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Changing Water Dynamics

The consequences of shifting snow, ice, and running water for ecosystems, people, and national forests in Alaska

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State-wide Patterns

Ecosystems of Alaska are rain-, snow-, and ice-driven systems. Consequently, the status of water—liquid or solid—strongly influences resources and the people using ecosystem services. This document examines changes in water dynamics, the resulting consequences for ecosystems and people, and management options for adapting to changing conditions.

Changes in snow, ice, and water ripple through ecosystems, social systems, and culture. State-wide patterns provide context to understand changing water dynamics in southcentral and southeastern Alaska associated with lands managed by the National Forest System.

Alaska covers a portion of the globe as vast as the entire 48 contiguous states. The state spans 19 degrees of latitude, has over 33,900 miles of coastline (NOAA n.d.), and includes terrain reaching 20,310 feet in elevation. The arrangement of coastal and interior landscapes, broad range of elevations, and the storm-generating Pacific Ocean result in extreme geographic and interannual variation in climate, and ultimately in the dynamics of water (Shulski and Wendler 2007).

Courtesy of Greg Hayward

Mid-winter travel across Alaska

Alaska Climate Extremes

Temperature extremes
- Prospect Creek: -80 degrees Fahrenheit
- Ft. Yukon: 100 degrees Fahrenheit

Average high temperature in July
- Barrow: 47 degrees Fahrenheit
- Fairbanks: 73 degrees Fahrenheit

Average low temperature in Jan./Feb.
- Umiat: -31 degrees Fahrenheit
- Ketchikan: 29 degrees Fahrenheit

Average annual precipitation
- Barrow: 4 inches
- Yakutat: 160 inches

This variation adds uncertainty for resource planning and business activities. For instance, snowfall in Anchorage ranged from 25 inches in 2015 to 134 inches in 2012, and January temperatures in Kotzebue ranged from near average in 2013 to 17 degrees Fahrenheit above the 30-year average in 2014 (Galloway et al. 2014).

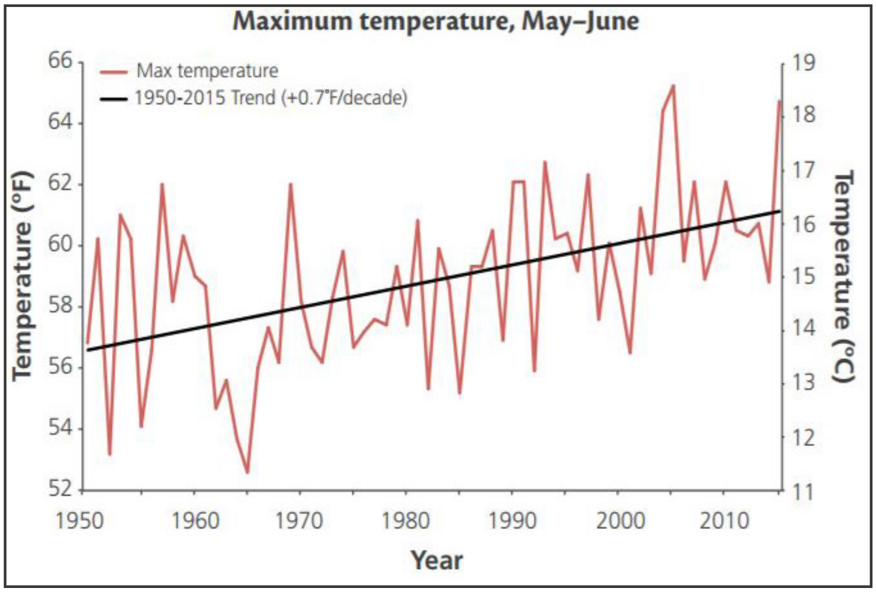

Figure 1 - May–June maximum temperature in central Alaska. In recent decades, there has been a trend of increasing temperatures and melting ice. [Click on the graph] for more information on ecological drought in Alaska.

Drivers for Changing Water Dynamics: Recent Climate Patterns in Alaska

» Over the past 60 years, Alaska warmed more than twice as rapidly as the rest of the United States. State-wide average annual air temperature increased by 3 degrees Fahrenheit and average winter temperature by 6 degrees Fahrenheit (Chapin et al. 2014, Stewart et al. 2013). See Figure 1 above.

» Length of the growing season in interior Alaska has increased 45 percent over the last century. The extended growing season and associated higher temperatures reduce the period of snow and ice, increase wildfire risk, and facilitate northward expansion of some insect species that affect trees (Chapin et al. 2014, Hollingsworth et al. 2017).

Historical Climate Patterns: Examples from Two Key Features

A historical perspective highlights the scope of change experienced in Alaska and provides context for current changes in water dynamics.

1. While evidence suggests that the area of arctic sea ice varied dramatically over a 1,300-year period prior to the 1900s, the pronounced decline in sea ice cover that began around 1990 is unprecedented compared to earlier changes (Kinnard et al. 2011, Halfar et al. 2013).

2. Retreat of glaciers since their maximum extent has led to strong directional (rather than cyclic) changes in stream geomorphology, hydrology, and ecology. (Gough and Wilson 2001, Hayward et al. 2017). At the last glacial maximum—approximately 20,000 years ago—most of southcentral and southeast Alaska was under ice. The current topography and vegetation represents the outcome of climate warming and resulting glacial retreat followed by species re-colonization over the last 14,000 years (Ager 2007).

Potential Future Climate Patterns Across Alaska

» Average annual temperatures in Alaska are projected to rise by an additional 2-4 degrees Fahrenheit by 2050. This level of warming is a consequence of current atmospheric composition and likely to occur regardless of social decisions. Depending on global emissions, temperatures are expected to rise 8-12 degrees Fahrenheit by the end of the century (Stewart et al. 2013, Chapin et al. 2014).

