JUNEAU'S CHANGING CLIMATE

& COMMUNITY RESPONSE

The Mendenhall Glacier is an icon of Juneau's changing landscape. Since its Little Ice Age maximum in the late 1800s, the glacier has retreated several miles, including 1.3 miles since the U.S. Forest Service built the Mendenhall Glacier Visitor Center near its face in 1962.

ALASKA COASTAL RAINFOREST CENTER

JULY 2022

TABLE OF CONTENTS

This work was supported by The Department of the Interior Alaska Climate Adaptation Science Center, which is managed by the USGS National Climate Adaptation Science Center.

WELCOME

THOMAS F. THORNTON

The Alaska Coastal Rainforest Center (ACRC) is pleased to bring you this report on climate change. ACRC and the University of Alaska Southeast Juneau reside on the ancestral lands of the Áak'w Kwáan Tlingit. Long before western observations of climate change, Indigenous people of Southeast Alaska observed and responded adaptively to changes in this dynamic environment, including rapid glacial advances and retreats, sea-level rise and fall, and a host of extreme events that are well-documented in oral histories. We honor and respect Indigenous experience with climate change and the intergenerational wisdom that has guided Alaska Natives through earlier periods of environmental changes.

Now, a new era of climate change unprecedented in human history is upon us, and Juneau, as a modern capital city and regional hub, must respond and adapt accordingly. Juneau's citizens have launched an innovative carbon offset program, its scientists engage in impactful marine, temperate forest, and glacial research, and its downtown port holds the world's first plug-in shore power for cruise ships to reduce harmful greenhouse gas emissions. Yet, even with Juneau's initiatives and successes, many questions remain about the nature and scale of the changes that are undeniably coming. As the Central Council of Tlingit and Haida Indian Tribes of Alaska (Tlingit & Haida) warns in its 2019 Climate Change Adaptation Plan,

"[We] cannot overstate the urgency for a response to changes in our climate. To that end, this report supports the United Nations Sustainable Development Goal 13, Climate Action, Target 13.3 which aims to 'Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.'" [1]

ACRC and its research partners, including federal, state, and tribal organizations, and other entities, share this sense of urgency. By prioritizing scientific investigations of local impacts of social-environmental change in the Pacific Coastal Temperate Rainforest and its coastal margins, ACRC seeks to inform the wellbeing of communities, ecosystems, and key species that support the livelihoods, cultures, and socio-economic systems of our unique bioregion.

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Juneau's climate report: History and background

BRUCE BOTELHO

In its February 16, 1959, edition, the *Alaska Daily Empire* carried a wire service story declaring that the earth was in the midst of a long warming trend, leading to—among other things— the retreating of glaciers in Alaska. "One theory is that the change is man-made, that a blanket of carbon dioxide given off by the burning of coal and oil retards the radiation of heat by the earth."[1]

By the turn of the century, scientific knowledge of the interactive processes affecting climate change, the role of humankind in those processes, and the dire consequences of those processes for the planet, ranging from sea level rise, extinction events, and insect infestations to massive droughts, wildfires, flooding, and erosion, had grown exponentially.

That scientific understanding found increasing public acceptance expressed through environmental movements across the globe. Unfortunately, efforts to curb greenhouse gas emissions and to implement mitigation and adaptation measures encountered hostile responses from an array of industries that either denied the existence of change and its human causes or decried the financial burdens any regulatory measures would impose. These latter attitudes dictated federal government policy through much of the first decade of the 21st century.

It was in part this federal policy of denial that prompted the convening of a scientific panel to examine climate change in Juneau. If federal and state government leadership was unwilling or unable to confront what was even then clearly a matter of planetary survival, then local governments should leap into the breach. A panel of scientists drawn from Juneau's wealth of academia and agencies with expertise could develop a baseline of information that the city could use in its planning and—as importantly— to inform local citizens about the changes that were occurring or likely to occur. To be sure, Juneau's residents were largely receptive to this information. They had experienced observable changes: isostatic rebound on the wetlands, receding glaciers of the Juneau Icefield, and warmer and wetter winters. Beyond this, the Tlingit community was keenly aware of changes in their traditional subsistence efforts, and long before others, started warning about the changes.

In the 15 years that have elapsed since Juneau's scientific panel first convened to examine its impacts on our community, the city and various citizen initiatives have together built on its foundations. This update comes at a propitious time, the outset of a new federal administration that acknowledges that climate change is the pre-eminent challenge of our generation.

Using this report

This report is designed as a living document to inform the community, decision makers, and academics and to serve as a learning and teaching tool. The nine key messages summarized on pages 6 and 7 are intended for use as a quick reference. Unique for this type of report, these key messages highlight actions by Juneau's civil society, including local nonprofit organizations.

The report begins with an introduction by Raymond Paddock, Environmental Coordinator for the Climate Change Adaptation Plan prepared by the Central Council of Tlingit and Haida Indian Tribes of Alaska (CCHITA). We recommend you read it in full along with this report.

We invite you to email your thoughts and feedback to us at uas.acrc@alaska.edu. The authors' hope is that this report will inspire continued action on climate change by community members and leaders in Juneau and beyond.

Acknowledgements

We thank the City and Borough of Juneau (CBJ) for its support in bringing this vital information on climate change to the Juneau community and to others. Thanks especially to all the co-authors and other contributors. The inclusion of such a diverse array of material, including local knowledge, was made possible by the many elders, scientists, and local experts who contributed their time and expertise. The report is online at acrc.alaska.edu/juneau-climate-report. It is an honor to be the lead editor and project manager for this critical effort. We have a chance to save our world from the most extreme effects of climate change. Let us take it.

Gunalchéesh, sincerely,
James E. Powell (Jim), PhD, Alaska Coastal Rainforest Center, UAS

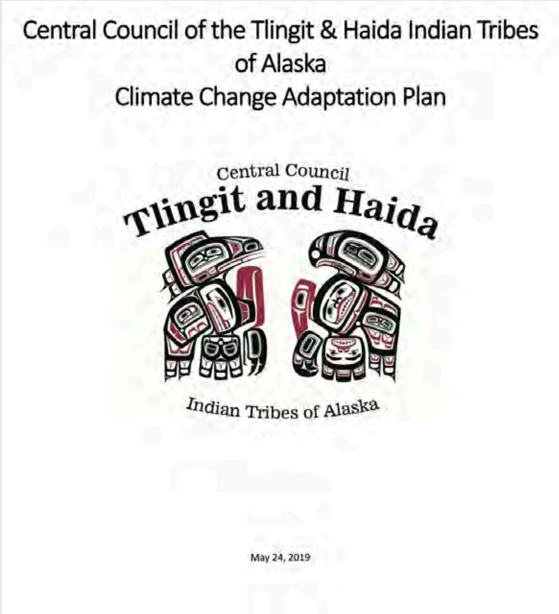
A regional Indigenous perspective on adaptation: The Central Council of Tlingit & Haida Indian Tribes of Alaska's Climate Change Adaptation Plan

RAYMOND PADDOCK

Faced with a changing climate, the Central Council of Tlingit & Haida Indian Tribes of Alaska (Tlingit & Haida) is adapting. Inadequate information about climate change specific to Southeast Alaska and its effect on cultural and traditional foods and resources prompted the need to develop CCTHITA's Climate Change Adaptation Plan.

The Plan marks the first time the Tribes have looked hard at the impacts of climate change on their traditional food and prioritized and ranked them. This is a very difficult and culturally significant action. The prioritization and the Plan itself are the result of a broad collaboration among Southeast Alaska's Tribes, representatives from Tribal organizations from outside Alaska, government agencies, universities, and nonprofit organizations, who were all assembled by the Tlingit & Haida. The Plan outlines four key steps to help Tribes "move forward and build preparedness for climate change": prioritizing adaptation strategies and implementation, building community support, incorporating climate preparedness, and collaborating with surrounding communities and key stakeholders.

A major part of the Plan, and an important contribution to understanding the impact of climate change on communities in Southeast Alaska, is its "Key Areas of Concern." These areas include climate impacts on salmon, herring, halibut, shellfish, yellow cedar, and other important species and special forest products that Tlingit and Haida people depend on. The Plan may serve as a template for other Southeast Alaska Tribes to assist their own efforts to respond to climate change. By sharing the Plan, Tlingit & Haida hopes to assist municipalities, Tribal governments, businesses, organizations, and everyone interested in understanding climate change in Southeast Alaska. Tlingit & Haida did not undertake their actions without understanding the difficult choices and the culturally significant step that ranking food would have. But, faced with the incredible impact of climate change upon them and us all, they have started on their journey to adapt - and have shared their extremely important Plan with us all.


Central Council of the Tlingit & Haida Indian Tribes of Alaska
Climate Change Adaptation Plan

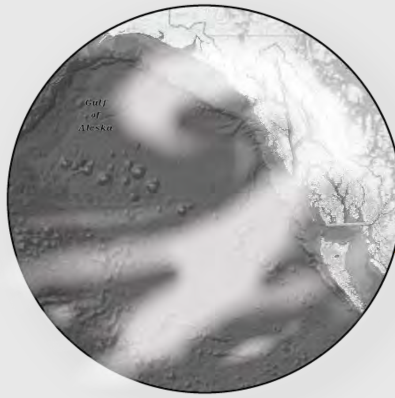
Central Council
Tlingit and Haida
Indian Tribes of Alaska

May 24, 2019

9 KEY MESSAGES

The information in this report can be summarized in nine key messages. These pages provide a visual display of complex climate data that can be used as a quick reference and guide to more in depth information throughout the report.

1. MORE PRECIPITATION



Juneau is experiencing a clear long-term upward trend of precipitation. The average annual precipitation has increased approximately 20 inches over the past 96 years.

Learn more in section A.2

2. RISING TEMPERATURE

Temperatures are generally rising, with significant increases in the winter and summer but much less change in spring and autumn.

Learn more in section A.3

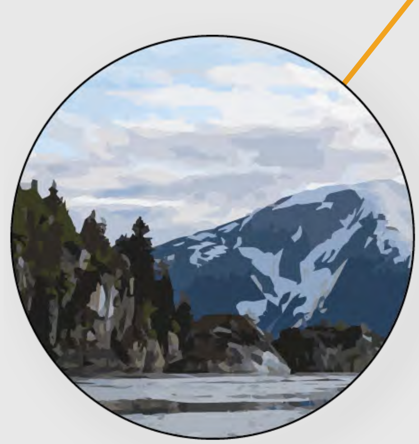
3. LESS SNOWFALL

Continued warming can be expected to decrease the amount of snowfall near sea level. From 1940 to 2020, average winter snow accumulation at the Juneau airport followed a downward trend.

Learn more in section A.4

4. SURFACE UPLIFT AND SEA LEVEL RISE

Sea level rise is currently outpaced by land surface uplift caused by receding glaciers, but sea level rise may overtake land surface uplift later this century.



Learn more in section B.1

5. OCEAN WARMING

Warming sea temperatures are anticipated to greatly stress many parts of the ocean's ecosystems, such as marine mammals, fish, and seabirds, and may enhance algal blooms.

Learn more in section B.2

6. INCREASING OCEAN ACIDIFICATION

Declining marine pH will likely cause broad negative social and ecological impacts to marine ecosystems.

Learn more in section B.3

7. MORE LANDSLIDES

Landslides are expected to increase, as the climate becomes warmer, wetter, and characterized by more extreme precipitation events.

Learn more in section C.1

8. RESPONSE: LOWERING GREENHOUSE GASES

The City and Borough of Juneau has developed a climate policy and proposed implementing strategic climate actions to lower greenhouse gases by obtaining 80% of Juneau's energy from renewable sources by the year 2045.

Learn more in section M

9. RESPONSE: RESIDENTS TAKING ACTION

Juneau's nonprofits and Tribal and local governments are taking action to mitigate and adapt to climate change.

Learn more in section N

What we're experiencing: Atmospheric, marine, terrestrial, and ecological effects

The five key messages concerning ecological effects are discussed in more detail in this section. Additional ecological effects from climate change are discussed in the following four sections covering local climate, ocean, land, and animals.

A.1 Setting and seasons

TOM AINSWORTH

Juneau is situated on the west coast of North America at 58 degrees north latitude. It lies in the heart of the Pacific coastal temperate rainforest that stretches along the west-facing coastal mountains from Southcentral Alaska to Northern California. Temperate rainforest regions are characterized by persistent cloud cover, abundant annual precipitation, and little annual temperature variability. The complex topography in and around Juneau causes tremendous variability of weather conditions over very short distances.

Our surrounding mountainous coastal terrain also causes variations in local sunlight and air drainage patterns, which result in wide differences in temperatures between downtown Juneau and Douglas, the Mendenhall Valley, and points farther north out Glacier Highway. Precipitation also varies considerably within the CBJ. Downtown Juneau receives about 50% more liquid annually than the Juneau airport, only eight miles away. Downtown also receives considerably less snow annually (approx. 40 inches) than the airport (86 inches) and the lodge at Eaglecrest Ski Area (185 inches).

Juneau's coastal marine environment is characterized by a narrow continental shelf, deep fjords, and long, narrow channels surrounded by rugged mountains and glaciers. This geological complexity creates seasonal and spatial variability in circulation processes, leading to an array of habitat types that supports one of the most biologically diverse marine ecosystems in the world.

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CLIMATE

FOLLOWING THE SEASONS

Tlingit people have always relied on a deep knowledge of seasonal dynamics for their survival. Summer is a time for gathering plants and berries, catching fish, and preserving food for winter. Fall is deer hunting season. Significant meteorological changes affecting this cycle (e.g., unusually wet, dry, or cool weather or lack of snow cover) can drastically reduce harvesters' success.

Photo: Dmitry Brant, CC BY-SA 4.0 via Wikimedia Commons

Seasons are caused by the tilted aspect of the earth as it rotates around the sun. Even though the earth is farther from the sun during our summer, the northern hemisphere is pointed more directly toward the sun during that season, resulting in longer days and warmer temperatures. Conversely, during winter, the northern hemisphere is tilted away from the sun, significantly reducing the duration and intensity of sunlight at our high latitude.

SPRING (March - May)
Spring is historically the driest and least cloudy season in Juneau. If preceding fall and winter months are drier than normal, spring's dryness can exacerbate and extend periods of drought. For example, the cumulative effects of drought in Southeast Alaska from 2017 to 2019 resulted in some reservoirs being too low to generate hydropower. The dryness of spring makes it the most likely time of year for wildfires in the CBJ - most of which are human-caused, with very few ignited by lighting.

SUMMER (June - August)
Summer, although the warmest season in Juneau, is relatively cool in the rainforest, with a narrow temperature range. Sea breezes blowing in from the ocean prevail during summer as does persistent, shallow cloud cover. Daily high temperatures are around 60°F. The highest temperature recorded in Juneau is 90° F (July 7, 1975). Thunderstorms occur here most often in June and July but are still rare. Lightning strikes are more often detected here by remote sensing technology (i.e., satellites or antenna networks on the ground) than by human observation. Glacier outburst floods (also known as "Jokulhlaups") affecting the Mendenhall and Taku River valleys are the most likely natural hazards to affect the CBJ during summer, but these occur in limited areas.

FALL (September - November)
Fall is the wettest season in Southeast Alaska. Large Pacific storms steer abundant precipitation into the Alaska Panhandle and can be associated with damaging winds. Excessive prolonged rainfall, typically from organized Atmospheric River Events (see Section C.1), can lead to flooding. Precipitation in Juneau typically remains in the form of rain until November. At times, the combination of rain, wind, and high tides can result in storm surge flooding - water intrusion beyond the normal high tide line.

