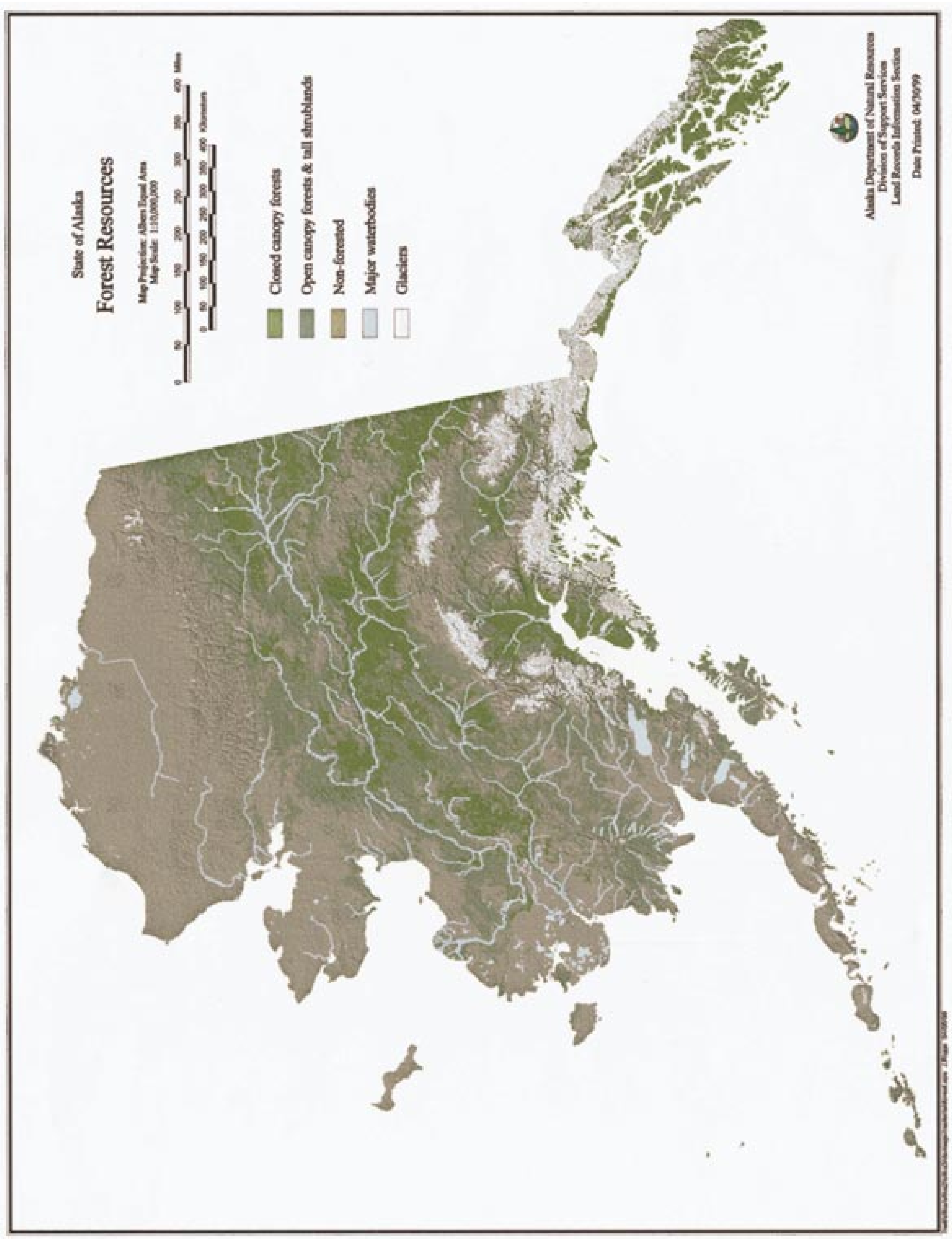


**Figure 1. State of Alaska Forest Resources** ***(Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, April 1999)***

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

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

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

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

### *Commercial Timber Operations*

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

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

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

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

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

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

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

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

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

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

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

### *Ecosystem Contributions*

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

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

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

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

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

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

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

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

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