» Alaska's far northern latitude and patterns of storm tracks create the potential for increases in precipitation and storms. Annual precipitation increases of about 15-30 percent are projected for the state by late this century (Stewart et al. 2013). However, increases in evaporation caused by higher air temperatures and longer growing seasons are expected to reduce water availability in some areas.

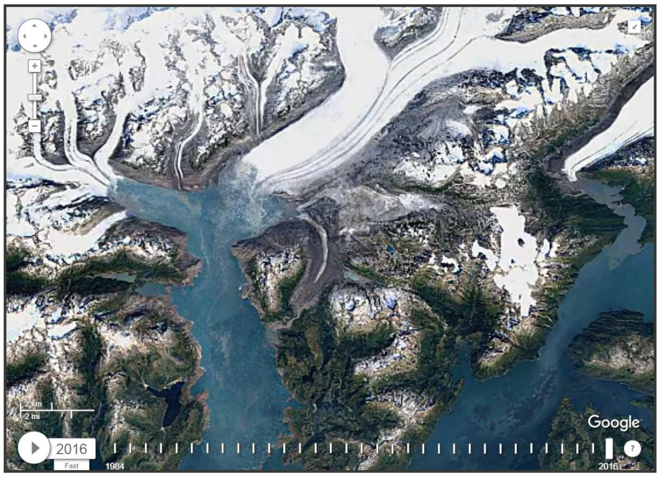

Figure 2 - The [Snows of Alaska](#) story map has information and interactive maps about glacial retreat, snowpack vulnerability, and snow-water equivalent.

Environmental Changes and Economic, Social, and Cultural Consequences

Changes in temperature and precipitation throughout Alaska are altering water dynamics, leading to fundamental changes in the physical state of water, with downstream consequences for ecosystems and people.

Sea ice decline

- The spatial extent of late summer sea ice is half that in 1980, increasing coastal erosion, altering marine species composition, and changing access for Arctic shipping (Stroeve et al. 2012, Kinnard et al. 2011, Halfar et al. 2013).

- Alaska Native and other subsistence hunters have seen thinning sea and river ice that makes harvest of wild foods more dangerous. They have also detected a northward shift in seal and fish species (Chapin et al. 2014). Changes in Arctic shipping routes could threaten traditional harvest of whales, walrus, and seals, thus altering cultural conditions for northern communities (Wang and Overland 2012).

Permafrost thaw

- Eighty percent of Alaska is underlain by permafrost, 70 percent of which is vulnerable to subsidence upon thawing (Jorgenson et al. 2008). This thawing will release the greenhouse gas methane, resulting in a feedback loop and further thawing.

- Over the next 20 years, subsidence in response to permafrost thaw will add between $3.6 and $6.1 billion (10 to 20 percent) to the costs of maintaining public infrastructure such as buildings, pipelines, and roads (Larsen et al. 2008). Damage to potable water and sanitation systems along with deterioration of family ice cellars threaten rural communities by forcing families to leave villages and move to culturally unfamiliar cities (Brubaker et al. 2011).