WINTER (December - February)
Winter is, not surprisingly, the coldest time of year. However, our temperate coastal climate allows many winter days to warm above freezing. Winter season temperatures are the average of three distinctly different weather regimes: warm and wet Pacific storms; cold and dry periods when inland air masses spill over the coastal mountains; and the transition periods between them. The first snowfall at sea level in Juneau usually occurs in early November but has been as late as mid-December. January is typically the snowiest month of the year, averaging 24.5 inches. The snowiest "full" winter season (Nov-May) was 194.3 inches in 1964-65. Snow levels fluctuate during the winter from sea level to the lodge at Juneau's Eaglecrest Ski Area and higher. Juneau's Taku windstorms occur most frequently in January and February during the coldest period of the year. These localized events cause high wind speeds blowing over mountain ridges east of Juneau to be forced downslope and accelerate at hurricane-force speeds toward downtown Juneau and Douglas.

A.2 More precipitation

RICK THOMAN

There is a clear long-term upward trend of more precipitation

Precipitation across Juneau varies dramatically across short distances and over time. While precipitation occurs here frequently throughout the year, it is usually light and manageable. Heavy rain is most common in the fall (August to October) as are damaging high winds associated with large Pacific storms. Juneau averages 230 days per year with "measurable" precipitation (at least 0.01 inch of liquid), including an average of 43 days with measurable snowfall. The average annual precipitation has increased approximately 20 inches over the past 96 years has seen a significant increase in annual precipitation, though there were short-term variations within this period. For example, the mid-1930s to mid-1940s were wet, then the 1950s to 1970s were comparatively dry, and since the mid-1990s wetter conditions have returned. And within these decade or two intervals, there are individual years that are unusually wet or dry. This year-to-year and decade-to-decade variability will continue in the future even as the long-term trend of precipitation continues to increase.

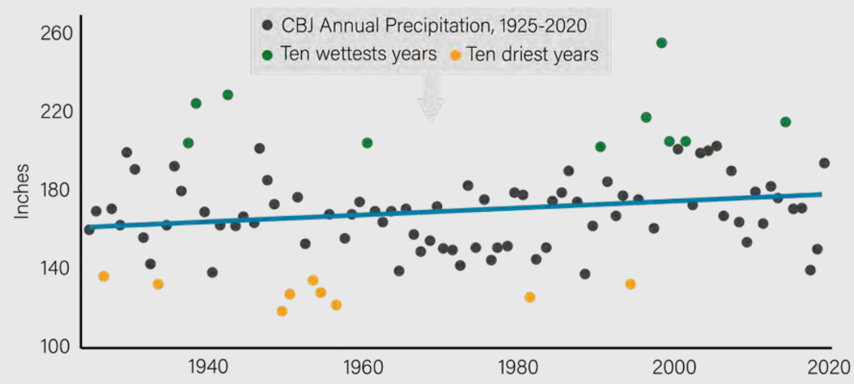


FIGURE 1. CBJ ANNUAL PRECIPITATION
Over the past 96 years, the CBJ has seen a significant increase in annual precipitation, with occasional short-term exceptions. Adapted from NOAA/NCEI 2021.

A.3 Higher temperatures

RICK THOMAN

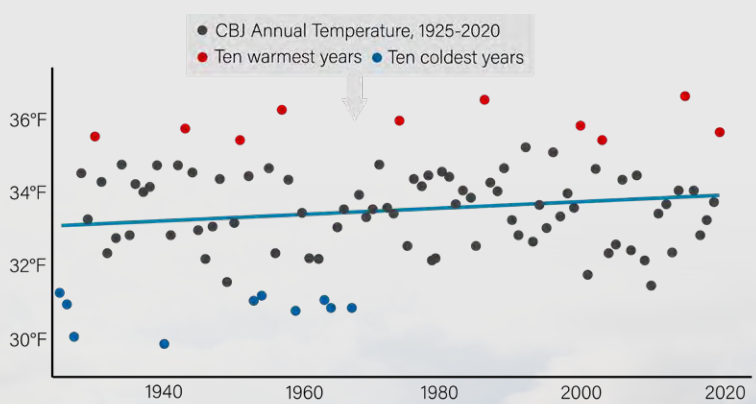
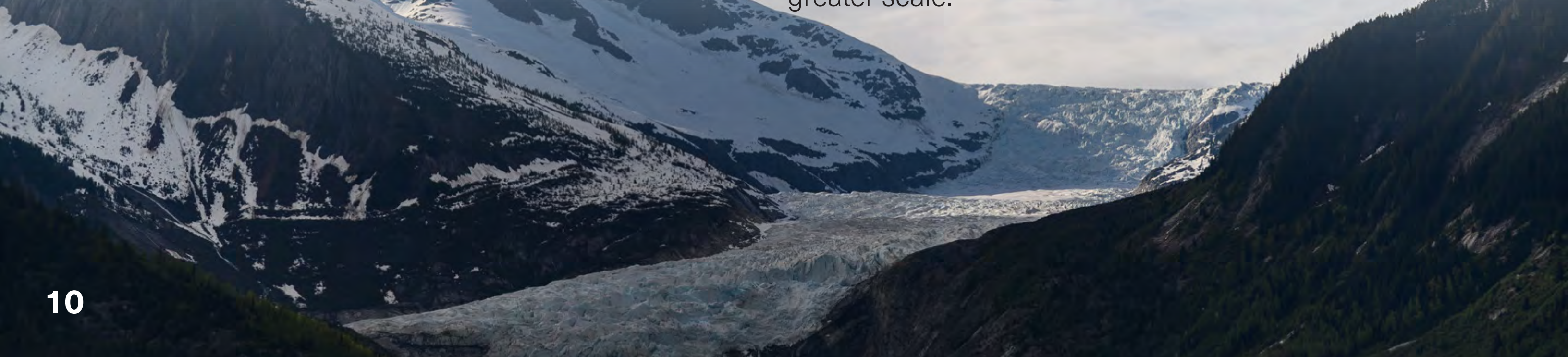


FIGURE 2. CBJ ANNUAL TEMPERATURE
Temperatures have been rising in the CBJ over the last 97 years. Adapted from NOAA/NCEI 2021.

Temperatures are generally rising, with significant increases in the winter and summer but much less change in spring and autumn

Annual average temperatures have been slowly progressing warmer, though this is mostly the result of the absence of any extremely cold years in recent decades rather than an increase in temperatures in the warmest years. Winter and summer show the most significant increases, with much less change occurring in spring and autumn. Taken as a whole, the retreat of glaciers, increased flooding, and greater avalanche threat are all related to these larger-scale changes in the environment. Other observed changes that have cascading impacts, such as the duration of low-elevation snow cover, are directly traceable to seasonal changes in temperature and total precipitation. These changes will continue in the future, possibly at a much greater scale.



A.4 Less snowfall

ERAN HOOD

Continued warming can be expected to decrease the amount of snowfall near sea level

The longest continuous measuring of CBJ snowfall has been done at the Juneau Airport. Between 1943 and 2020, the average annual snowfall recorded at the airport was 93.7 inches. Despite well-documented warming during this period, there was a very modest downward trend in winter snowfall.

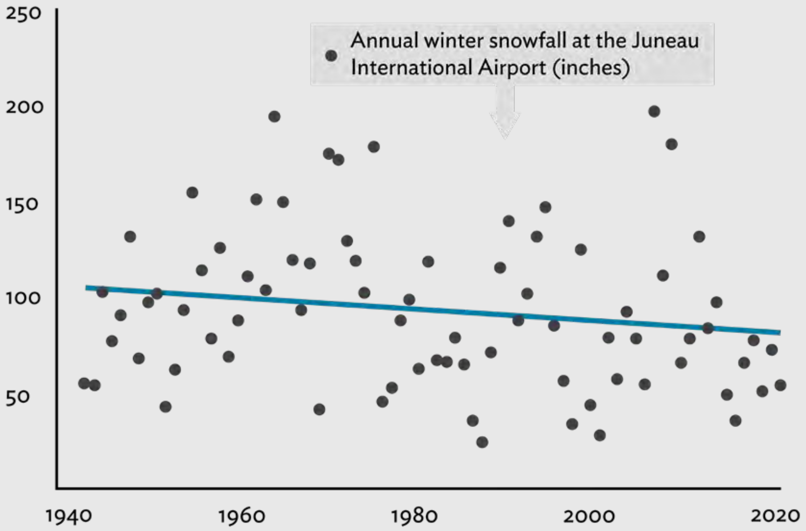


FIGURE 3. ANNUAL WINTER SNOWFALL AT THE JUNEAU INTERNATIONAL AIRPORT

Winters are represented by the year in which they begin. For example, 1980 represents the winter of 1980 -1981 (November through April). Source: National Weather Service, Juneau

Winter temperatures in Juneau hover very close to the freezing point of water, so small changes in temperature can dramatically alter the proportion of precipitation that falls as snow in winter. In particular, continued warming is expected to decrease the amount of snowfall near sea level in the CBJ. On a regional level, winter snowfall in Southeast Alaska and coastal British Columbia is projected to decrease 22-58% by the end of the century, with most of the decrease dependent on rates of global greenhouse gas emissions in coming decades.[1]

Changes in snowfall will affect the broader ecosystem

The proportion of annual precipitation that falls as snow has widespread implications for Juneau. Winter snowfall impacts the amount and temperature of water flowing in streams during summer months, which can influence the suitability of spawning habitat for salmon. Snowfall also has a strong impact on the health of local glaciers and icefields because snow adds mass to glaciers and protects glacier ice from exposure to and melting by solar radiation during summer. From an ecological standpoint, snowcover acts as a blanket that insulates the soil, protecting small mammals and tree species such as yellow cedar from mortality due to freezing.

Winter recreation at risk

Snowfall is also important from a social standpoint because it influences recreational opportunities.
For example, recreational opportunities available through downhill and Nordic skiing at Eaglecrest Ski Area and several locations in Juneau (below ~3000 feet) can be considered to be "at risk," similar to low elevation areas of mountain ranges in the Pacific Northwest.[2]

Darker surfaces lead to less snow

Decreasing snow cover creates a self-reinforcing cycle of less snowfall via the ice-albedo feedback effect. Less snow cover results in more warmth being absorbed through solar radiation into the darker ground surface, which increases surface air temperature and decreases the chance of future snowfall. Taken together, projected increases in air and ocean temperatures combined with the ice-albedo feedback effect can be expected to result in lower snowfall amounts near sea level in Juneau in the future.

Changing snowfall patterns lead to an uncertain future for avalanches

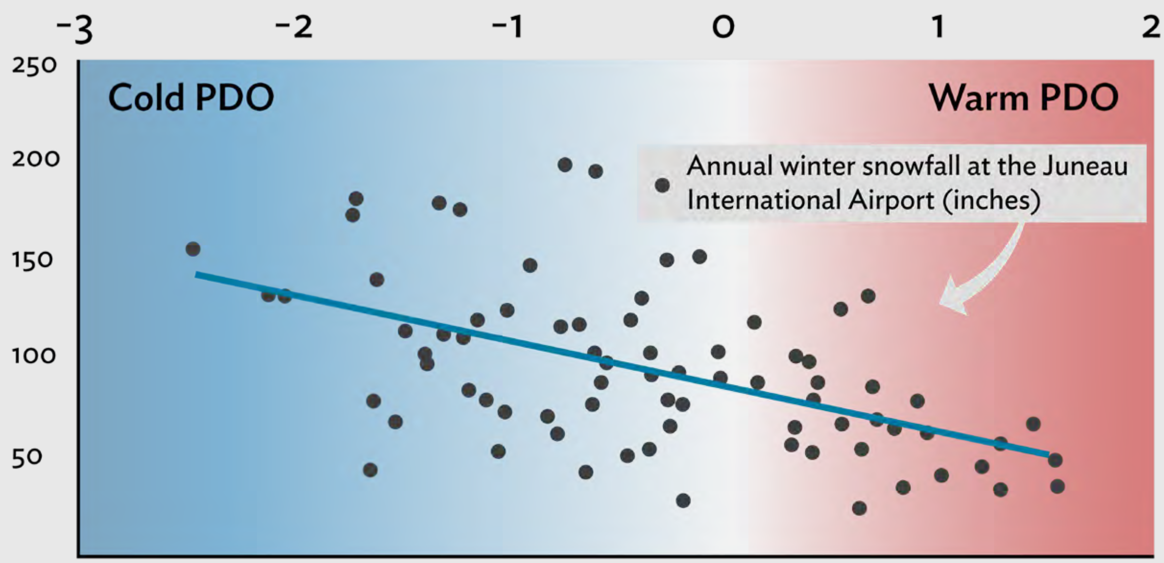
At higher elevations in the Coast Mountains where winter temperatures rarely get above freezing, future snowfall could increase as warmer air temperatures produce wetter storms along the Gulf of Alaska. The impact of changing snowfall regimes on avalanche hazards in Juneau is difficult to predict. Decreasing snowfall could lower the risk of avalanches; however, more frequent rain-on-snow events could increase the occurrence of large slab avalanches.

Sea surface temperatures have varying effects on snowfall

Winter snowfall at sea level in Juneau varies greatly from year to year, driven largely by variability in winter air temperatures. One consequence of this is that annual snowfall in Juneau shows a relatively strong correlation with the Pacific Decadal Oscillation (PDO), a long-lived pattern of Pacific climate variability similar to El Niño. The warm phase of the PDO is characterized by higher than average sea surface temperatures along the North Pacific coast, while the cold phase of the PDO is characterized by lower sea surface temperatures in the same region. In the warmer (more positive) phase of the PDO, snowfall decreases in Juneau, with generally less overall snowfall at sea level during the warm phase of the PDO compared to the cold phase. This relationship suggests that future ocean warming will likely decrease the amount of snow falling at lower elevations around Juneau.

FIGURE 4. EFFECTS OF PDO PHASE ON JUNEAU SNOWFALL

Correlation between the Pacific Decadal Oscillation (PDO), which reflects sea surface temperatures in the North Pacific. Positive PDO values denote the “warm” phase of the PDO characterized by warmer than normal sea surface temperatures, and negative PDO values denote the “cold” phase of the PDO with cooler than average sea surface temperatures.



OCEAN

B.1 Surface uplift and sea level rise

ERAN HOOD

Sea level rise is currently outpaced by land surface uplift (isostatic rebound) caused by receding glaciers

Southeast Alaska is currently experiencing extreme rates of land surface uplift and sea level change. Glaciers and icefields in the Coast Mountains have thinned rapidly since the end of the Little Ice Age approximately 250 years ago, and the associated unloading of the Earth's surface has led to land surface uplift (or glacial isostatic rebound) across the region.[1] Current rates of uplift in the Juneau area average about 0.6 inches (15 mm) per year according to a model using GPS measurements. Rates of uplift vary significantly along the coast, reaching up to 1.2 inches (30 mm) per year around Yakutat and Glacier Bay, where rates of post-Little Ice Age glacier loss have been highest, and tapering off rapidly to the south of Juneau.[2]

Juneau is experiencing a relative decrease in sea level

Globally, sea level rise has averaged 0.06 inches per year over the last century, with current rates exceeding 0.12 inches per year. Because land surface uplift rates in Juneau have outpaced rates of sea level rise, Juneau has and continues to experience a relative decrease in sea level. For example, shoreline mapping has demonstrated that shorelines in Juneau have been raised by roughly 10 feet since uplift started in the late 1700s. Land surface uplift is predicted to continue for multiple centuries as a result of past and continued glacier ice loss around Juneau.