## Assessing Human Dimensions of Climate Change

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

### *What Do We Need to Know?*

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

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

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

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

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

### *Three Time Horizons for Viewing Regional Effects of Climate Change*

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

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

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

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

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

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

## Climate-Driven Changes in Alaska Forest Ecosystems

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

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

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

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

*(Adapted from Juday et al. 1998)*

### *Short-term Effects*

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

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

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

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

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

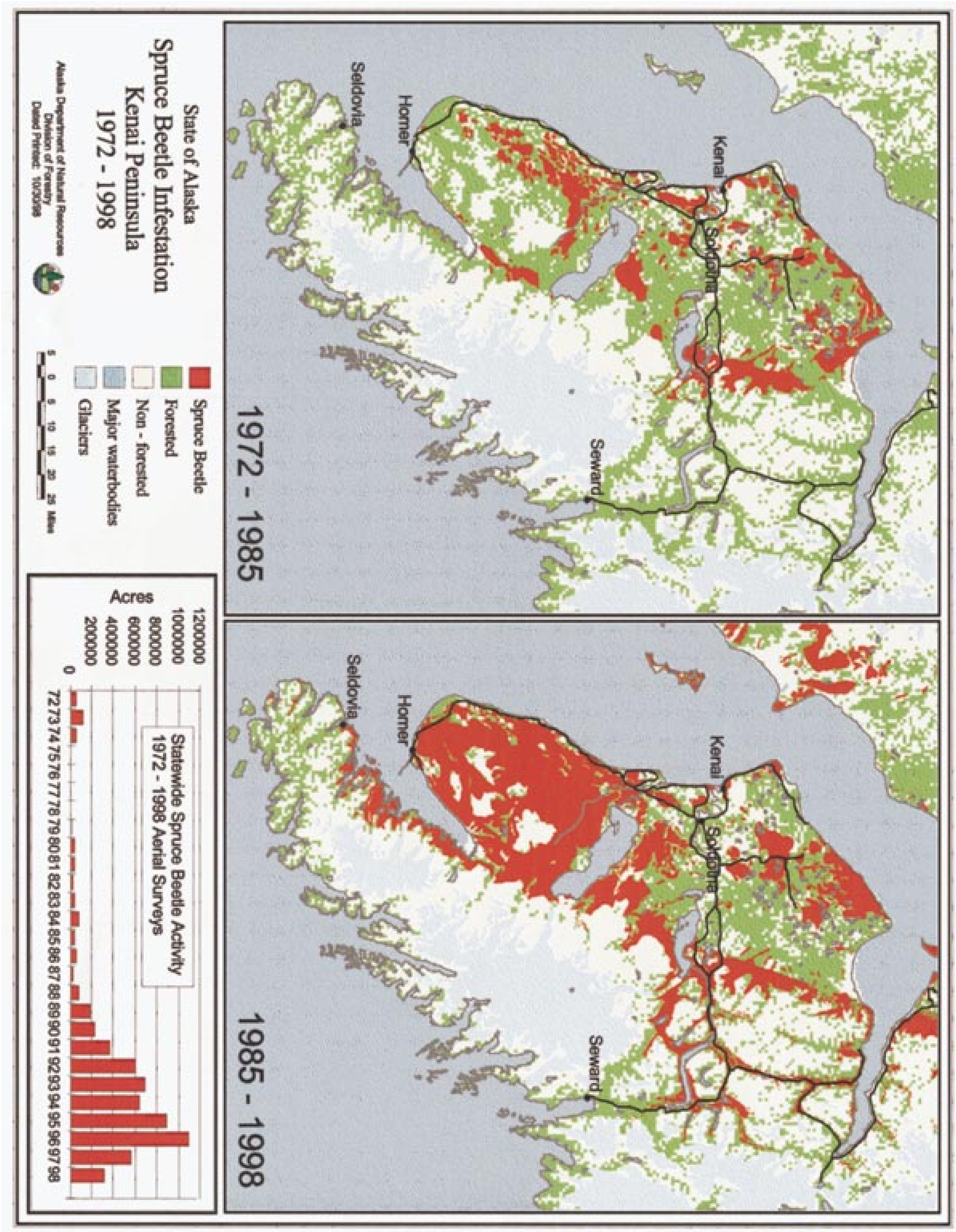


**Figure 2. Early and recent total extent of spruce bark beetle infestation on the Kenai Peninsula** ***(Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, October 1998)***