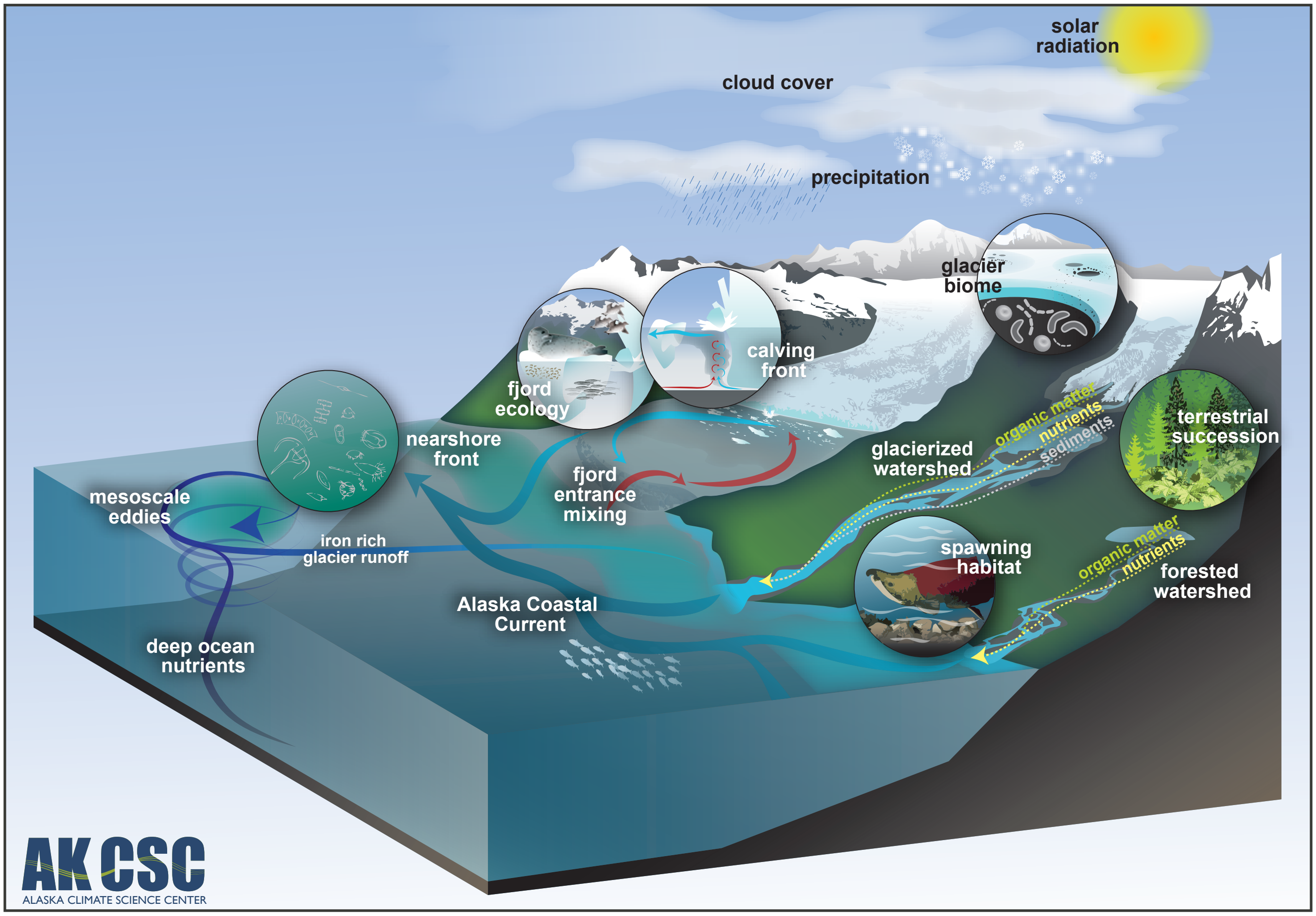

Figure 3 - Click on the graphic to see how glaciers impact Alaska's coastal ecosystems, and what glacier changes mean for ecological and economic systems. (Courtesy of Kristin Timm, Alaska Climate Science Center.)

Watch the [Adapting to Climate Change in Alaska](#) video to see how some communities are adapting and maintaining their lifestyles in the face of climate change.

Read more about the loss of permafrost in the New York Times article [Alaska's Permafrost is Thawing](#) (Fountain 2017).

Vegetation change

- Changes in water dynamics may result in increases in area burned by wildfire. Some scenarios suggest that by mid-century there will be a doubling in area burned (Balshi et al. 2008). In boreal forests, increases in fuel moisture from increases in rainfall are more than offset by higher temperature and associated evapotranspiration from fine fuels (Flannigan et al. 2016). Tundra that rarely burned in the past 5,000 years now burns regularly (Hu et al. 2010, Chapin et al. 2014).
- The distribution of shrubs and trees is expanding into tundra biomes in northern Alaska in response to changing water availability and growing season, resulting in changes in the distribution of wildlife such as moose and ptarmigan (Tape et al. 2006, Hollingsworth et al. 2010,Tape et al. 2016).

Courtesy of Pat Hayward

Changing Water Dynamics in Southcentral and Southeast Alaska: Chugach and Tongass National Forests

The Alaska Region is unparalleled among national forests in size and the extent of untamed lands. It is a land of ancient ice and thousands of miles of rugged shoreline. The Alaska Region contains 17 percent of all National Forest System lands and the northern-most portion of temperate coastal rainforest on the planet.

The 16.8 million acre Tongass National Forest in southeast Alaska stretches the 500-mile length of the Alaska Panhandle. The communities of Juneau, Sitka, Wrangell, Ketchikan, Petersburg, and more than 25 other villages are closely tied to this vast temperate rainforest.

The Chugach National Forest, encompassing nearly 5 million acres in southcentral Alaska, makes a 210-mile arc around Prince William Sound, contributing to the culture and economies of Anchorage, Seward, Cordova, Valdez, Chenega Bay, Whittier, and other communities.

Culture, recreation, and ecosystems of southcentral and southeast Alaska all reflect the coastal North Pacific setting. Cool summers, winters with sea level temperatures near freezing, and high levels of precipitation throughout the year result in substantial (and highly variable) rainfall. Glaciers and icefields comprise 10 million acres of the region (EcoAdapt 2014, USDA 2014). These glaciers and snowfall patterns are predisposed to rapid transformation in a warming climate.

Glacier Retreat: Coastal Glacier Dynamics

Decreased glacier volume and extent is a widely recognized symbol of changing water dynamics in southcentral and southeast Alaska. Glaciers cover about 5 percent of Alaska and are losing an estimated 16 cubic miles of ice per year—equivalent to more than a year of discharge on the Copper River. Glaciers in southeast Alaska contribute 43 percent of the runoff flowing into the Gulf of Alaska, a volume comparable to that flowing in the Mississippi River basin (Neal et al. 2010, Hill et al. 2015).

Glaciers in Chugach National Forest are thinning at their termini by about 10 feet per year, largely as a result of warming summer temperatures (Neal et al. 2010, Hill et al. 2015, Larsen et al. 2015, Littell et al. 2017).

Muir Glacier in southeast Alaska, 1880 and 2005.

Glacial retreat results from several factors. For example, Columbia Glacier, an extensive tidewater glacier in Chugach National Forest, lost 37 cubic miles of ice in the past 30 years, but less than 10 percent of this loss has been caused by recent climate patterns. For instance, the shape of the glacial fjord can interact with long-term dynamics of glacier movement, particularly delivery of ice from high in the icefield, resulting in rapid changes in tidewater glaciers unrelated to current climate patterns (O'Neel 2012, Post et al. 2011, Rasmussen et al. 2011).

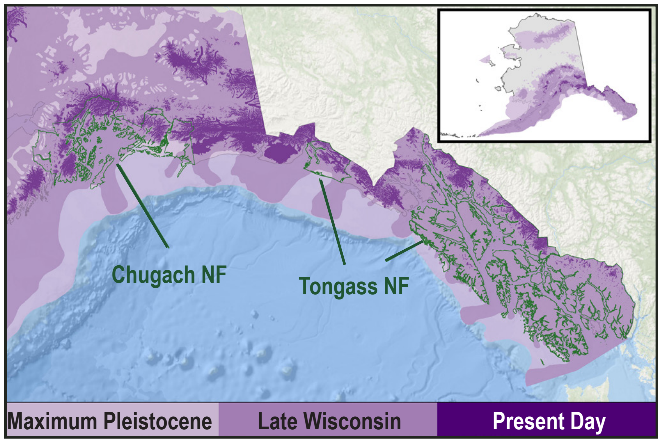

Figure 4 - Comparison of glacier extent at three points in time: the maximum Pleistocene limit (over the past 3 million years), the late Wisconsin glaciation (about 20,000 years ago), and the current extent. Click on the graphic for more information.