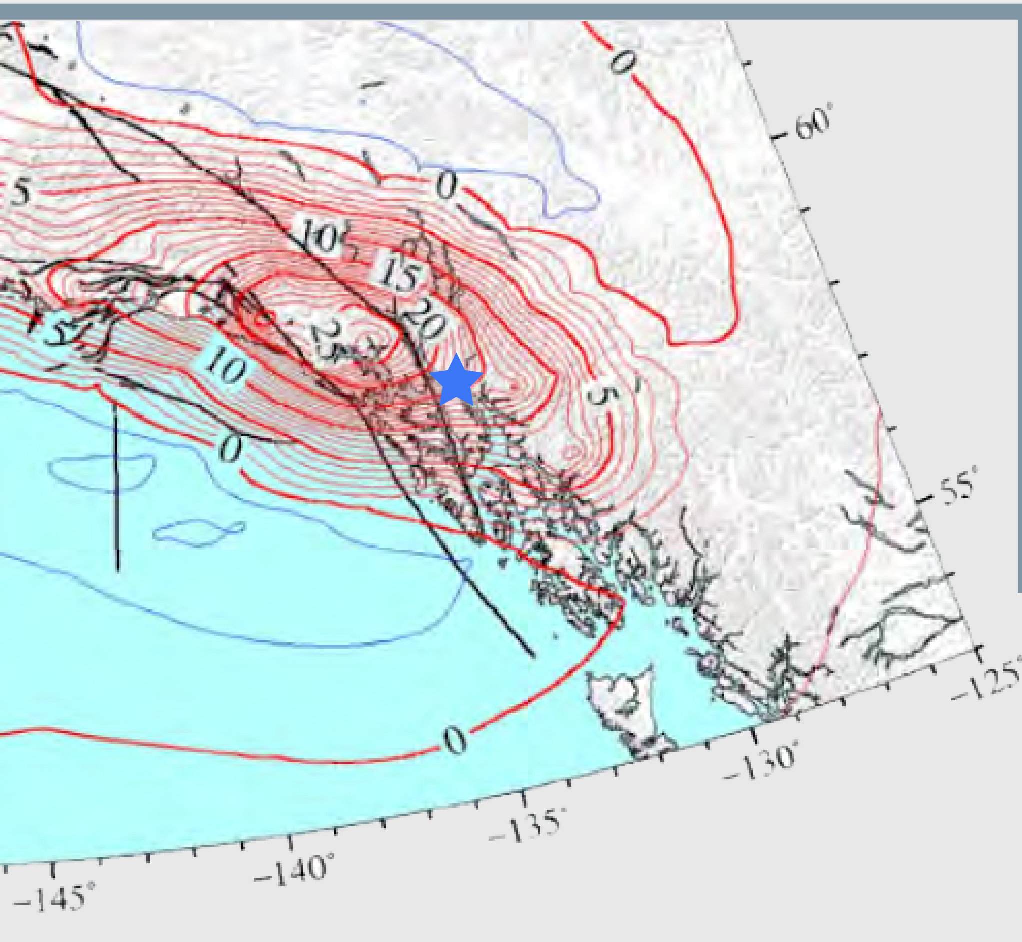
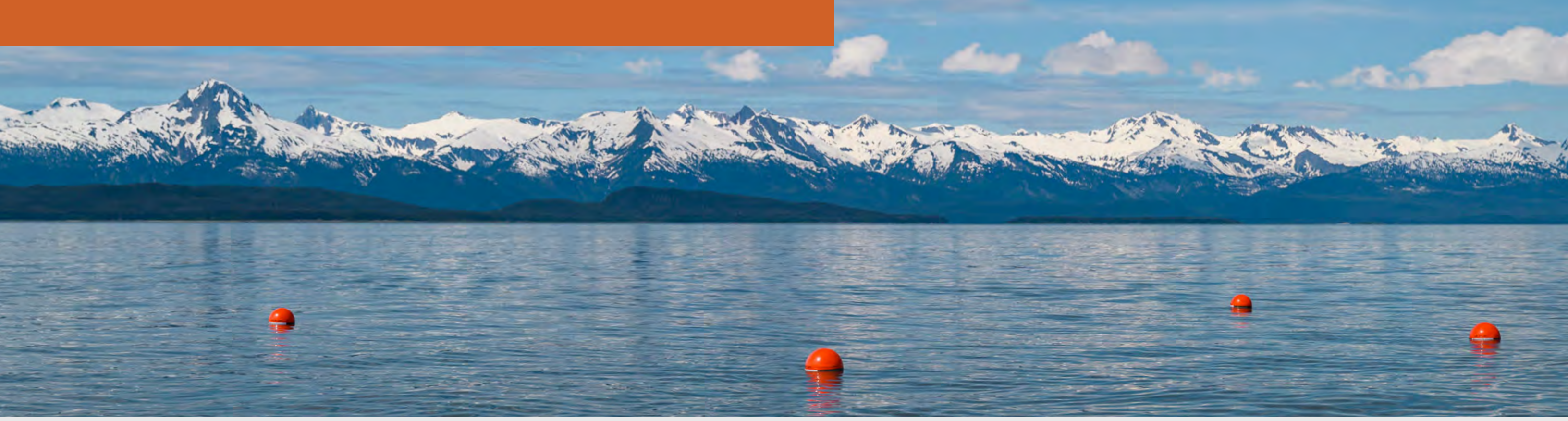


FIGURE 5. COASTAL UPLIFT RATES

Land surface uplift rates predicted by a glacial isostatic adjustment model (including the Last Glacial Maximum components) for southeast Alaska. Contours are drawn every 0.04 inches (1 mm)/year with thicker contours every 0.2 inches (5 mm)/year. Contours for uplift are shown in red, while those for subsidence are shown in blue. The location of Juneau is denoted by a blue star. Adapted from Hu & Freymueller (2019).



Future sea level rise is dependent on greenhouse gas emissions

Assuming rebound rates remain steady, Juneau can expect to experience about 3.9 feet of additional land surface uplift by 2100. This uplift is roughly equal in magnitude to mid-range projections of global sea level rise by the end of the century, making it likely that sea level in Juneau will be roughly the same in 2100 as it is in 2020. In this scenario, relative sea level position would continue to decrease in the near term (at least until 2050) until rates of sea level rise have increased to the point where they exceed land surface uplift rates. However, projections of sea level rise by the end of the century span a large range (1-8.2 feet) due in large part to uncertainties about future concentrations of greenhouse gases in the atmosphere. The low-end sea level rise scenario would result in about 2.9 feet of sea level decrease in Juneau, while the extreme sea level rise scenario would result in roughly 4.3 feet of sea level rise in Juneau by 2100.

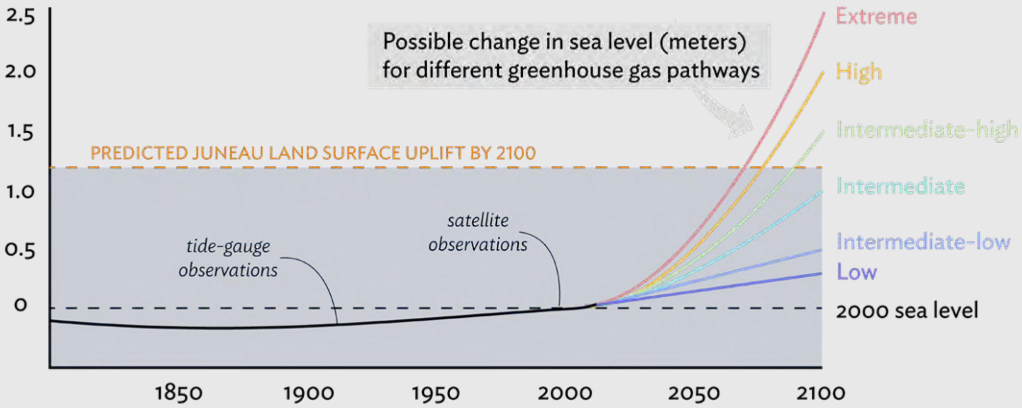


FIGURE 6. SEA LEVEL RISE SCENARIOS

Observed global sea level from tide gauges and satellites from 1800-2015, with projected sea level through 2100 under six possible future scenarios. The scenarios differ based on potential future rates of greenhouse gas emissions and differences in the plausible rates of glacier and ice sheet loss. Total predicted land surface uplift in Juneau (assuming rates remain constant) is shown.

Uplift impacts migratory birds

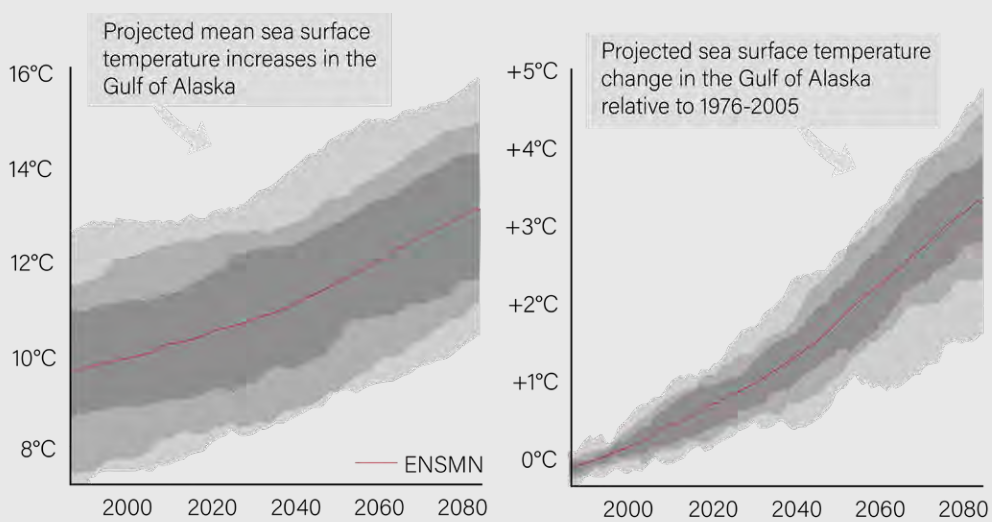
Glacial retreat and the resulting isostatic rebound is reducing the area of protected habitat within the Mendenhall Wetlands State Game Refuge that is especially important for migratory waterfowl and shorebirds.

B.2 Extensive effects of a warming ocean

HEIDI PEARSON

The cascading and broad effects of climate change are anticipated to greatly stress many parts of the ocean's ecosystem, such as whales, fish, seabirds, and algae (phytoplankton). By 2080, the mean sea surface temperature is predicted to increase by about 3°C (compared to 1976-2005) in the Gulf of Alaska. The marine heatwave of 2013-16 may be viewed as a harbinger of climate change impacts likely to affect Juneau and the rest of Southeast Alaska's marine ecosystem in the future.[1, 2, 3]

FIGURE 7. SEA SURFACE TEMPERATURES
Projected increases in sea surface temperature for the Gulf of Alaska (left) and future temperatures relative to historic means (right).
Source: Dorn et al.



Phytoplankton decline in warmer waters

Warming waters hold less dissolved oxygen and decrease upwelling, the mixing of dense, cooler, nutrient-rich waters towards the ocean surface, and increase stratification, leading to fewer nutrients in the mixed layer and declines in phytoplankton abundance. This can impact species throughout the marine food web, from microorganisms to whales. However, tidal influences in Southeast Alaska may decrease stratification and dampen these effects.[4]

Die-offs follow extreme conditions

From 2013 to 2016, a warm water mass in the Northeast Pacific known as "the blob" coincided with a dramatic positive (upward) swing in the Pacific Decadal Oscillation and a strong El Niño.[5, 6, 7] This "potent trifecta of climatic events" caused warmer seawater temperatures, decreased upwelling, decreased primary production, and harmful algal blooms.[8, 9, 10, 11, 12] Commercial fisheries species such as walleye pollock, Pacific cod, and Pacific sand lance in the Gulf of Alaska showed lower survival rates into adulthood during this time. Effects were also particularly evident in marine birds and mammals, including the largest common murre die-off in recorded history, high sea otter mortality and a large whale Unusual Mortality Event.[13, 14, 15, 16, 17]

Marine heatwaves put whales at risk

In Juneau and Glacier Bay, the marine heatwave coincided with the presence of fewer humpback whales in the area, with those being in poor body condition, and fewer calves born from 2014 to 2018.[18,19] These observations were reflected in low humpback whale reproductive rates on the Hawaiian breeding grounds during this same time period. Taken together, these observations indicate reduced prey availability during and after the marine heatwave. Changes in the humpback whale population could have dramatic consequences for Juneau's whale-watching industry, which generated $37.7 million in direct economic impacts in 2019.[20] Whales and seabirds are regarded as climate and ecosystem sentinels, and effects on these species are often more readily observable than in other marine species.[21] Climate-induced changes to these top predators are likely to tell us about effects occurring throughout the marine ecosystem.

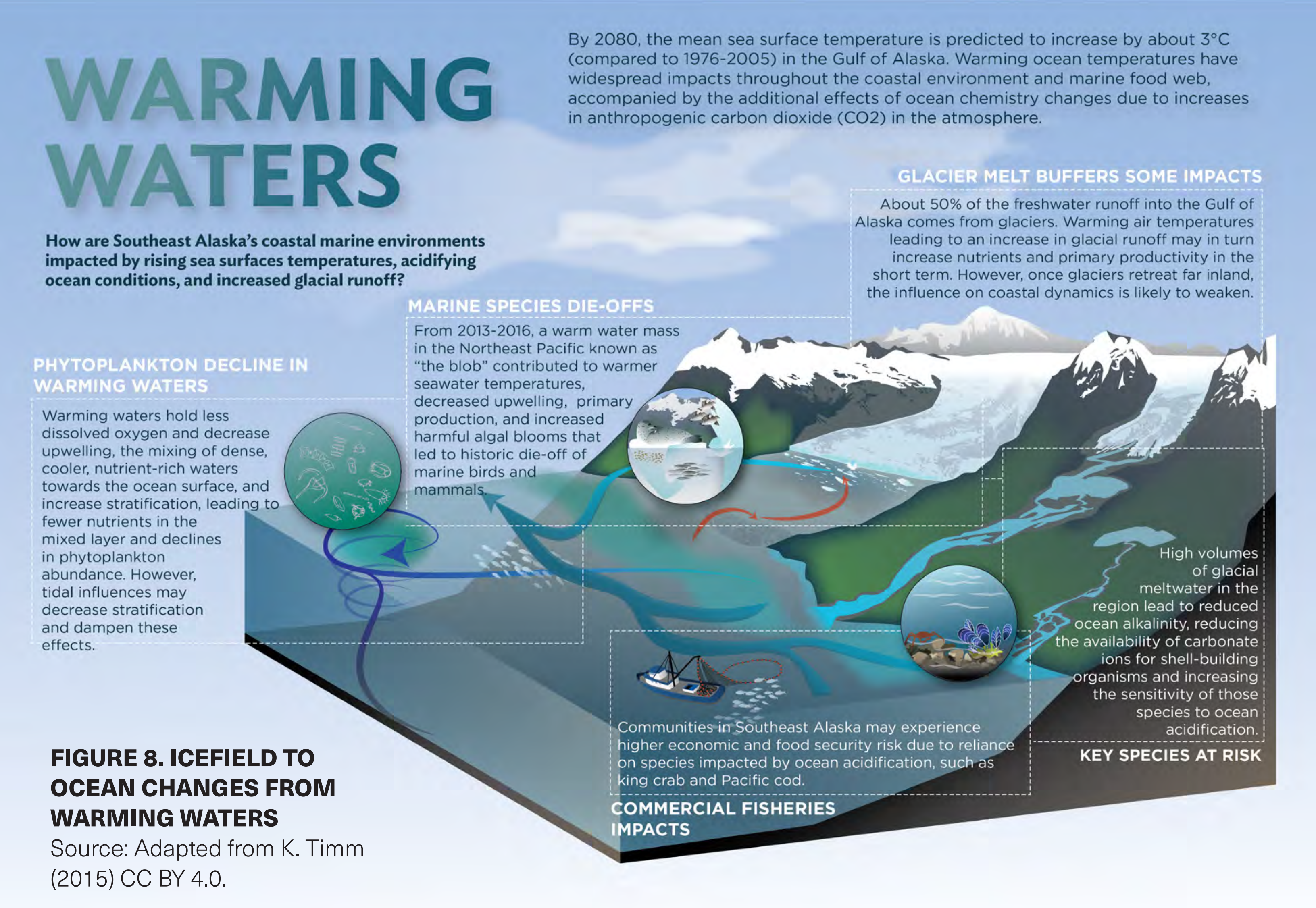


FIGURE 8. ICEFIELD TO OCEAN CHANGES FROM WARMING WATERS
Source: Adapted from K. Timm (2015) CC BY 4.0.