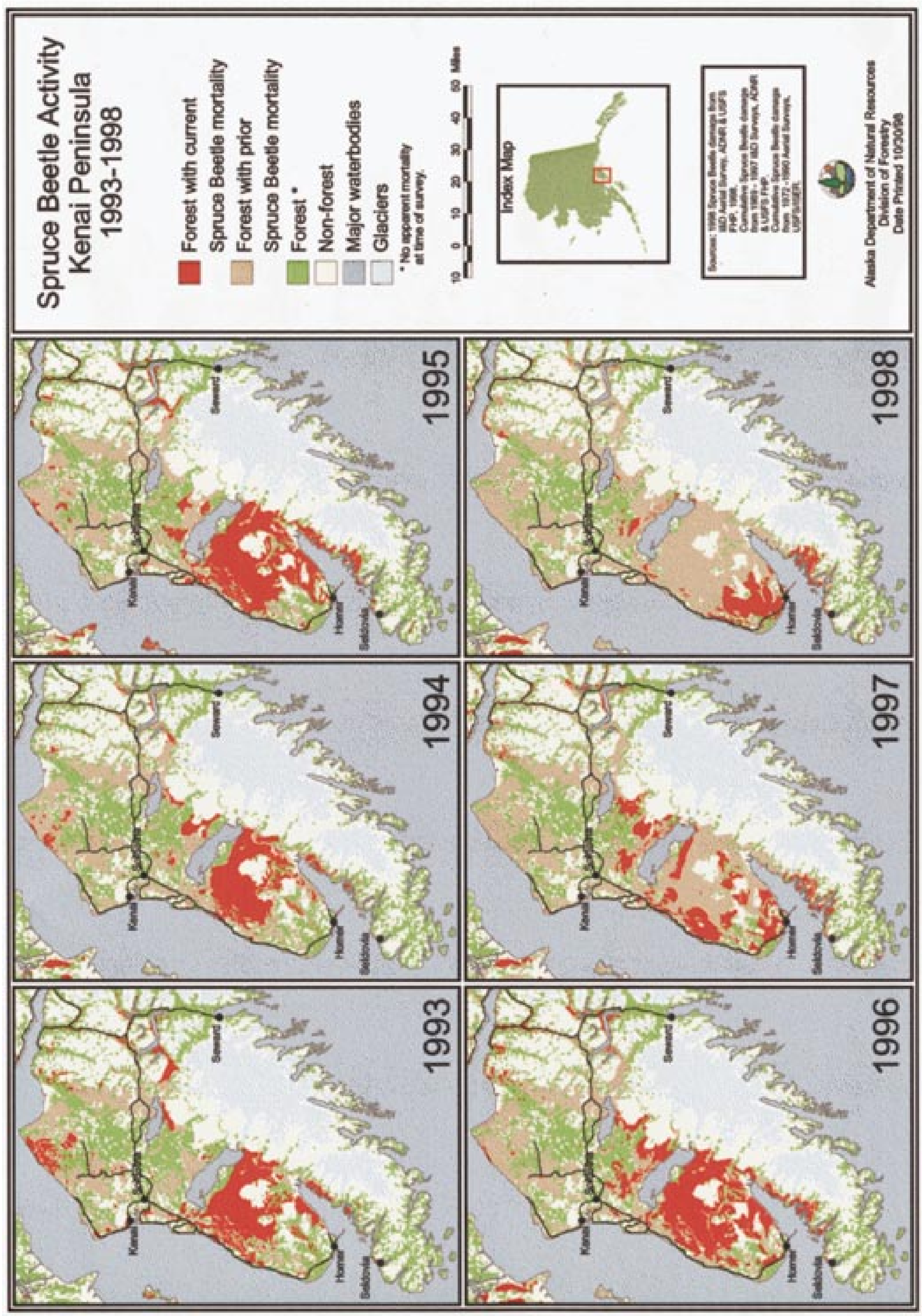


**Figure 3. Annual spruce bark beetle activity on the Kenai Peninsula, 1993–1998** *(Alaska Department of Natural Resources, Division of Support Services, Land Records Information Section, October 1998)*

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

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

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

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

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

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

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

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

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

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

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

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

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

*(adapted from Nash and Duffy 1997)*

### *Intermediate-Term Effects*

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

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

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

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

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

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

### *Long-Term Effects*

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

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

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

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

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

## Conclusion

### *Summary of Most Important Effects*

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

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

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

### *Role of Institutions and Policy*

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

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

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

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

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

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

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

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

## The Major Uncertainties

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

## References


Bonan, G.B., D. Pollard, and S.L. Thompson. 1992. Effects of boreal forest vegetation on global climate. *Nature* 359:716–718.

Brooks, D.J., and R.W. Haynes. 1997. Timber products output and timber harvests in Alaska: projections for 1997–2010. Gen. Tech. Rep. PNW-GTR-409. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 17 pp. (Shaw, Charles G., III, technical coordinator; Conservation and resource assessments for the Tongass land management plan revision).