Columbia Glacier, which is responsible for half of the Chugach glacial ice loss, has declined by 50 percent in the past 35 years (O'Neel et al. 2013). Retreat is expected for the next 20 years resulting in over 9 miles of further retreat (Pfeffer 2015). Visit the Snows of Alaska story map to see a time-lapse video of Columbia Glacier's retreat over time.

Calving dynamics result in a range of tidewater glacier behaviors (Larsen et al. 2015). Since 1950, Harvard Glacier on the Chugach National Forest has advanced more than 1,600 feet while 10 other tidewater glaciers on the forest retreated 1,600 feet or more. The remaining tidewater glaciers have relatively static termini (McNabb and Hock 2014, Littell et al. 2017). Several tidewater glaciers moved up onto bedrock reducing their direct ecological function in the marine environment.

Rapid loss of glacial cover in a fjord or on a mountainside alters the viewscape. However, changes in ecological function and ecosystem services may be even more significant than the visual change and will influence natural resources in several ways as described below.

Habitat for marine mammals, seabirds, and fish

» Icebergs from tidewater glaciers provide important structures for seal habitat, as well as attractive scenery.

» The delivery of nutrient-rich water at the base of tidewater glaciers, deep in the marine water column, circulates nutrients and stimulates productivity that ultimately increases food for fish, seabirds, and marine mammals (Hood and Scott 2008, Renner et al. 2012, Bartholomaus et al. 2013). Twenty glaciers in southeast Alaska have direct contact with marine waters (Ecoadapt 2014) and a similar number exist in southcentral Alaska (McNabb and Hock 2014).

Blackstone Glacier with its toe in Prince William Sound

Ocean circulation contributions to marine productivity and salmon fisheries

Glacial meltwater and associated streamflow from watersheds in Tongass and Chugach national forests drives the Alaska Coastal Current which moves nutrients and organisms northwest along the Alaska coast through the Aleutian Islands into the Arctic (O'Neel et al. 2015). Changes in freshwater discharge influence the strength of the current and productivity well beyond Alaska coastal waters.

Stream hydrology and geomorphology

Annual patterns of discharge in watersheds differ substantially depending on the presence of glaciers (Hood and Berner 2009, Littell 2017, O'Neel 2015). Watersheds with glaciers release high volumes of silt-laden water in mid and late summer after the peak flow from snowmelt. Glaciated watersheds therefore exhibit geomorphology and habitat features that differ from clear-water systems, resulting in differing biota. As glaciers recede, altered glacier melt will affect geomorphology and hydrology, changing freshwater productivity (EcoAdapt 2014, Chilcote et al. 2017).

Consequences of Glacier Decline for Ecosystem Services, Economic Systems, and Culture

» Glacial outburst floods (also known as jökulhlaups) occur periodically in some glacial systems sending large volumes of silt-laden water downstream. As glaciers recede, outwash floods may occur in systems where they were absent in the past. These floods, along with higher than historical summer flows, endanger infrastructure such as roads, bridges, buildings, and travelways for subsistence along traditionally used waterways.

» Stream systems in Tongass and Chugach national forests support subsistence, recreation, and commercial fisheries. About 15 percent of the world's Pacific salmon originate from the Chugach National Forest. Commercial salmon harvest from the Tongass National Forest represents 25 percent of the entire west coast catch (Chilcote et al. 2017, Tongass salmon factsheet 2017).

» Over the past decade, the at-dock value of commercial salmon harvested from the Alaska Region averaged $105 million annually. The combined economic impact of salmon from the two forests translates to over $1.5 billion, contributing over 10,000 jobs in Alaska (Chilcote et al. 2017, USDA 2017).

» Some salmon stocks occur in glaciated systems. For instance, over 1,500 miles of Tongass National Forest streams originate in glacial watersheds. Most of these provide important fish spawning and rearing habitat, contributing to commercial, recreation, and traditional use fisheries (EcoAdapt 2014).

» Melting glaciers will change streamflow, often displayed as a hydrograph (see Figure 5) on associated streams, altering fish habitat. However, the diversity, redundancy, and intact nature of watersheds in the region are expected to provide resilience against these changes, suggesting that predicting short term consequences for salmon will require drainage-specific assessments (Chilcote et. al. 2017).

» Fishing reflects vital relationships of people and land that are woven into the history, cultural identity, and community life of Alaskans. Many Alaskan communities have a strong tie to Pacific salmon and the particular characteristics of local rivers and lakes. Alaskans consume significantly more fish than the average U.S. citizen (Nobmann et al. 1992). Changes in salmon populations influence the formal and informal economies and culture of Alaska coastal communities (Thornton 1998). Deliberate approaches to social, economic, and cultural adaptation will aid communities responding to potential changes in salmon distribution and abundance.

» Glaciers fascinate people, particularly tidewater glaciers that dramatically release mountains of ice into marine waters. The aesthetic value of glaciers is apparent from cruise ship advertisements for Alaska—virtually every website and advertisement includes striking glacier views. Mendenhall Glacier near Juneau attracts over 600,000 visitors a year. As tidewater glaciers retreat, views of and access to calving glaciers will decline (Erickson et al. 2017). In addition to aesthetic and ecological consequences, changing glaciers will influence local economies.

Dip netters—here at the mouth of the Kenai River—contribute an average of 116 pounds of fish annually to each participating family.

Tourists view Mendenhall Glacier near Juneau, AK (© fon thachakul/Shutterstock).

Glacier Dynamics—*Management Response Options*

1. Inventory and assess areas where glacier outwash floods threaten agency infrastructure or users of national forest lands. Develop safety plans and evaluate modifications to infrastructure in vulnerable watersheds.