Glacier melt buffers impacts for now
In coastal regions with glacial influence, like Juneau, warming air temperatures and more glacial runoff may increase nutrients and primary productivity in the short term. However, once glaciers retreat far inland, the influence on coastal dynamics is likely to weaken.[22] Increased freshwater runoff has already been linked to regional declines in Pacific herring in Prince William Sound and the Gulf of Alaska.[23]

B.3 Increasing ocean acidification

ROBERT FOY

Acidifying oceans are likely to cause broad negative impacts on the marine ecosystem
The effects of climate change on the marine environment are accompanied by the additional effects of ocean chemistry changes due to increases in anthropogenic carbon dioxide (CO_2) in the atmosphere. The uptake of that CO_2 by the ocean has led to the acidification of the world's oceans with an average decrease in pH of 0.1 (approximately a 30% greater acidity).[1]

Alaska faces greater and variable impacts
This uptake of CO_2 by the ocean will be greater in Alaska due to the state's relatively colder water.[2] Alaska's deep waters are also naturally higher in CO_2 (i.e., more corrosive) due to global ocean circulation. Measurements of ocean acidification in the large seas surrounding Alaska have revealed expected seasonal variability in CO_2 levels. This variability is driven by a combination of declines in CO_2 by marine phytoplankton production, increases in CO_2 due to winter storms mixing up deep ocean water, and variable effects on CO_2 by contributions from glacial melt.

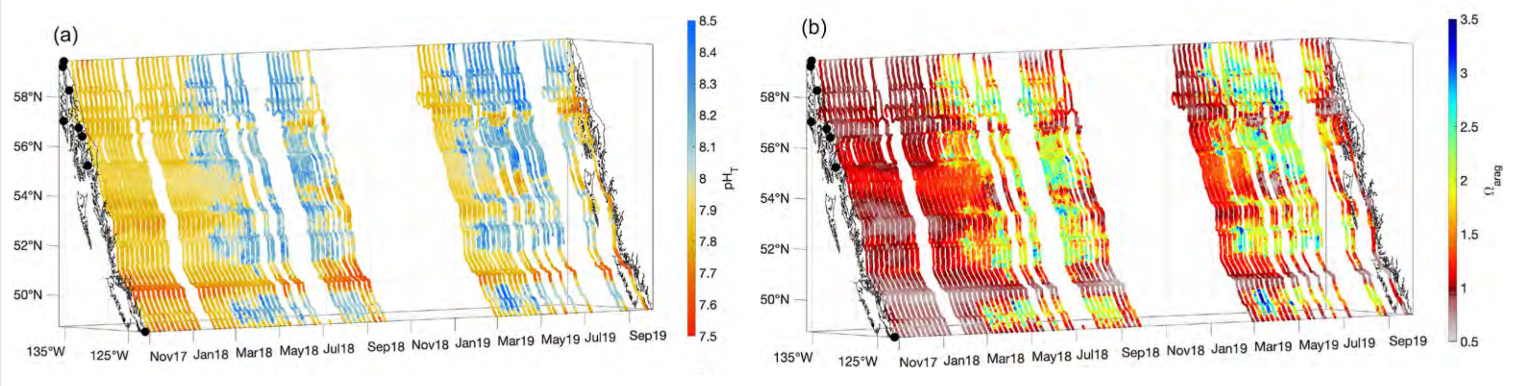


FIGURE 9. SEASONAL ACIDIFICATION
Seasonal trends of pH (left) and argonite (right) from the M/V Columbia ferry over a period from 2017 to 2019 show that acidification spikes in the fall and winter. Source: Evans et al.

In Southeast Alaska, the high volume of glacial meltwater reduces ocean alkalinity, also reducing the availability of carbonate ions for shell-building organisms and increasing the sensitivity of those species to ocean acidification.[3] The M/V Columbia ferry has collected data throughout Southeast Alaska's inside waters since 2017, showing a seasonal trend in CO_2 levels with higher CO_2 in the fall and winter (highlighted by the Alaska Ocean Acidification Network in a 2018 report).[4, 5] Data collected at a site outside Sitka Sound show similar seasonal trends in CO_2 levels and provide a baseline that will allow scientists to detect future changes from ocean acidification.

Shell-building organisms are at risk

As ocean acidification increases in Alaska, these seasonal trends will become more pronounced and pass thresholds that affect marine organisms. Recent models for nearby Prince William Sound, which is influenced by similar physical processes as Southeast Alaska, predict that by 2050 there will be a decrease in pH between approximately 0.1 and 0.15 in the water column, most pronounced between 160 feet (50m) and 500 feet (150m).[6] This reduction in pH would cross thresholds where carbonate would not be available for some shell-building organisms.

Key species in Southeast Alaska are at risk

Ocean acidification has the potential to affect marine organisms by reducing pH, which impairs physiological functions, reducing calcium carbonate in the water column affecting some shell-building organisms, and through ecosystem changes affecting prey resources. Laboratory studies have shown that crab species such as red king crab found in Southeast Alaska will be particularly sensitive to ocean acidification.[7, 8] Linkages between ocean acidification impacts on sea snails and sea slugs, known as pteropods, and pink salmon diets may also have implications for Southeast Alaska's food web.[9, 10] Indicators to assess the potential economic impacts of ocean acidification on Gulf of Alaska salmon species are currently being developed, following research that identified negative physiological impacts of CO_2 on coho salmon.[11] As ocean acidification continues to become a more pervasive issue in Alaska's coastal waters, communities in Southeast Alaska may experience higher risk of economic losses and food security due to residents' reliance on species impacted by ocean acidification.[12]

LAND

C.1 More landslides

SONIA NAGORSKI & AARON JACOBS

Juneau landslides are often linked to intense precipitation events
Landslides include many types of mass movements, ranging from dry rockfalls to torrential mudflows that release materials downslope, often in rapid pulses. In Juneau, the most common type of landslide hazard is a debris flow, although rockfalls and debris slides also commonly occur.[1] Debris flows are turbulent mixtures of fine-to coarse grained soils, rocks, trees, and any other material that gets caught up in the flow of material released. Factors that contribute to debris flow potential include steep slopes, thick soils, freeze-thaw cycles, oversteepening of slopes, and prolonged or intense precipitation events. Landslide potential can build up over time, and debris flows can be triggered by heavy and/or prolonged precipitation, earthquakes, undercutting of slopes (e.g. by road cuts or stream erosion), and logging, all of which are factors in Juneau, which has an extensive history of landslides.[1] Many of the historically known landslide events in Juneau over the past century are linked to episodes of high rainfall. Prolonged or intense precipitation can trigger landslides because as water saturates the soil, the pore pressure increases and the soil shear strength is weakened.[2]

Photo: Sonia Nagorski

Atmospheric rivers increase the risk of flooding and landslides
The most intense and prolonged high precipitation events in Juneau arrive in the form of atmospheric rivers (ARs).[3] These are formed by the transport of tropical moisture poleward across the Pacific Ocean northward and over Southeast Alaska. These ARs are typically long, narrow plumes of enhanced atmospheric water vapor. They are identified and observed via integrated water vapor in satellite imagery and result in rainfall amounts of 2-9 inches, with some rates of >0.30 inches per hour or 3-6 inches per day. Often accompanying ARs are high winds, which can add further damage by loosening trees in saturation-compromised soils and starting a cascading effect downslope from a windfall.[4] The impacts of ARs are exacerbated if they arrive onto already saturated soils, as is often the case in Juneau, especially in the fall season, or onto existing snowpack that can quickly melt when in contact with the warmer rainfall (as was the case in the December 2020 event), a process that increases the amount of surface runoff, intensifies flooding, and increases the risk of landslides.

Southeast Alaska has experienced fatalities and significant property damage due to atmospheric rivers
Atmospheric river events have caused hillslope failures in Southeast Alaska in the recent past, such as in Sitka in 2015, when an AR caused over 40 landslides and 3 fatalities, in Haines in December 2020, when an atmospheric river dumped over 10 inches of rain onto snow-covered ground in 2 days, caused a major landslide, killing 2 residents. In Juneau, during the same December 2020 AR event, there was extensive flooding, debris flows, and property damage in the Juneau communities of Mountainside, Twin Lakes, Glacier Highway near downtown, and in the Salmon Creek watershed, where a landslide damaged the pipeline that supplies water to the DiPAC hatchery, resulting in the destruction of thousands of rearing fish.

As precipitation increases, atmospheric rivers are becoming more frequent on the west coast
As discussed in Section A.3, Juneau is experiencing a trend toward higher precipitation due to the warming climate. Continued warming is expected to increase the total number of atmospheric rivers that impact the west coast of North America.[5] Trends of annual precipitation across Southeast Alaska from 1969 to 2018 show increases ranging from 4.7% to 15.1%.[6]

There is an increasing trend from 1980 to 2019 in the number of days per year that the Juneau International Airport received more than 0.50 inches of precipitation. Maximum consecutive 3-day precipitation amounts are projected to increase from 2031 to 2060, and these events typically occur in the autumn and early winter and are frequently associated with atmospheric rivers, which would relate to an increase in flood risk and, in turn, landslides.[7]

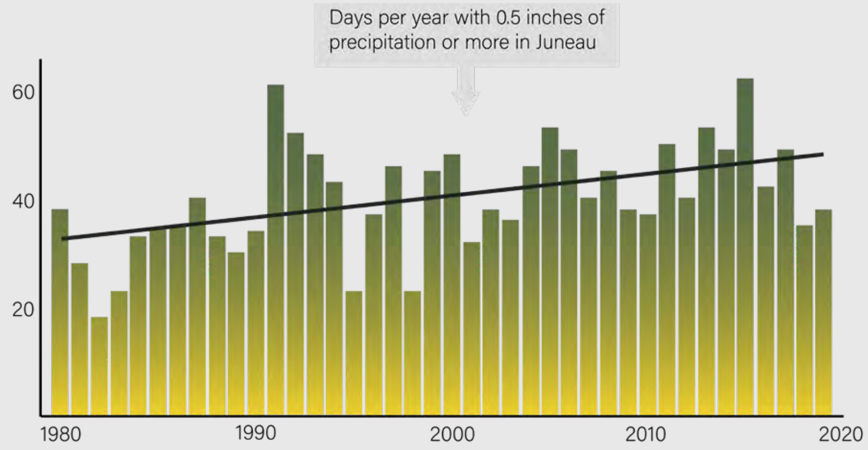


FIGURE 10. DAYS PER YEAR OF PRECIPITATION GREATER THAN .5 INCHES
Climate data from the Juneau airport showing days per year of precipitation greater or equal to 0.50 inches with the black line representing the trend from 1980 to 2019. Extreme high precipitation events are major triggers for landslides. Source: McFarland (2019).

With each atmospheric river, risk of landslide activity is renewed, particularly if soils are already saturated from prior rainfall events. Other hazards linked to intense storms and atmospheric rivers include endangerment of the integrity of the Salmon Creek dam, flooding of streamside neighborhoods, overwhelming of storm drains and other infrastructure, road erosion, and endangering safe passage on roads and bridges.

Juneau infrastructure is increasingly susceptible to landslides
In 2021, a CBJ-commissioned study found that about half of Juneau's downtown buildings are located in areas of moderate to severe risk of landslides or avalanches.[1] Not all parts of Juneau are equally susceptible to debris flows; those at greatest risk are likely at the base of steep, undercut slopes made up of deep, unconsolidated soils atop weak geologic materials and that are proximal to gully or stream channels draining the slopes. Landsliding is a natural geological process in steep terrains such as that surrounding Juneau's neighborhoods. However, as Juneau continues on its current trend of receiving higher amounts of precipitation, increased frequency of ARs, rain-on-snow, and other extreme weather events, all of which are triggers for landslides, it will likely experience a commensurate increase in landslide magnitude and frequency.

Photo: Sonia Nagorski

Photo: Mia Bennett/Cryopolitics

C.2 Mendenhall Glacier continues to retreat

JASON AMUNDSON

Mendenhall Glacier is a major tourist destination and a focal point of the Juneau community. The glacier has retreated since its Little Ice Age maximum in the late 1800s, and about 1.3 miles since the U.S. Forest Service Mendenhall Glacier Visitor Center (MGVC) was built in 1962.[1] As a result of the glacier's ongoing retreat, visitors now see a shrunken, narrower glacier with more bedrock exposed on either side of the lower glacier and less ice reaching and calving into Mendenhall Lake.

The glacier continues to retreat and thin at high rates, with some of the highest observed thinning rates occurring from 2014 to 2019 (averaging about 9.8 feet/year across the glacier).[2] When observed thinning rates are projected forward in time and applied to surface and bed elevation maps of the glacier,[3,4] the glacier continues to retreat at rates of about 55 yards/year. Lower or higher thinning rates result in rates of terminus retreat of 20-80 yards/year. In moderate climate warming scenarios, the glacier will barely be visible from the MGVC by 2050.

FIGURE 11. FUTURE GLACIER RETREAT
Artistic rendering of the view from the Mendenhall Glacier Visitor Center in 2040, based on the mid-range thinning rate scenario. Source: Amber Chapin, Michael Penn

Glacial lake outburst floods in Juneau

The retreat of Suicide Glacier, a former tributary to Mendenhall Glacier, has created an ice-dammed basin a few kilometers upstream from the Mendenhall Glacier terminus. Each summer since 2011 the basin has filled with water and drained catastrophically in glacier outburst floods (also known as jökulhlaups), that threaten downstream infrastructure. Because of interannual variability in the magnitude of the floods, it is challenging to assess and prepare for hazards.[5] The magnitude of the floods depends on how much water can be stored in the basin, which depends on ice dam thickness and the amount of remnant ice left behind in the basin by the retreat of Suicide Glacier. Thinning of the ice dam that blocks water from escaping the basin decreases the storage capacity, whereas melting of the remnant ice floating in the basin increases the amount of water that can be held. Because we don't know exactly how the drainage event begins, and the floods vary in magnitude from year to year, it is unclear whether floods from Suicide Basin will increase or decrease in size in the coming years.

FIGURE 12. MENDENHALL GLACIER RETREAT
Computed glacier outline in 2020, 2030, 2040, and 2050, from the mid-range thinning rate scenario. Source: Jason Amundson, Mike Hekkers

C.3 Tongass Forest impacts and carbon

DAVE D'AMORE

A globally significant carbon sink

The Tongass National Forest is a globally significant carbon sink. How we manage the forests in Southeast Alaska has far-reaching impacts on climate change. As natural buffers to rising greenhouse gas levels, forests can capture or store atmospheric carbon dioxide (sequestration), reducing the carbon in the atmosphere and mitigating the effects of global climate change.

Carbon research to inform forest management

Forests are important carbon pools that continuously exchange CO_2 with the atmosphere, due to both natural processes and human action. Understanding how the forest participates in the greenhouse effect requires a better understanding of the carbon cycle at a local level. How the Tongass is used for timber, wildlife values, recreation and other uses will influence carbon sequestration rates. The Tongass National Forest is one of the most dynamic environments relative to the carbon cycle, with nearly nine times the amount of carbon dissolving in our streams as the Amazon River basin per unit area.[1] Researchers are working to better understand the dynamics of carbon on the Tongass and how they impact the global carbon cycle. Understanding the carbon cycle and where and how long carbon is stored on land or in deep waters after flushing out of streams will inform forest management practices.