Chapin, F.S., and G. Whiteman. 1998. Sustainable development of the boreal forest: interaction of ecological, social, and business feedbacks. *Conservation Ecology* [online] 2(2): 12. Available from the Internet. URL: http://www.consecol.org/vol2/iss2/art12

Cooper, C.F. 1983. Carbon storage in managed forests. *Canadian Journal of Forest Research* 13:155–166.

Daily, G.C. (Panel Chair). 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology*, Number 2, Spring 1997. 16 pp.

Goldsmith, O.S., and T. Hull. 1994. *Tracking the Structure of the Alaska Economy: the 1994 ISER MAP Economic Database*. Working Paper 94.1, Institute of Social and Economic Research, University of Alaska Anchorage, March.

Haley, S., O.S. Goldsmith, T. Hill, M. Berman, and H.J. Kim. 1997. *Economics of Sport Fishing in Alaska*. Public review draft, Institute of Social and Economic Research, University of Alaska Anchorage, September.

Hill, A., and T. Hull. 1997. *Timber Harvest and Wood Products Manufacture in Alaska: 1996 Update*. Institute of Social and Economic Research, University of Alaska Anchorage, September.

Juday, G.P. 1996 (on-line version). Boreal forests (Taiga) In *The Biosphere and Concepts of Ecology*. Volume 14, Encyclopedia Britannica, 15th edition, pp. 1210–1216. [hardcopy version 1997]

Juday, G., R. Ott, D. Valentine, and V. Barber. 1998. Forests, climate stress, insects, and fire. In *Implications of Global Change in Alaska and the Bering Sea Region*. Proceedings of a workshop, University of Alaska Fairbanks, June 1997. G. Weller and P. Anderson, eds. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, pp. 23–49.

Labau, V.J., and W. van Hees. 1990. An inventory of Alaska's boreal forests: their extent, condition, and potential use. In *Proceedings of the International Symposium Boreal Forests: Condition, Dynamics, Anthropogenic Effects*, Archangelsk, Russia, July 16–26, USSR State Committee on Forests, Moscow, Russia.

Leask, L. 1985. Changing ownership and management of Alaska lands. *Alaska Review of Social and Economic Conditions*, October.

McDowell, E., J. Calvin, and N. Gilberten. 1989. *Alaska Seafood Industry Study: A technical report*. The McDowell Group, Juneau, Alaska, May.

Nash, Charles E. and Associates and D. Duffy. 1997. *Miller's Reach Fire Strategic Economic Recovery Plan: Final Revised Plan*. Matanuska-Susitna Borough Department of Planning, October.

Pollard, D.F.W. 1991a. Climate change as a current issue for the Canadian forest sector. *Environmental Professional* 13:37–42.

Pollard, D.F.W. 1991b. Forestry in British Columbia: planning for future climate today. *The Forestry Chronicle* 67(4):336–341.

Powell, D.S., J.L. Faulkner, D.R. Darr, Z. Zhu, and D.W. MacCleery. 1993. *Forest Resources of the United States, 1992*. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, General Technical Report RM-234.

Purcell, B. 1998. Public perception of the beetle outbreak on the Kenai Peninsula. In *Managing for Forest Condition in Interior Alaska: What Are Our Options*. Proceedings of a workshop sponsored by the Alaska Boreal Forest Council et al., Fairbanks, April 9–10, pp. 41–42.

*Timber Supply and Demand*. 1996. Alaska National Interest Lands Conservation Act Section 706(a) report to Congress. USDA Forest Service, Alaska Region.

Warren, D. 1998. *Production, Prices, Employment and Trade in Northwest Forest Industries, Second Quarter 1997*. USDA Forest Service, Pacific Northwest Research Station Research Bulletin PNW-RB-228, March.

Weller, G., A. Lynch, T. Osterkamp, and G. Wendler. 1998. Climate trends and scenarios. In *Implications of Global Change in Alaska and the Bering Sea Region*. Proceedings of a workshop, University of Alaska Fairbanks, June 1997. G. Weller and P. Anderson, eds. Center for Global Change and Arctic System Research, University of Alaska Fairbanks, pp. 15–21.

Werner, R.A. 1996. Forest health in boreal ecosystems of Alaska. *The Forestry Chronicle* 72(1):43–46.

Werner, S. 1998. Concepts of health for the boreal forest. In *Managing for Forest Condition in Interior Alaska: What Are Our Options*. Proceedings of a workshop sponsored by the Alaska Boreal Forest Council et al., Fairbanks, April 9–10, pp. 12–15.

Wolfe, R., et al. 1984. *Subsistence-Based Economies in Coastal Communities of Southwest Alaska*. U.S. Dept. of the Interior, Minerals Management Service, Anchorage, Alaska.

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