2. Incorporate potential for glacier outwash floods and changing viewscapes in the design and location of new infrastructure such as trailheads, trails, roads, campgrounds, cabins, administrative sites, and fish habitat improvements.

3. Collaborate with and educate ecotourism establishments and other businesses that rely on glacier viewscapes. For instance, adapt permits as the views change, the potential for resource damage increases, seabird concentration areas shift, and possible safety issues emerge. Inform the public and permittees of expected changes in key glacier systems that currently attract thousands of visitors.

4. Work closely with local communities reliant on aquatic subsistence resources to develop a common

understanding of potential changes in local fisheries as tidewater glaciers recede and stream dynamics change. Dialogue should include an emphasis on the time scale of changes (which in some cases will be very long) and the potential for certain food resources to increase as others decrease.

5. Fish habitat restoration efforts can consider the potential to incorporate changes in streamflow patterns resulting from glacier melt (see Figure 5) into expectations for stream geomorphology, temperature, water chemistry, and sediment. Consider changes in glacier melt when setting restoration priorities among watersheds and among reaches within watersheds.

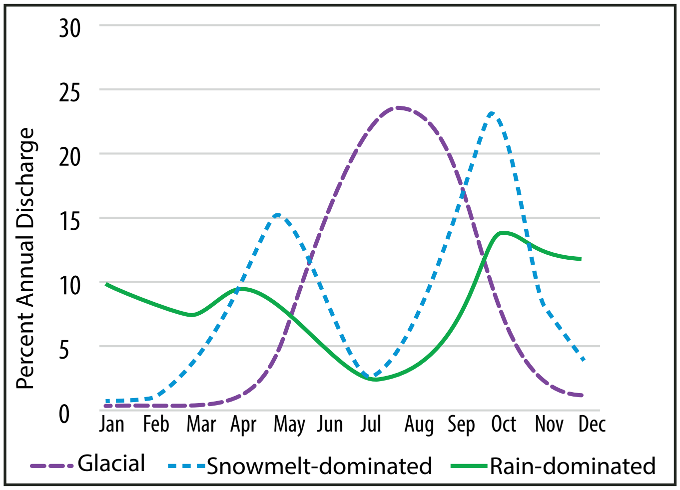

Figure 5 - Characteristic hydrographs for three watershed types in coastal temperate rainforest of the Alaska Region: glacial, snowmelt-dominated, and rain-dominated (adapted from [Climate change implications in the northern coastal temperate rainforest of North America](), Shanley et al. 2015).

Snow Drought

Forested systems of the Alaska Region are rain-, snow-, and ice-driven systems. Changes in rainfall and snowpack have significant consequences for most elements of the ecological and human environment, including vegetation development and growth, avalanche frequency, road and trail conditions, and runoff for stream systems.

Proximity to the marine environment on the Gulf of Alaska results in winter temperatures often near freezing, combined with substantial precipitation. Consequently, a small change in temperature results in substantial change in snow accumulation. Although deep accumulations of snow at low elevations along the coast were common in the past—and still occur—the trend of increasing temperatures may result in less frequent snow at low elevations in the future (Littell et al. 2017).

By mid-century, warming trends are projected to result in a snow drought for low-elevation landscapes in both national forests. At elevations below 1,500 feet in the Chugach National Forest, snow-day fraction (proportion of days when precipitation falls as snow) is projected to decrease by 23 percent between October and March, resulting in 26 percent less water in snowpack at winter's end (Littell et al. 2017). Similarly at low elevations, the warm season (when freezes are rare) may increase from 200 to 230 days (Fresco and Floyd 2017).

Conversely, because of increases in winter precipitation, snowpack at high elevations (above 5,000 feet) may increase in the future. See Figure 6.

(Courtesy of Pat Hayward)

Winter sports face an uncertain future in Alaska.

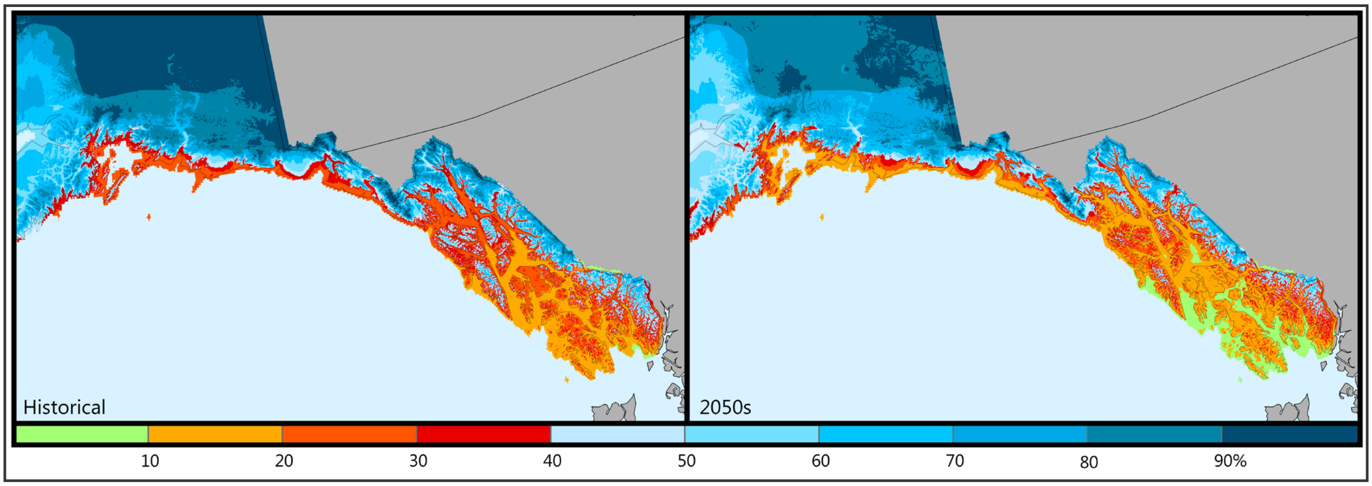

Figure 6 - Snow vulnerability index: the proportion of precipitation falling as snow, compared between the historical period (1971-2000) and 2040-2069. Click the map for more information.