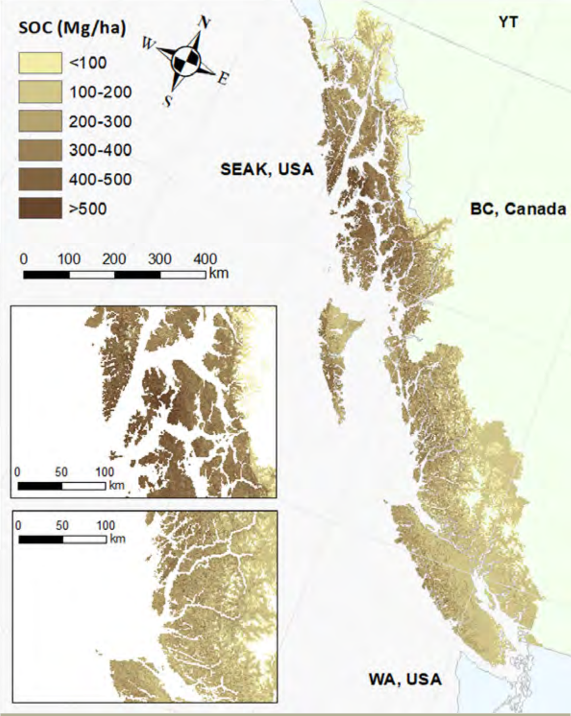
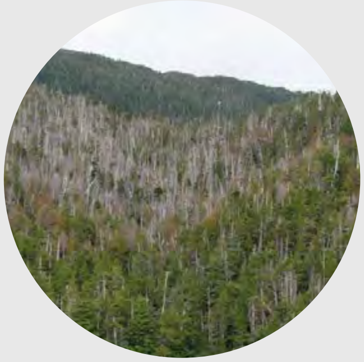


FIGURE 13: AK AND BC SOIL CARBON
Soil organic carbon stock predictions to 1 m (Mg C ha−1) at 90.5 m resolution for small NPCTR watersheds across BC and SE Alaska. Source: McNicol (2019)

Climatic changes in Southeast Alaska are leading to shifts to plant species and abundance

Predicted changes in temperature and precipitation have implications for future alterations to both soils and plants in Southeast Alaska. Plant rooting depth responds to physical and chemical conditions in the soil surface.



Tree species abundance is influenced primarily by soil hydrodynamics with Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) dominating the drier end of the spectrum, and red cedar (*Thuja Plicata*), yellow-cedar (*Callitropsis Nootkatensis*) and shore pine (*Pinus contorta, contorta*) found on wetter sites.[2] One clear implication for change is in the abundance of yellow-cedar, which has experienced a dramatic decline due to the loss of protective snowpack over the past 100 years.[3] Yellow-cedar is shallow rooted and vulnerable to soil freezing events that damage fine roots.[4, 5] Projections for the region have varying rates of decline continuing, but the Juneau area has several refugial stands that have not been impacted by decline and are relatively stable.[6] Red cedar has a similar rooting behavior but has not experienced the same extent of decline across the landscape. However, several red cedar flagging events have been noted in recent forest health surveys.[7]

Carbon stored in soil is on the move

Soils of the Southeast Alaska coastal rainforest store the majority of ecosystem carbon.[8] Soil carbon is not static and is always undergoing changes due to the activity of microorganisms and tree roots.[9] Organic matter is mineralized by microbes that use the reduced organic carbon as a source of energy and release plant-essential nutrients in the soil organic matter. Organic material can be deposited as leaf litter, woody debris, or soluble carbon consisting of organic acids leached from vegetation. The soluble organic acids pass through the organic horizon and flow downward to the lower soil horizons and can move carbon deeper into soil profiles. An emerging insight is the ephemeral nature of soil organic matter rather than long-term stable pools.[10] Total soil carbon stock estimates for the coastal rainforest soils range from 1.9 to 4.8 petagrams of carbon (Pg C) with a total Tongass National Forest stock estimated at 2.8 Pg.[8, 11]

Increasing temperatures could drive soil decomposition

Juneau has a mix of mineral soils along with dense pockets of deep organic soil peatlands. In warming temperatures, peatland soils are susceptible to decomposition, releasing stored carbon back into the atmosphere.[12] Predicted increases in air temperatures could cause a loss of stored organic matter in peatland and the organic material covering mineral soils. The decomposition is not always complete, and dissolved carbon can flow from soils to streams at different rates across watershed types, resulting in an uncertain influence on nearshore coastal resources.[13]

Weather extremes impact soil water storage, plant health, and stream ecosystems

Changes in precipitation as both snow and rain have led to extreme drought and floods due to large storms. Both of these climatic events have implications for soils and plants. Drought reduces the available water capacity in surface soils and the ability of trees to transpire. This has impacts on the tree itself and the soil water balance. Soil moisture deficit causes stress on the tree as it tries to pump water to the upper tissues, which can cause physiological stress and reduced growth and reproduction or, worse, the death of the plant. Soil moisture deficit is exacerbated by the pumping of water from the soil into the trees. During droughts, soil water storage can be reduced to a point where baseflow to streams is diminished or ceases entirely. Reduced detention storage from soils to streams reduces streamflow, which negatively impacts aquatic resources. The reduced soil moisture storage results in lower baseflow and discharge to streams. Reduced soil moisture supply to groundwater can also reduce streamflow, especially in back channels and low flow areas. Because these zones serve as important rearing areas for salmon, drought stress can lead to reduced fish production or hypoxia events and massive fish kills.[14]

In conclusion, both drought and storms provoke major responses in Juneau's forests. Climate change brings impacts to trees, soils, streams, fish, and the ocean in a complex process that, under normal circumstances, would instead provide a huge amount of carbon.

D.1 Terrestrial vertebrates in Áak'w & T'aak̲ú Aaní

RICHARD CARSTENSEN

Moving northwest up the Pacific coast from California through Alaska, the variety of species of terrestrial vertebrates declines, along with a variety of other kinds of organisms such as butterflies and vascular plants. Along the way, species that require a specific type of habitat drop out, leaving mostly species that can thrive in a range of habitats at our 58 degrees North latitude, such as western toad, raven, and black-tailed deer.

While these less-specialized species may fare better as habitats are displaced and restructured under most climate change scenarios, there are many factors contributing to resilience or vulnerability of a species. The movement of competing or supporting species into and out of the region, introduction of parasites and disease, changes for migratory species, and human disturbances are some of factors species face.

These factors operate in concert. For example, recent arrival of fisher and cougar to this region—to an unknown degree climate-related—could alter many predator-prey relationships with continued expansion into the area. Changing weather conditions that bring spruce bark beetle and hemlock sawfly infestations to our forests have cascading impacts to animals living in the suddenly defoliated forest. So far, our low-diversity Áak'w & T'aak̲ú rainforest hasn't felt the catastrophic losses—ash, eastern hemlock—upending forests in the eastern US. But climate change is knocking. A comparable loss to our spruce or hemlock could have more sweeping wildlife impacts than in eastern forests, where one acre might host more tree species than the entire North Pacific ecoregion does.

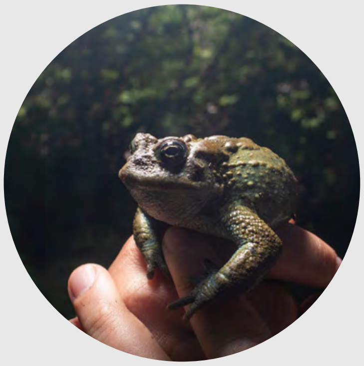
D.2 Three animals as indicators of change

RICHARD CARSTENSEN

Complexity of interacting factors makes it difficult to predict response to climate change for any terrestrial species. Western toad, mountain goat, and olive-sided flycatcher are three examples of how species in the coastal temperate rainforest are impacted by climate change.

INDICATOR SPECIES
Three samples of animals impacted by climate change. Representatives from Classes Amphibia, Mammalia & Aves will respond disparately to climate change & reconfigured habitat. L to R: western toad (*Anaxyrus boreas boreas*), mountain goat (*Oreamnos americanus*), and olive-sided flycatcher (*Contopus cooperi*). They face synergistic factors bound up with climate change, such as fungal infection. 'rezoned' elevational belts, and a migratory gauntlet, thousands of miles from our home in Áak'w & T'aak̲ú Aaní.

Western toad



Amphibians worldwide are canaries in the climate-change coal mine, vulnerable to decline and extinction from habitat loss and ailments like chytridiomycosis infection—both exacerbated by climate change. Beginning in the late 1980s, western toads dropped from possibly the most abundant animal in some local watersheds to a smattering of populations.[1] Areas least susceptible to declines tend to be "snowholes," such as Cowee Meadows and Taku Inlet. The fungus *Batrachochytrium*, for which many local swab samples have tested positive, attacks adults on shoulder-seasons of dormancy. Western toads, like yellow-cedar, may have suffered from thinning late-winter snowpack.

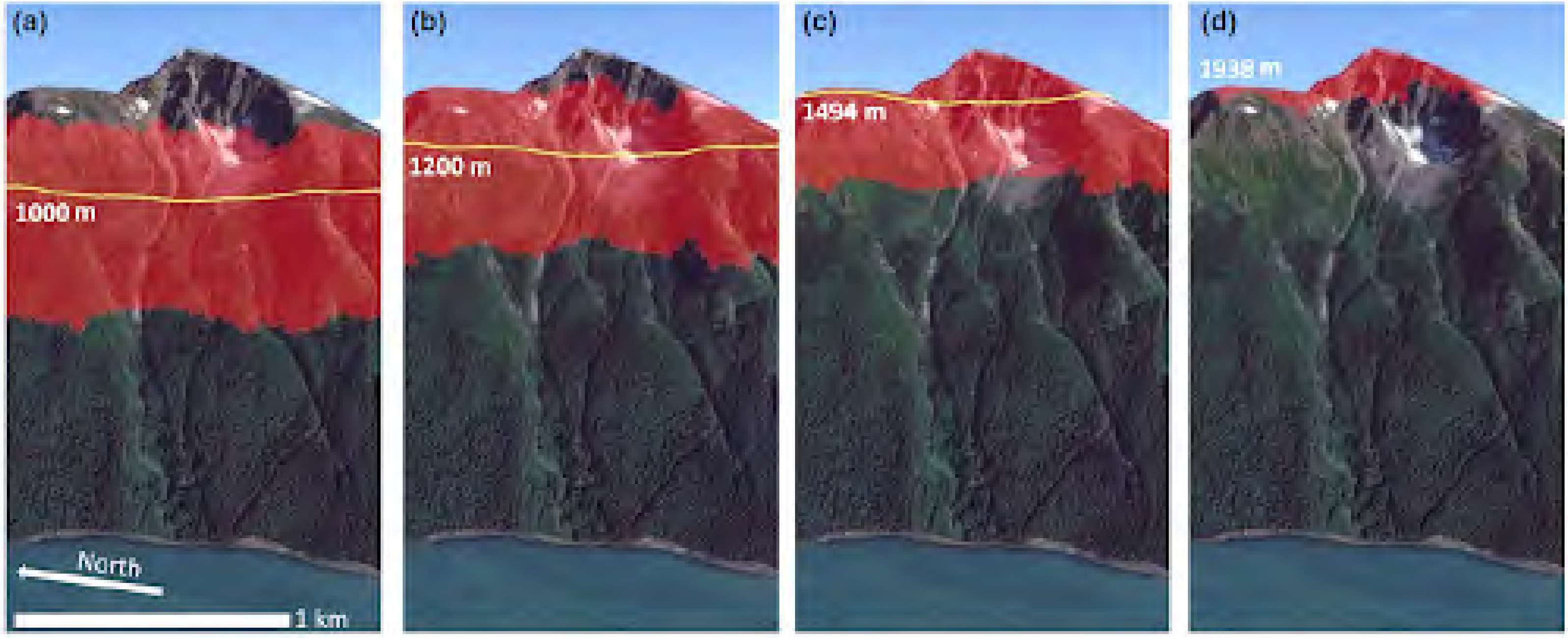
Mountain goat

Mountain goat—or in Lingít, *jánwu*—is one of the capital city's most charismatic mammals, often observable from any downtown sidewalk between October and May. Mountain goats are habitat specialists, whose options may narrow under some climate change scenarios. Summer and winter ranges are constricted and not well connected with those of neighboring populations, leading to genetic isolation.[2] Goat herds produce relatively few offspring and take longer than deer or moose to recover from dieback over severe winters.

Mountain goats are susceptible to winter-kill and avalanches, but also rely on cool summers to survive. Warming summer temperatures may reduce foraging habitat. In the series below, worst-case summer range (d) shows almost complete loss of habitat for mountain goats by 2085.

FIGURE 14. PREDICTED MOUNTAIN GOAT RANGE

These predictive maps uses Resource Selection Function modeling to show the summer mountain goat habitat under different global climate scenarios:
a) Current distribution (2005–2015 baseline)
b) Year 2085, best case scenario
c) 2085 midpoint
d) 2085, worst case.
Source: White, Gregovich & Levi (2017)



Olive-sided flycatcher

Insect-eating birds are the most rapidly declining group of birds in North America, and within this group, longest-distance migrants are faring worst. That includes olive-sided flycatcher, a species that annually commutes between Alaska and South America, whose numbers, continent-wide, have fallen by 79% since 1970. Some attribute declines of insect-hunting birds to an insect die-off driven by habitat loss, pesticides, and climate change.[3]

But not all arthropods are declining. Freshwater groups such as mayflies and dragonflies are increasing in many regions, due to strengthened water quality regulations.[4] On their breeding grounds in Southeast Alaska, olive-sideds heavily target dragonflies born in pond-studded wetlands.[5] However, olive-sideds may be nesting successfully on the northern Tongass only to struggle at their winter grounds or along their migratory route.

D.3 Insects

BOB ARMSTRONG

Worldwide, we are seeing a massive decline in insects. Over 27 years, there has been a more than 75 percent decline in flying insects in protected areas.[1] Very few overall studies of insects in the Juneau area have been conducted. Entomologists at the U.S. Forest Service are monitoring the effects of certain insects, such as the hemlock sawfly, on trees in the area. The best example of the effects of climate change on insects in Juneau might be what happens to freshwater lakes and streams along our roadsides during periods of drought and high temperatures. Many aquatic insect species live in these waters and die or diminish when they dry up or reach high water temperatures. Salmon, trout, and charr in Alaska are dependent on aquatic insects as food during at least part of their life cycle. Without aquatic insects, the region would not have commercial salmon fisheries and sport fisheries would be greatly reduced. Some plants in the Juneau area, such as a couple of orchid species, are dependent on adult aquatic insects as pollinators. Many birds depend on aquatic insects at certain stages of their lives, such as the American Dippers and Harlequin Ducks that forage for food in Juneau's streams and rivers.

DROUGHT IN THE RAINFOREST

During periods of drought and high temperatures, drying streambeds like the one pictured here result in diminishing populations of aquatic insect species, which in turn reduces food availability for salmon, trout, and charr that live in streams, as well as birds.

What we're doing: Community response

In 2006, Juneau's Mayor asked the University of Alaska Southeast to prepare a report on the potential impacts of climate change. At the time, the report, titled "Climate Change: Predicted Impacts on Juneau" (the precursor to this report), was one of the few scientific reports on climate change prepared for a local community. The report presented an objective look ahead at what global warming will mean for Juneau. Subsequently, several climate change-related reports and activities were undertaken by the CBJ, including a greenhouse gas (GHG) emissions inventory and reduction strategies, climate change implementation plans, and other projects, many of which are highlighted below and included in the timeline in Figure 20.