Consequences of a Declining Snowpack

Declines in snowpack at lower elevations could have far-reaching consequences by mid-century. Stream conditions and fish habitat, infrastructure, wildlife populations, travelways, recreation, and other socio-economic conditions may be affected.

Stream conditions and fish habitat

Stream dynamics—including changes in bank and bed morphology, seasonal patterns of flow, silt and bedload, and water chemistry—are influenced by the source of water (Dery et al. 2009, Schnorbus et al. 2014). Groundwater, runoff from rain, runoff from snow, and rain-on-snow events each result in substantially different stream conditions (Paustian 1992, Battin et al. 2007, Chilcote et al. 2017). As snow becomes less common at low elevations, and snowpack increases at the highest elevations, the dynamics of streams in the region will alter fish habitat (see Figure 5).

» Reductions in snowpack at lower elevations over the next 60 years on the Chugach National Forest are expected to significantly alter the timing and amount of runoff in 61 of 720 watersheds (Chilcote et al. 2017: 124-130). These vulnerable watersheds are expected to transition from streamflow patterns characteristic of snow-dominated toward patterns characteristic of rain-dominated systems (see Figure 5). Watersheds that transition from snow-dominated to rain-dominated may periodically experience extreme low flows and high water temperatures, resulting in marginal conditions for some fish species and the potential for fish mortality (Isaak et al. 2012).

» Outer islands in the southern Tongass National Forest could experience the largest decrease in snowfall, receiving little or no snowfall (EcoAdapt 2014). Hence, streams in these areas will transition from snowmelt to rain-fed systems, significantly altering the hydrograph (see Figure 5).

In the Alaska Region, freshwater systems used by salmon are largely intact and resilient to change, suggesting that shifts in the hydrograph may favor one species over another, but not result in broad scale declines in the capacity of most freshwater systems (EcoAdapt 2014, Chilcote et al. 2017, Schoen et al., 2017).

Infrastructure

Although average snowpack is projected to decline in coming decades, high variability in snow accumulation, combined with the potential for more severe storms, may lead to occasional deep snowpack and significant rain-on-snow events. Snowpack and melt conditions have the potential to damage infrastructure.

» High runoff following rain-on-snow events, increased glacier melt, and very high snowpack may exceed the capacity of road culverts, leading to road washout and damage.

» Land and snowslides or extraordinary snowloads threaten recreational cabins, campground structures, utility structures, road-based travel, and administrative buildings, posing potential safety risks.

Wildlife populations

Snow conditions represent a critical feature of wildlife habitat. Changes in the distribution and timing of snow will alter habitat conditions favoring some species and reducing habitat quality for others. Examples of important relationships between wildlife and snow include the following:

» Subnivean (under snow) environments protect small animals and plants from extreme cold in winter (Pauli et al. 2013, Emers et al. 1995). Similarly, wolverine rely on snow dens during winter to reduce energy expenditure, provide thermal cover, and care for young during winter (McKelvey et al. 2011).

» Snow conditions, including depth and stability of snowpack, influence the ability of Sitka black-tailed deer to forage, deer and wolf mobility, and predator-prey dynamics (Person et al. 1996).

Travelways for recreation and food procurement

Snow, river ice, and frozen soils facilitate winter travel in portions of the region. As the growing season lengthens, the “mud season” will extend later in the autumn and begin earlier in the spring, while snowpack suitable for skiing and snow machine travel will occur for less of the winter.

» Existing recreation trailheads could become stranded below elevations with sufficient snow for snow machines and backcountry ski access. Where over-snow motorized vehicles are allowed, there may not be adequate snow to prevent vegetation damage.

» Most cabins, day use sites, trailheads, and campgrounds are below 1,500 feet where reductions in snowpack are projected to be greatest. Consequently, the period of snow-free use will increase resulting in higher maintenance costs. Users who enjoy winter sports associated with trails will experience reduced opportunities and may choose to recreate elsewhere.

» During the next 30 years, the extended snow-free period at low and mid elevations is expected to reduce the winter recreation season by an average of 0.5 to 1 day per year (15 to 30 days total reduction) (Littell et al. 2017).

» Winter access to subsistence resources (e.g., hunting, trapping) will be altered at traditional low elevation access points with less snow and frozen soils. A reduced snow depth will allow Sitka black-tailed deer to remain dispersed throughout the winter, reducing the success of subsistence hunters.

Socio-economic and ecosystem services

» Strong economic, social, and cultural relationships between salmon and human communities suggest that changes in snowpack will have economic and cultural ramifications resulting from changes in the timing and abundance of salmon runs. The complex salmon lifecycle, however, makes it difficult to predict outcomes for salmon and therefore for social, economic, and cultural systems (Chilcote et al. 2017).

» Winter transportation with sled dogs, sled dog racing, and recreational mushing are part of Alaska Native culture and modern social traditions in Alaska. Declines in snowpack led to recent cancellations (two consecutive years for the World Champion sprint dog race) as well as changes in major sled dog races (three changes in five years for the Iditarod). These events draw thousands of tourists.

» Heli-skiing and other forms of powder-dependent snow sports represent significant economic elements of the tourist industry, particularly in small communities. Locations such as Valdez have significant potential for snow sports expansion as skiers and snowboarders from the conterminous U.S. seek out dependable high-elevation snowpack (McDowell Group 2015, Littell et al. 2017).

» As low elevation areas become stranded below the snowline, the Alaska Region may see a shift from downhill skiing and other snow sports to high elevation activities and other activities like hiking and biking (Hayward et al. 2017).

Snow Drought—*Management Response Options*

1. Employ snow modeling to aid in prioritizing relocation of current recreation infrastructure to support backcountry skiing and snow machine travel. Consider flexible trailhead locations to accommodate variation in snowlines and access to sufficient snow for winter sports. Employ variable snow sport season openings to ensure sufficient snowpack to prevent resource damage.

2. Incorporate expectations for longer “mud-seasons” and higher than normal overland runoff into design and maintenance of trails. Consider temporary closures for some modes of travel when safety issues or damage to resources caused by mud or flooding are likely.

3. Design recreation infrastructure (e.g., recreation cabins, trail bridges, trail drainage systems) to accommodate larger storm events including higher snowloads, overland flow, and higher streamflow.

4. Anticipate high variation in Sitka black-tailed deer winter habitat conditions as annual snowpack varies. Accommodate altered overwinter survival through close collaboration with state agencies on subsistence and sport harvest, road openings, and associated travel management to respond to short-term changes in deer abundance.

5. Employ stream restoration to replace large wood (logs) in streams and floodplains where instream wood and streamside trees were removed during logging in the 1960-70s. The wood restores ecological function, creating complex habitat for salmon (Trombulak and Frissell 2000). Restoring stream function and connections to floodplain habitat improve stream and fish resilience to climatic changes.

Stream restoration on West Middle Fork Staney Creek, Prince of Wales Island, AK

6. Develop a common understanding with national forest users about the declining snowpacks at low elevations and potential consequences for recreation and infrastructure.

7. Discuss potential changes and resilience in salmon populations with stakeholders who use salmon originating on national forest lands. Prepare the public for potential fish kills in stream systems prone to temperature increases.

8. Evaluate and alter drainage structures, roads, and other infrastructure (e.g., relocate roads out of floodplains) so they are not restricting flow from a main channel to a floodplain, restricting fish access to upstream habitats, or increasing scouring of spawning gravels (Sloat et al. 2016).

9. Employ riparian restoration where past management has damaged riparian function or altered floodplain dynamics. Promote alder based on agency guidelines (see Tongass Young Growth Strategy). Encourage development of large trees in young-growth riparian areas to deliver large wood to streams. Select project sites strategically to focus on conifer-dominated stands to get big trees faster. Place thinned wood in stream for restoration if warranted.

10. Maintain roads and other infrastructure to avoid erosion. Decommission and remove roads or infrastructure where possible to accommodate gradual flow into floodplains. Add culverts or water bars to disconnect streams from roads.

11. Replace or augment structures (e.g., culverts, bridges) to accommodate peak flows, and storm proof roads.

12. Evaluate the potential for fish passage barriers developing during low flows and consider options for altering the barriers.

Vegetation Distribution, Disturbance Dynamics, and Associated Soils

Climate, particularly the availability of water, strongly influences plant species distributions, influencing how plant communities and biomes develop over centuries to millennia. The Alaska Region has exhibited directional vegetation change for thousands of years—the region was largely ice covered 14,000 years ago. The temperate coastal rainforests in Chugach National Forest formed only about 2,000 years ago (Ager 2007, Hollingsworth 2017).

Vegetation development continues as glaciers retreat and new land is exposed. As temperature and growing seasons increase, vegetation and soils will continue to change in the future (Fresco and Floyd 2017).

Temperate coastal rainforest is the dominant forest vegetation in southcentral Alaska. Modeling of biomes and species climate envelopes suggests that these rainforests are quite stable and distribution is not expected to shift appreciably, although distribution and abundance of some species could change (Hollingsworth et al. 2017).

Barnes Cove at Knight Island supports productive tidewater wetlands and temperate coastal rainforest resulting from a combination of rain, snow, ice, and high tidal flux. Forests in this area will likely to remain similar in composition and structure while the other vegetation types will continue to change following the directional trajectory dictated by water dynamics.

In contrast, outside the coastal rainforest, conifer and shrub communities on the Kenai Peninsula have been moving upward in elevation 30 feet per decade since 1950 (Dial et al. 2007). The rise in treeline is expected to continue the process of afforestation, potentially reducing alpine vegetation.

Other expected changes in vegetation and associated processes include:

Carbon sequestration

The Tongass National Forest stores 650 million tons of above-ground carbon (Barrett 2014)—more carbon than any other national forest. As temperatures warm, the capacity for soil decomposition to increase may result in net carbon loss (D'Amore et al. 2015, Fellman et al. 2017) while above-ground carbon storage may continue to increase. For more information, see Storage and Flux of Carbon in Live Trees, Snags, and Logs in the Chugach and Tongass National Forests (Barrett 2014) and Baseline Estimates of Carbon Stocks in Forests and Harvested Wood Products for National Forest System Units (USDA Forest Service 2015).

Yellow-cedar

Yellow-cedar is an especially important tree in Alaska. Its wood is valued as a commercial product and the cultural value to Alaska Native people stems from its use for shelter, clothing, canoe paddles, and totem poles (Turner 1998).

Yellow-cedar mortality is strongly linked to water dynamics associated with climate. Injury to fine roots occurs when low snowpack and poorly drained soils results in springtime freezing of roots (Hennon et al. 2012).

During the past century, yellow-cedar stands covering 200,000 acres experienced mortality of 70 percent or more, although this represents a small portion of the total distribution of the species whose basal area has recently increased as distribution expanded (Barrett and Christensen 2011, Barrett and Pattison 2017). See Figure 7.

Wildfire

Large wildfires are rare in Alaskan national forests and are expected to remain rare in the temperate coastal rainforest (Barrett and Christensen 2011, Hollingsworth et al. 2017). Only national forest lands in the far western portion of the Alaska Region, which support transition boreal forests, are prone to periodic wildfires.