After the 2006 report was released, several new local nonprofit organizations were formed to raise awareness and education through public forums and programs to reduce GHGs. A list of these organizations and their contact information is attached in the Appendix.

E. Upgrading infrastructure and mitigation

KATIE KOESTER

Effectively responding to climate change can be a difficult task. However, as Juneau's citizens experience more frequent episodes of flooding, landslides, glacial retreat, and more extreme weather events, public support for investing in climate mitigation and adaptation is growing. While the demand on public funding to fix aging infrastructure is already daunting and heading off future damage from climate change may have not that long ago seemed distant and abstract, rapidly changing conditions have strengthened citizen and government resolve to respond proactively to climate-related challenges.

Photo: Lynn Coffee, ElleSeaAK, CC BY-NC-SA 2.0

Juneau's storm drain system is not built to withstand extreme events

One example of the impact of climate change is the stress being placed on Juneau's storm drain system. High precipitation events like the storms of October 2019 and December 2020 have overwhelmed Juneau's infrastructure. Both of these events represent 100-year storms, while Juneau's storm drain system is designed to handle a 20-year event. More concentrated rainfall results in storm drains overflowing and water backing up into drainage systems, homes, businesses, and streets. The December 2020 storm brought the most rainfall ever recorded at the Juneau International Airport—just shy of five inches in one 24-hour period.[1] This storm also created many small local landslides that devastated homes and caused damage to roads and other public infrastructure. According to the Federal Emergency Management Agency (FEMA) damage report for the City and Borough of Juneau, the CBJ experienced $4.7 million in damage.[2] The Mendenhall Wastewater Treatment Plant experienced a dramatic influx of effluent, partially as a result of residential and business roof drains being illegally connected to the sewer system. Large volumes of fresh water going into the wastewater influent disrupt the ecology of biological treatment and require additional resources to be moved through the system to help it recover.

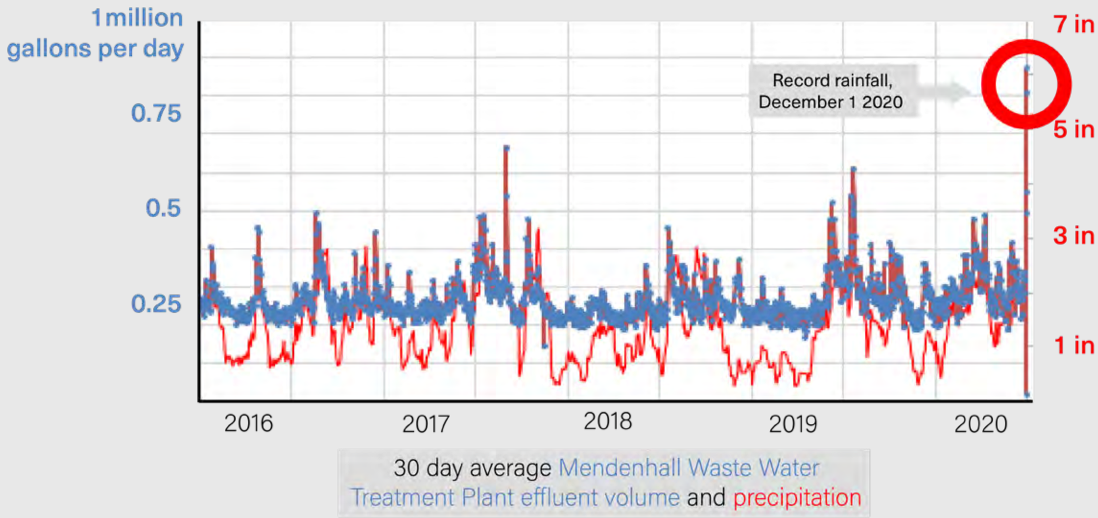


FIGURE 15. 30 DAY AVERAGE OF EFFLUENT VOLUME AND PRECIPITATION
The average precipitation compared to effluent intake at the Mendenhall Wastewater Treatment Plant. The outlier corresponds to record rainfall on December 1, 2020. Source: CBJ Mendenhall Waste Treatment

Many of the issues with drainage from the December 2020 storm involved debris clogging drains, which larger culverts would not necessarily have fixed. Additional engineering and analyses need to go into any recommendations for mitigating the effects of increasing precipitation in the borough.

Mitigating climate change in Juneau

With the 2011 CBJ Climate Action and Implementation Plan, Juneau began planning to measurably reduce greenhouse gas emissions. Actions included encouraging weatherization programs, updating the building code, encouraging all levels of government to reduce emissions in their operations, and extensive public outreach and education, including partnering with the University of Alaska Southeast to develop local professional expertise.[3] In 2018, the CBJ adopted the Juneau Renewable Energy Strategy, or JRES, which established an ambitious goal of having 80% of Juneau's energy provided by renewable resources by 2045.[4] While these mitigation actions will help slow climate change in the future, the community is facing the impacts of changes in weather patterns and severe storm events today. Potential mitigation or adaptation measures could include upscaling infrastructure such as stormwater drains to handle more flow, building retaining walls to protect against mass wasting from avalanches and mudslides, and strengthening coastal infrastructure and riparian development.

Adapting to landslide and avalanche hazards

In 2021, CBJ contracted for a hazard assessment and assessment maps for landslides and avalanches in the downtown Juneau area, including Mt. Juneau and Mt. Roberts. The study will be used to inform potential updates to the existing hazard maps created for downtown in the 1970s and adopted in 1987. Key parts of the hazard assessment include an update of surficial geology mapping, changes in slope features and mass movement activity, location of landslide and avalanche types, categorization and refinement of hazard designation map polygons, and preparation of geohazard designation mapping in support of the future development of appropriate zoning, building regulation, and mitigation options.[5]

F. Upgrading utilities and other energy consumers

ALEC MESDAG, VP AND DIRECTOR OF ENERGY SERVICES, ALASKA ELECTRIC LIGHT & POWER

Changing winter supply and demand from hydroelectric plants could help meet heating needs

Juneau currently receives nearly all its electricity from hydroelectric plants that have storage reservoirs, including existing alpine lakes and a reservoir behind the Salmon Creek dam. Inflows into these reservoirs do not align with seasonal demand for electricity, as freezing temperatures in the watersheds that supply storage reservoirs reduce inflows for much of the year. In an average year, reservoirs receive only around one-quarter of annual inflows from November to May, when nearly two-thirds of annual electricity is consumed. Predicted increases in average temperatures and precipitation will lessen this effect – more inflows will occur in the November to May period, while the demand for heat in those months is expected to decline with higher average temperatures – and this will in turn allow the electric system to more easily meet heating loads.

Heating loads put additional strain on energy reservoirs and infrastructure

The two primary energy loads to be electrified in Juneau are for transportation and heating, which have differing effects on the grid. The use of transportation fuel in Juneau peaks during the tourism season (see Section G) and integral energy storage allows electric vehicles to draw energy from the electric grid at various times throughout the day. In contrast, the community's demand for heat increases as temperatures decline, when inflows into storage reservoirs slow, and heating systems do not typically include or require significant heat storage. The lack of storage in electric heating systems means most electric heat is supplied as needed, which leads to overlapping demand for heat and high peak non-heating loads on the grid. Because of these differences, electrified transportation tends to place less strain than heating loads on both the need for reservoir storage and the infrastructure required to deliver electricity to customers

Greater efficiency and reduced energy consumption are needed to balance the costs and challenges of electrification

Accommodating the desire to electrify transportation and heating loads in Juneau will require a concerted effort to manage how electrification occurs to avoid negatively impacting Alaska Electric Light & Power's ability to meet Juneau's demand for electricity with affordable, reliable, and renewable sources. The community should pursue complementary efforts to increase the use of electrified transportation, improve the thermal efficiency of buildings, and replace electric resistance heat (such as electric baseboard heaters) with heat pumps. Eventually, the ability to cost-effectively improve efficiency will no longer keep up with increased demand for electricity because of increasing electrification. Conserving energy and using more efficient technology early will ensure the system is not overbuilt and more costly than necessary.

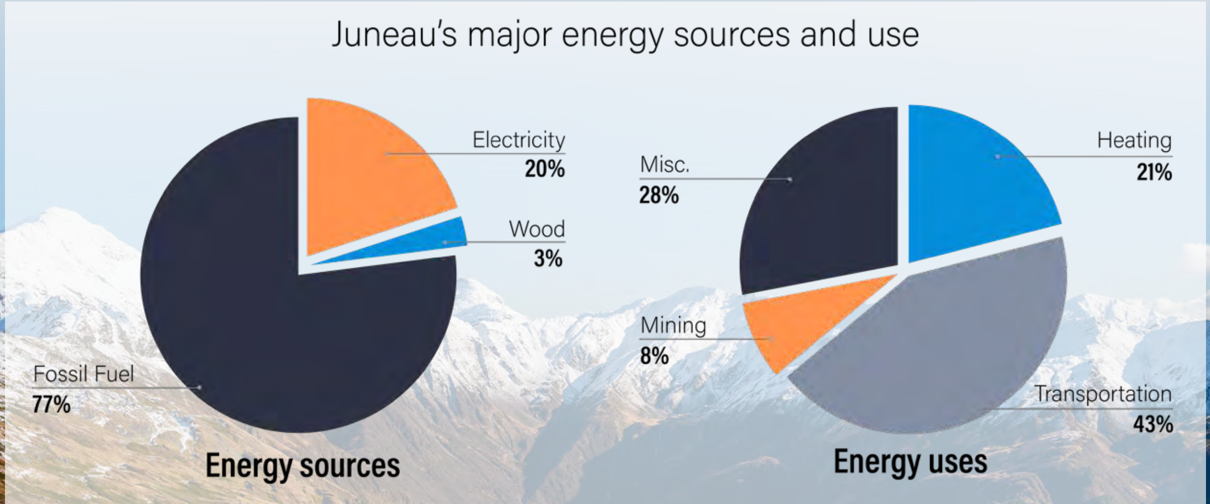


FIGURE 16: JUNEAU'S MAJOR ENERGY SOURCES AND USE
Source: CBJ Renewable Energy Strategy

G. Growing demand for hydropower

DUFF MITCHELL, MANAGING DIRECTOR, JUNEAU HYDROPOWER

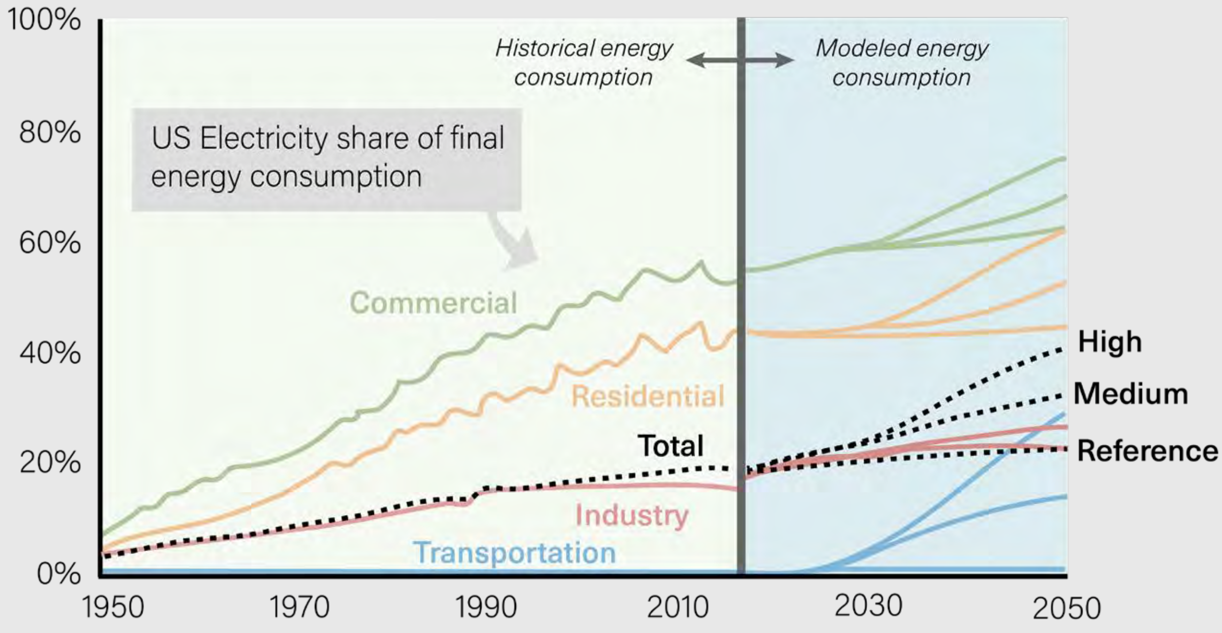
With its recent growth in electric vehicles and air source heat pumps, as well as potential increases in centralized renewable space heating and cruise ship shore power, Juneau's demand for hydropower for electricity is increasing. This section will briefly discuss the current situation with hydroelectric power in Juneau, seasonality and hydropower, planning and development, and potential opportunities for continuing to provide a workable, equitable system that provides predictable, low-cost energy to Juneau and our neighbors.

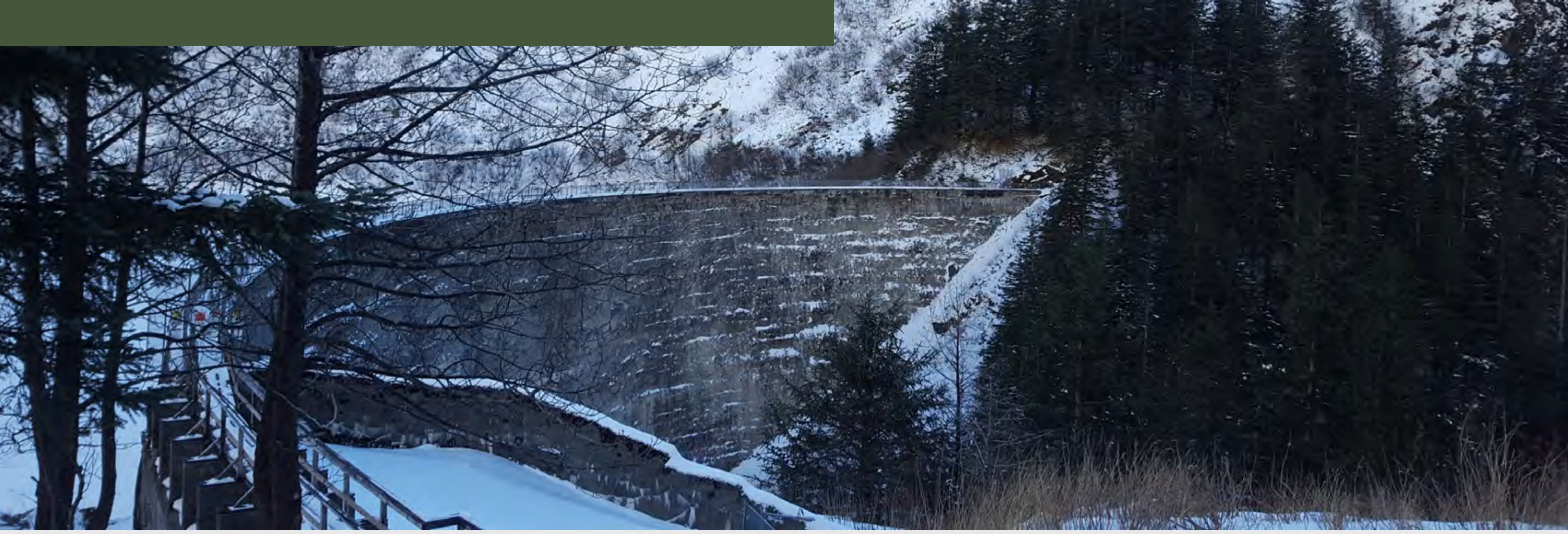
Current hydropower situation

Juneau is fortunate to have substantial developed and undeveloped hydropower resources, a growing public desire to change to this cleaner energy source, and the natural resources to do that. Hydropower generation in Juneau provides a zero-carbon source of electricity as it does not contribute to atmospheric pollution, including greenhouse gases.[1] Hydropower is a readily available local climatic solution for displacing diesel generation for uses that have expanding need or are not already on hydropower. Transforming Juneau's energy use toward renewable energy supplies may create regional opportunities to develop and transmit electricity to serve not only increased local but also regional electric demands. Juneau strongly supports increased hydropower to meet need and climate impact changes, as reflected in the CBJ's Resolutions 2593 (Juneau Climate Action and Implementation Plan) and 2802 (Juneau Renewable Energy Strategy).