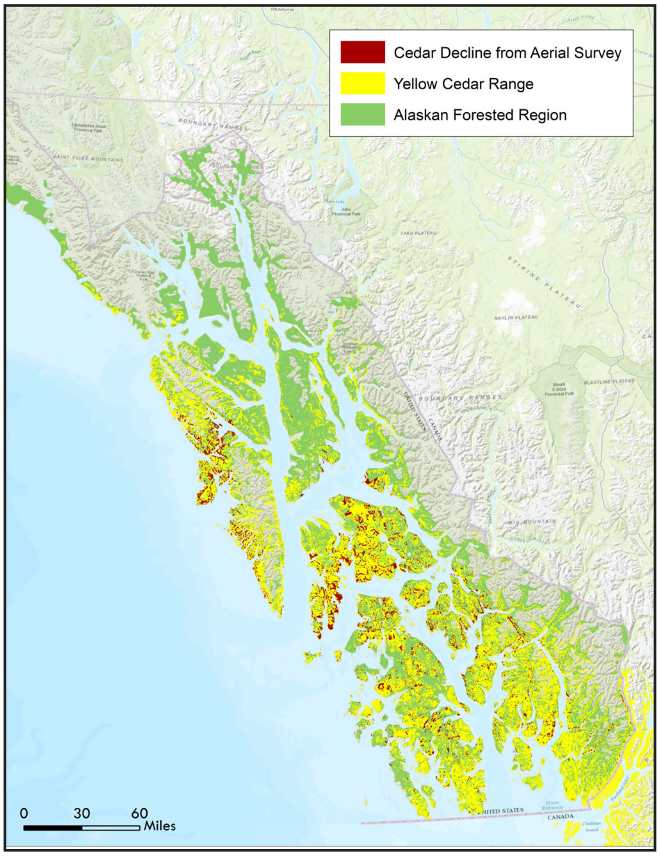

Figure 7 - Occurrence of yellow-cedar decline in southeast Alaska (click on the map for more information).

Evaluation of future fire risk and rural development indicates that vulnerability of property to fire in this area will increase in the next 50 years. The value of structures at risk to fire on the Kenai Peninsula is projected to grow by 66 percent on private lands by 2065—an estimated $3.8 billion in 2016 dollars. (Hollingsworth et al. 2017). Most of this occurs to the west of Chugach National Forest but influences fire suppression on national forest lands.

Forest insects and disease

Threats to trees from insects and pathogens may increase when water dynamics change as a result of climbing temperatures and longer growing seasons (Hollingsworth et al. 2017). Widespread deciduous tree defoliation or extensive mortality of conifers would alter habitat conditions for animals and change the visual landscape for tourists.

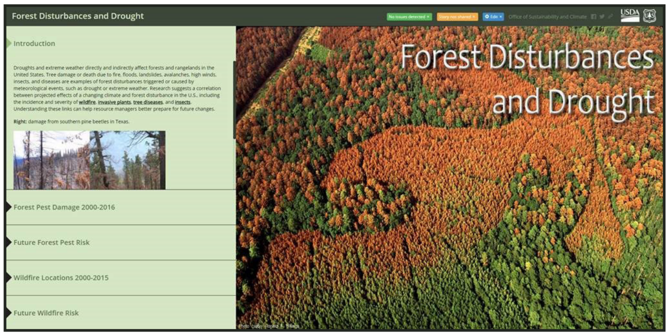

Figure 8 - The [Forest Disturbances and Drought] story map has information and maps about wildfire, insects, and disease throughout the U.S. Click on the image to access.

Vegetation Distribution, Disturbance Dynamics, and Associated Soils—*Management Response Options*

1. Consider salvage of yellow-cedar in stands with high mortality to meet a portion of the cultural and economic demand for this high value tree. A focus on stands affected by high levels of mortality within timber management areas could shift some timber production from currently healthy forests (Hennon et al. 2016).

2. Continue to employ snow modeling and mapping of current yellow-cedar distribution to identify areas that have a high probability of sustaining robust stands in the future. Use results of modeling to design forest management prescriptions in lands currently identified for timber production, and to evaluate the broader conservation framework (Hannon et al. 2016).

3. Employ existing tools to evaluate probability of natural yellow-cedar establishment following timber harvest, to prioritize sites for regeneration.

4. Continue close collaboration with local governments developing plans for wildfire response, vegetation management, and public education on the Kenai Peninsula.

5. Employ silvicultural prescriptions that promote regeneration of a diversity of tree species within timber harvest areas to promote resistance to insects and pathogens.

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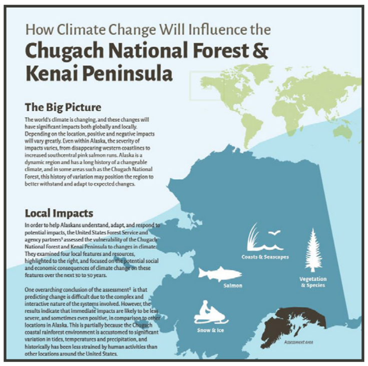
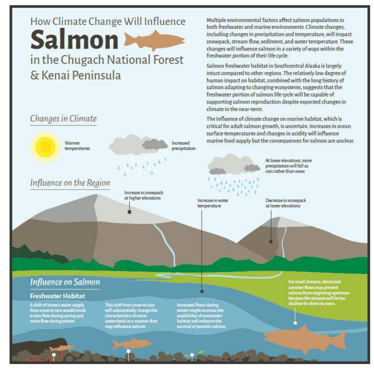
Educational Posters

How Climate Change Will Influence the Chugach National Forest and Kenai Peninsula describes impacts on features and resources of the national forest lands and waters.



How Climate Change Will Influence Salmon in the Chugach National Forest and Kenai Peninsula describes multiple environmental factors that affect salmon populations in both freshwater and marine environments.



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