Juneau is positioned to meet hydropower demand as fossil fuel-based heating systems are converted to heat pumps. According to the 2017 Juneau Renewable Energy Strategy (JRES), nearly 70% of Juneau's homes are still heated by fossil fuels.[2] These fossil fuel-based heating systems provide a large potential market for heat pump conversion and a corresponding rise in hydropower demand as economic and climate change decisions are made to convert from local diesel use to more electricity for heating. District energy development identified in the Juneau Climate Action and Implementation Plan (JCAIP 2011) and the 2018 JRES will eventually provide additional growth of beneficial electrification and hydropower development. Further, the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) model identified a substantive increase in electrical power across the United States, providing additional evidence that electrical energy growth is coming.[3]

FIGURE 17: US ELECTRICITY SHARE OF ENERGY
Electricity share of final energy doubles from 2016 to 2050 under the High scenario. Source: Adapted from Mai, T. (2018).





Widespread adoption of end-use electric technology would result in substantial fuel, electricity, and total energy consumption shifts. Beneficial electrification, which is the substitution of fossil fuel use for cleaner and, in many cases, lower-cost, electricity, may environmentally and economically fuel a continued market shift toward displacing fossil fuels in Juneau and elsewhere.[4] This substitution could provide the opportunity and impetus for hydropower growth to meet local and regional beneficial electrification needs.

Increasing temperatures will alter seasonal runoff patterns

It is well established in this report that climate change is upon us, and that Juneau can expect warmer temperatures and more precipitation. The seasonality of precipitation causes variability in hydroelectric generation. Geographic regions with distinct seasonal rain cycles and snowmelt typically experience fluctuations in generation due to precipitation's influence on flow.[5, 6] The U.S. Dept. of Energy (DOE) recently reported to Congress about the effects of climate change on federal hydropower, with in-depth analysis of the percentage change in the projected multi-model median temperature, precipitation, runoff, and hydroelectricity generation in each Power Marketing Authority (PMA) study area in the United States from ten-downscaled climate models. Overall, air temperature is projected to increase in all PMA areas annually and seasonally for both the near-term (2011-2030) and midterm (2031-2050). While the increase in temperature may not directly influence annual runoff, it will cause earlier snowmelt and a shifted seasonal pattern in runoff.[7]

Predictions of climate change impacts on Southeast Alaska hydropower made in 2010 appear to be validated by subsequent regional research findings.[8, 9] As noted in 2010, climate variability and change both have implications for shifts in the timing and magnitude of river discharge that could pose challenges to the management of capacity-limited reservoir systems.

Potential planning and development for resilience toward drought and runoff variability

Climate change impacts pose challenges for hydropower planning and development. The recent Southeast Alaska drought, beginning in 2017 and culminating in 2020, is a reminder.[10,11] The U.S. Government Accountability Office (GAO) reported that more frequent droughts and changing rainfall patterns may adversely affect hydroelectricity generation in Alaska as well as in the Northwest and Southwest regions of the United States.[12] Further, the GAO provided recommendations to the Federal Energy Regulatory Commission (FERC) and DOE to develop strategies to enhance grid resilience and identify and assess climate change risks to grids.[13] A well-planned transmission grid provides more flexibility by enabling more generation resources to be built in the lowest-cost locations.[14] An integrated grid system, like that in climatically similar Norway, makes it possible to take advantage of spatial variability in precipitation and runoff. Grid resilience options include consideration and integration of Battery Energy Storage Systems (BESS), which are becoming more common in Alaska and elsewhere.[15]

Climate change impacts that threaten the local energy supply might be mitigated with regional grid leadership and planning to help Southeast Alaska reduce environmental and climate change impacts by building and transmitting lower cost hydroelectricity to current diesel-using communities. This could possibly not only reinforce climate resiliency but also help provide economic and environmental justice.[16] As mentioned above, when hydroelectric capacity grows in Southeast Alaska and the system becomes more interconnected along a physical grid, the region could have more options for managing climate risk.[7] Moving lower-cost hydropower to displace fossil fuels in higher-cost diesel communities, cruise ship dock electrification, and mining loads reduces regional GHG emissions and enables additional community tools to deal with climate change.

Opportunities to mitigate and adapt to climate change through electrification

Juneau is turning toward clean, less expensive electricity from hydropower, and demand will increase. There are major decisions requisite to building more infrastructure for hydropower, but the need and desire are there-from EVs to heat-source air pumps, to cruise ship dock electrification, to partnering with Juneau's neighboring communities and industries. Feasibility studies and funding efforts for an interconnected power grid including the integration of Battery Energy Storage Systems (BESS), need to continue as well as hydrological modeling and integrated resource planning as Juneau responds to climate change. These areas of expansion, research, and planning provide potential opportunities for Juneau to further integrate hydropower into the CBJ's energy future.

Interconnected power grid

An increasingly interconnected power grid in Southeast Alaska might minimize climate impacts. As hydroelectric capacity increases and the system grows increasingly interconnected along a physical grid, the region may have more options for managing climate risk. Grid optimization and incorporation of BESS help stabilize grids, but also increase reliability against outages.

Continued hydrological modeling

Planning and development will require adaptation to new conditions in hydrological modeling to capture and reflect the anticipated and continued changes in seasonal precipitation caused by long-term climate change.

Integrated resource planning

IRP is a planning methodology that integrates supply and demand-side options for providing energy services at a cost that appropriately balances the interests of all stakeholders.[17] Incorporating JCAIP and JRES into a Juneau IRP would integrate climate change and beneficial electrification into Juneau's energy planning future. Alaska does not currently place IRP requirements on utilities, but it is common in other states.

Photo: A. Davey, CC BY 2.0

H. Leading a shift in transportation

DUFF MITCHELL, MANAGING DIRECTOR, JUNEAU HYDROPOWER

Juneau is a leader in US electric transportation

The rapid transition from internal combustion engines (ICE) to zero-carbon electric transportation represents an unprecedented adoption shift that is swiftly occurring worldwide and one in which Juneau has taken a US leadership role. Juneau already boasts one of America's heaviest per capita percentages of electric vehicle ownership. In 2021, Juneau's Capital Transit purchased the first electric bus for Juneau's public transportation system. Capital Transit has secured federal funding for several additional electrical buses that will provide quieter and cleaner transportation, lowering operating and maintenance costs and greenhouse gas emissions.

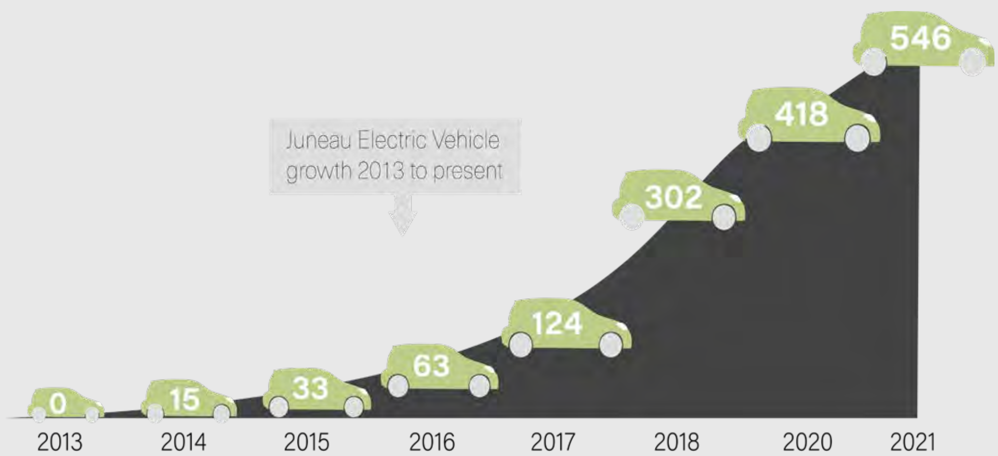
Electric alternatives for delivery trucks, construction equipment, and marine transportation represent a competitive market opportunity

Most local electrical transportation has focused on vehicles and buses, but the larger market development involves delivery trucks, mining equipment, heavy construction equipment, and marine transportation. In Alaska, 47% of the vehicles on the road are CUVs/SUVs, while 30% are pick-up trucks.[1] Few electric vehicles are sold in these market categories, but recognizably represent a large market for near-term Juneau EV adoption as more electric SUVs and pick-up truck models enter the market. Delivery trucks, heavy construction equipment, and marine transportation are also migrating to electric, with new model entries competing on life cycle and operation cost and displacing fossil fuel models.[2, 3, 4]

Marine electric transportation could mitigate climate impacts and bring cost savings

Interestingly, the conversion of Washington State's largest ferries to electric has already begun with the State of Washington VW Settlement funds.[5, 6] Similarly, BC Ferries (the British Columbia provincial ferry system) is operating an electric ferry fleet with planned expansions.[7, 8] BC Ferries has announced its intent to build seven additional battery-electric hybrid Island Class ferries in British Columbia.[9, 10] The implications of marine electric transportation for Juneau and Southeast Alaska include not only mitigation of climate change causes like greenhouse gases and effects like ocean acidification, but it could bring cost savings to the Alaska Marine Highway System comparable to those currently enjoyed by the Washington and B.C. ferry systems.

FIGURE 18: ELECTRIC VEHICLE USE IN JUNEAU
Juneau has one of the highest per capita percentages of electric vehicle ownership, with growth since 2013. Development of electric alternatives for SUVs and pick-up trucks could present a large market for local EV adoption.



Electric ferry docking infrastructure
Dock electrification should be viewed as charging stations for current and future hybrid vessels and not just used for ship hoteling needs while in port. Juneau was the first port in the world to provide visiting cruise ship industry with electricity, and the community is exploring expansion to CBJ's publicly owned docks.[11] Future Juneau and regional dock electrification may encourage and enable diesel hybrid battery systems where vessels could use shore power to charge batteries in Juneau, similar to what the Hurtigruten cruise line and the electric ferries in the Washington State and BC Ferry systems do at other ports.[12, 13] BC Ferries announced in September 2021 that it will convert one-half of its 36 operating ferries to electric.[7,14]

I. Maintaining mental health through community and recreation

LINDA KRUGER & KEVIN MAIER

Climate change impacts our mental health, with some more affected than others
The World Health Organization maintains that climate change is one of the greatest threats to global health in the 21st century.[1] While the physical drivers of climate change will impact environmental determinants of health—clean air and water, as well as food and energy security—even the awareness of anthropogenic climate change can impact mental health. Acute weather events (such as the landslides that impacted Haines in December of 2020, or more extreme Taku winds) create immediate anxiety, but more gradual changes in our environment (the recession of the Mendenhall Glacier, for example), as well as the long-term existential threat of climate change also impact mental health in ways society is just beginning to understand.[1]

These impacts are not evenly or equitably distributed. As the climate justice movement reminds us, climate change will disproportionately affect the economically and socially disadvantaged. Moreover, climate anxiety can exacerbate existing mental health issues, as well as broader socio-economic stresses; for example, we should be asking how climate change stress may compound transgenerational trauma associated with colonization.

Time in nature and access to outdoor spaces can help mitigate mental health challenges
While we monitor the mental health impacts as a community, we can also mitigate them. We know that spending time in nature can reduce stress, anxiety, depression, and the feelings of loss that often accompany change.[2,3] Parks, trails, and recreation areas take on even more importance by providing opportunities for people to connect to the greater world around them and come together with others in the community, all leading to greater individual and community resilience and increased capacity to cope with and adapt to the changes and challenges that we are facing.

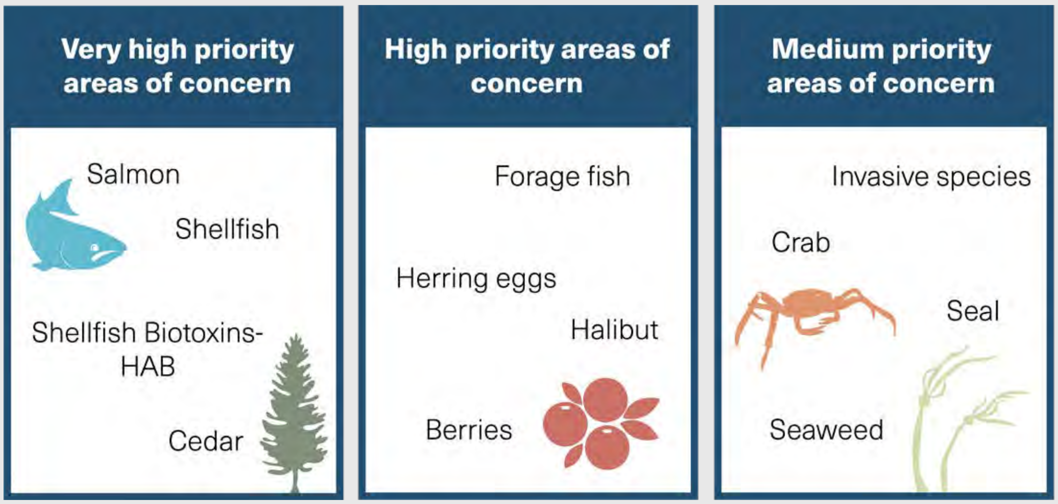
Careful planning is needed to manage the use of and impacts on recreational spaces
An increase in demand for recreational spaces has led at times to conflicts between user groups, particularly motorized vs non-motorized vehicle users on trails and vessels vs marine mammals. This is especially true for winter recreational opportunities, such as cross-country skiing at Montana Creek and in the backcountry adjacent to Eaglecrest Ski Area. Climate change needs to be carefully considered as the CBJ plans, manages, and mitigates climate impacts on recreational areas, including those along the waterfront, in low lying areas, and at the developed ski area at Eaglecrest, and the opportunities these places provide.

J. Food security

DARREN SNYDER & JIM POWELL

Wild foods and food history

Before colonization, Indigenous peoples living in the Juneau area subsisted solely on the area's abundance of wild food. Some of the more important subsistence foods threatened by climate change are highlighted in Tlingit & Haida's Climate Adaptation Plan, which includes a ranked list of specific foods and resources organized into three Key Areas of Concern. These rankings were developed using a vulnerability assessment consisting of climate impact variables, environmental stressors, and relative importance to communities. The three levels of importance are labeled Very High Priority, High Priority, and Medium Priority. For any culture with a non-hierarchical view of the natural world, this kind of value ranking is counter-intuitive; the fact that CCTHITA found it necessary to rank the foods that physically and spiritually nourish its members demonstrates the degree to which climate change is already affecting traditional hunting, fishing, and gathering activities.



Key areas of concern for local Tribes

CCTHITA's Key Areas of Concern form the basis for implementation strategies. As next steps, several actions are listed for each key area with qualitative information, including cost, ease of implementation, political/community support, timing of action, and partnerships. The fact that traditional wild food sources are now being ranked so that Indigenous people can better manage harvests under the limits imposed by climate change is a testament to the resilience of the Tlingit and Haida people. Faced with the bitter facts of change, the authors of the Climate Adaption Plan opted to tackle the situation head-on and find ways to adapt. The broader community can learn from this, as everyone in the CBJ can expect to have to adjust to changes in their food supply brought on by climate-related factors.

Juneau's cultivated food history

At the turn of the century, after Juneau was settled as a gold mining town, there were few local non-wild cultivated food sources. With the exception of a few vegetables that families grew, and a small dairy production, food was imported from out of state. Beginning in the 1890s, several dairy farms started up in Juneau. However, with the advent of air service beginning in the 1940s, and improved refrigeration, the dairy farms were no longer profitable, and by 1965 the last dairy had closed.[1]

Climate impacts and supply chain problems highlight the importance of greater food independence

Economic globalization, including advances in transportation, have dramatically changed the lifestyle of people in the CBJ and throughout Alaska. Juneau currently obtains as much as 95 percent of its food supply from out of state.[2] This is alarming, given the current stressors on food production outside of our state from climate change, COVID-19, and supply chain problems. We are starting to recognize and deal with the precarious situation we are in. We need to move toward greater food independence. Time is important for food quality--vitamins C, B, and E are all important antioxidants that are sensitive to time—spinach stored at room temperature loses between 50 and 90 percent of its vitamin C within 24 hours of being picked.[3] Yet most of our food arrives after spending at least four days on a barge from Seattle. The benefits of having an abundant and affordable locally grown food supply cannot be overemphasized. Climate change provides an opportunity and motivation to support greater local food production using new technologies, taking advantage of an extended growing season and Juneau's market for quality food.

Local food production

Juneau's climate has always presented a challenge for the plants and animals we grow for food. Cool, wet, short summers combined with brief, stormy autumns and highly variable (freeze/thaw) winters are typical in Southeast Alaska. Fortunately, this expected annual variability of seasonal conditions has already prompted a healthy degree of adaptive capacity in local growing methods. Through the use of infrastructure and innovative techniques such as raised beds, low tunnel hoops covered with visqueen or polyspun fabric, greenhouses, integration of local soil additives, and other practices, our ingenuity is already overcoming many growing challenges. Overall, these practices have resulted in improved drainage, increased soil and air temperatures, decreased pest pressure/damage, and other benefits, resulting in more successful production and harvests.

Extreme conditions reduce crop productivity and success

Even with the ability to contend with highly variable conditions, increasing challenges facing agricultural producers brought on by more pronounced annual fluctuations plus trends of factors such as rainfall, freeze/thaw cycles, snow cover, pests and diseases, confer exposure and sensitivity to climate change within our local and global agriculture production systems. These factors, which were generally not of concern for the more reliably successful crops (such as potatoes, root vegetables, berries, fruit trees, and rhubarb), can result in even these crops requiring more effort and management interventions when extreme conditions exist for longer durations. In these conditions, the most reliable crops are less productive, more marginal/difficult crops are less successful, and overall harvests are greatly reduced, with the result that personal producers get less food for their families and commercial producers get less income to cover costs. Another outcome can be frustration, with fewer people growing local food due to diminished returns on their efforts.

New methods and high demand for local products, among other factors, have led to growth in Juneau's commercial agriculture sector

Despite the short growing season and the above-mentioned challenges from climate change, the last decade has seen modest growth in Juneau's commercial agriculture sector in overall income, number of participants, and total production. A number of supportive factors have contributed, including increased market opportunities, intensified entrepreneurial efforts, innovative production methods, government support, and a strong market for fresh local products. Private gardening for personal use has also been increasing, as have community gardens and other collective grows. The days of Juneau's dairies are a thing of the past, but personal raising of smaller ruminants, meat rabbits, and especially chickens has increased.

Photos: Emily Whitney

Steps towards local food security

As discussed above, and similar to other Alaska communities, Juneau is extremely dependent on non-local foods. Moving into a future of continued and increasing success in local agricultural production while dealing with climate change (including less predictable weather), Juneau needs to

1. increase awareness of known successful food growing and processing practices;
2. study and better understand the natural, economic, and societal impacts of climate change on food security as well as the potential benefits of warmer temperatures;
3. create conditions to make growing more affordable;
4. maximize the use of inexpensive hydroelectricity for indoor and other controlled environment food production;
5. identify and develop CBJ or other land for commercial agriculture and additional community gardens;
6. as the regional hub, support local food production research, demonstration, education, and incubation programs that will positively impact current and future cultivated food producers throughout Southeast Alaska.

With the growing threat to national and global food systems, we all must adapt locally. Excellent opportunities exist to increase local food security. With a focused effort, food production can be greatly increased in Juneau and throughout Southeast Alaska.

K. Large cruise ship air emissions

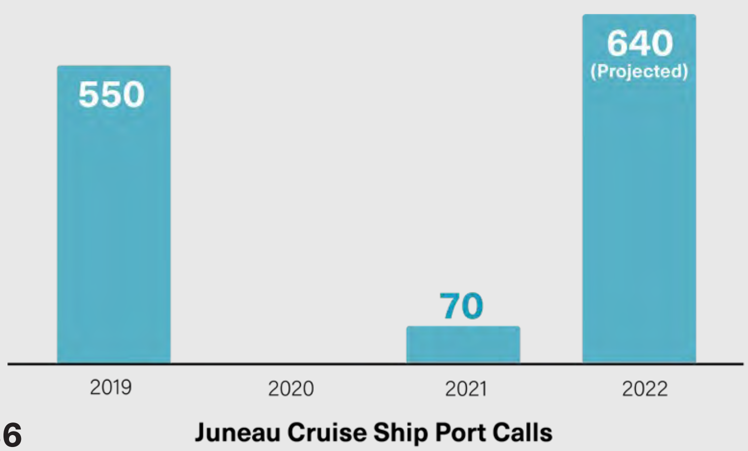
JIM POWELL

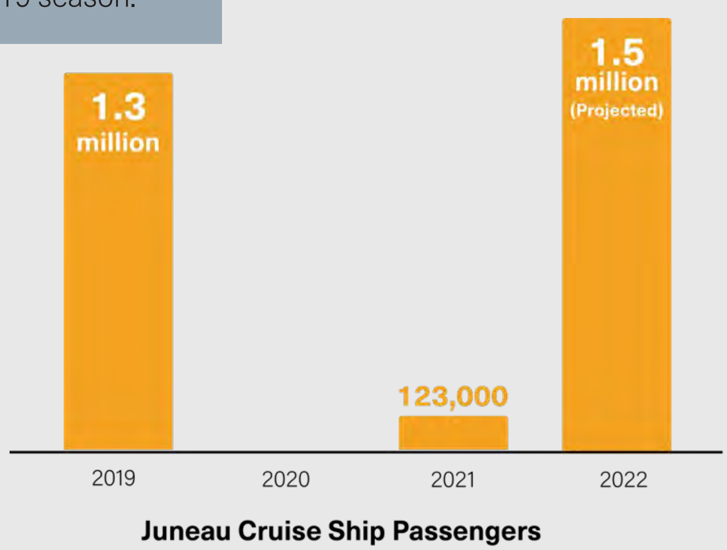
Cruise ship port calls and passengers are projected to increase

Visitors have been coming to Juneau on cruise ships since the late 1880s to enjoy the dramatic scenery, rich cultures, and wildlife of Southeast Alaska. Today, Juneau is a major global cruise ship destination with up to six large cruise ships docked or at anchor in the harbor at any one time from April to October. Carrying thousands of passengers each, the number of cruise ships visiting Juneau each year has significantly increased. In 2019, there were a record 549 port visits by large cruise ships carrying approximately 1.3 million passengers. In 2020, the COVID-19 pandemic stopped all port calls, with cruise traffic only rebounding slightly with 70 port calls in 2021.[1,2] Projections for the 2022 cruise ship season are 639 port calls, far surpassing the record 2019 season.

FIGURE 19. JUNEAU CRUISE SHIP VISITORS

The number of large cruise ship port calls in the Juneau harbor in 2022 is anticipated to be 639, far surpassing the record-breaking 2019 season.





Cruise ships are a major air pollution source

Ship emissions constitute a large, and historically poorly regulated, source of air pollution.[3] Large cruise ships burn bunker fuel oil, marine diesel oil, and marine gas oil that release substantial amounts of CO_2 and hydrocarbons, both well-known greenhouse gases, into the atmosphere.[4, 5] While in port, large cruise ships burn approximately 320 gallons of diesel fuel per hour—the equivalent of 21,000 diesel-powered trucks.[5] Early in the 2019 cruise season, cruise line companies worked with the state of Alaska to lower their emissions by reducing idle times in the harbor and switching to a low sulfur marine fuel while in port.[6] It is difficult to compare Juneau's 2019 cruise ship-related air quality impacts to previous years' as no monitoring data exists for 2018, but city officials received fewer complaints in 2019 than in the previous two years. The data collected did not identify a single maximum impact site but indicated that various parts of downtown Juneau were impacted simultaneously by emission plumes, the severity of which depended on weather conditions.[6]

Available studies show that cruising is a carbon-intensive activity; in fact, cruising has been demonstrated to be a more carbon-intensive mode of international transport than aviation.[7] Major cruise companies score low on air pollution, with all but one of the 18 companies reviewed in the Cruise Ship Report Card receiving a score of "C" or lower.[8]

Low carbon, renewable shore power will reduce emissions and improve air quality

Juneau and the state of Alaska have taken steps toward mitigating air emissions from cruise ships. The CBJ, in collaboration with Princess Cruises, led the world in 2001 as the first locality to offer land-based low carbon, renewable energy (hydropower) as a technological alternative to letting ships' engines run in port. Currently, more than 10 ports globally now have shore power. The CBJ's 2019 Visitor Industry Working Group has recommended expanding shore power to all ships, and feasibility studies are currently underway. This will greatly decrease greenhouse gas emissions while ships are in port and improve local air quality. The Working Group also recommended that regulations be established to strengthen its authority over the cruise ship industry, which has largely been managed by non-regulatory agreements such as the Tourism Best Management Practices.

International and state authorities have a significant responsibility and opportunity to mitigate greenhouse gas emissions. Consistent with the 2015 UN Paris Agreement, in 2018 the UN International Marine Organization (IMO), the regulatory body that sets standards and regulates shipping, required ships to reduce the total annual GHG emissions by at least 40% by 2030 and 70% by 2050 compared to 2008. Additionally, the UN North America Sulfur Emissions Control Area limits sulfur to 0.1%.[9] Despite these limits and a 0.50% limit on sulfur in ship fuel oil required globally in 2020 under the MARPOL Convention, to date there has been no systematic monitoring of ship discharges by public authorities, and fuel quality is very rarely monitored.[9]

L. Tourists' views on climate change mitigation

JIM POWELL

Tourists are willing to pay to decrease their ships' carbon footprint

Cruise ship tourism is largely managed through a combination of industry best management practices, regulatory agency permits and operations, and services. CBJ Resolution 2170, adopted in 2002, outlines tourism industry-related policies and is the government's guiding document. Voluntary compliance is the main tool for managing tourism in the CBJ, along with some federal, state, or local laws. A recent survey of tourists found that over 71% of adult American visitors would pay more for a vacation in order to decrease their carbon footprint.[1] This equates to more than 182 million people. Even more impressive, 33.20% of people stated they would be willing to pay up to $250 extra to lower their vacation's carbon footprint and fight climate change. This study suggests the cruise ship industry can move decisively toward deep decarbonization with strong support from its passenger base. Some of the proceeds from the passenger fee for cruise ship visitors collected by CBJ and the state could be used to monitor cruise ship GHG emissions while ships are in port.

M. Lowering greenhouse gas emissions

JIM POWELL & PEGGY WILCOX

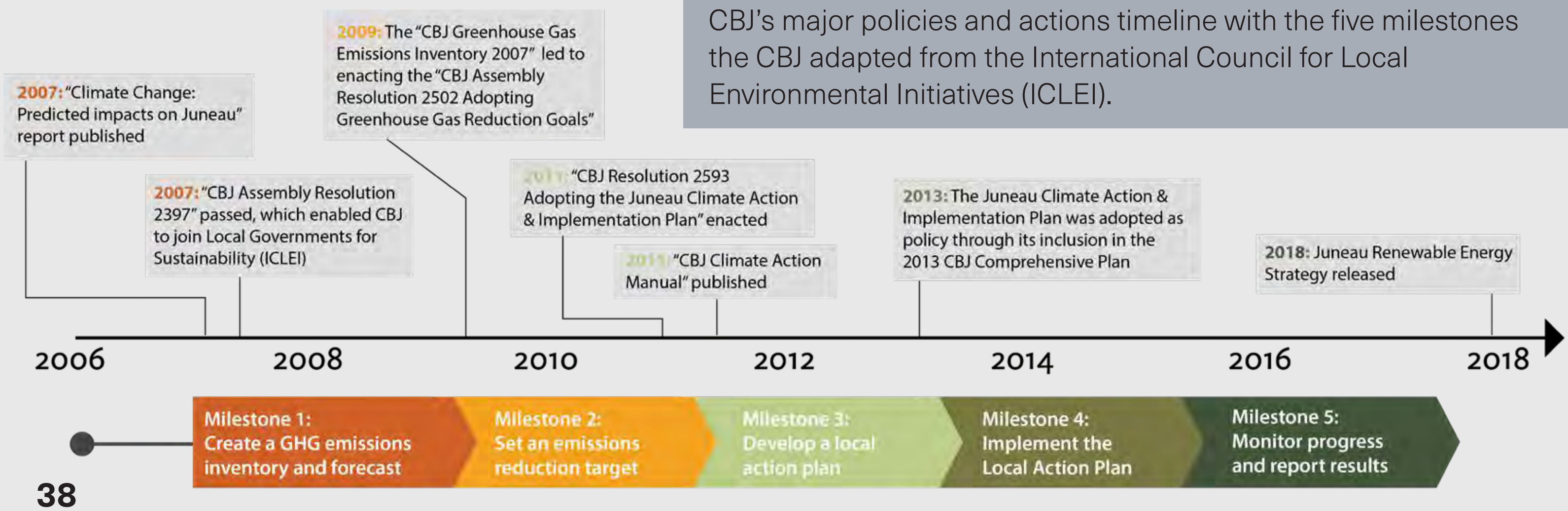
Local government authorities have a key role to play in responding to climate change, as they control vital areas and assets that affect GHG emissions, such as land-use planning, building codes and standards, transportation, energy infrastructure, waste services, and water and wastewater utilities.[1, 2, 3]

Cities are high consumers of energy and producers of waste and GHG emissions. An estimated 30-40% of human-caused GHG emissions emanate from within cities.[4] Over 50% of the world's population now lives in cities, and that amount is estimated to grow to 60% by 2030. Cities consume more than two-thirds of the world's energy and account for 75% of global GHG emissions.[5] Given their impact, communities should be leading the way to find innovative solutions to address climate change impacts—particularly in light of our polarized national government and lack of international agreement on specific and enforceable climate reduction strategies. Juneau is an active and engaged community with 19 citizen boards and commissions playing a role in local government. In 2007, the CBJ took the first step to address climate change with a scientific report titled "Predicted Impacts on Juneau," the precursor to this report. Since that time, the CBJ has issued Assembly Resolutions and policy statements, including an emission inventory, a climate change plan, and energy reduction programs. The most recent policy is contained in the 2018 Renewable Energy Strategy which calls for 80% of Juneau's energy to come from renewable sources by 2045.

Although the CBJ has produced climate change studies, policies, plans, and implementation strategies, it faces many challenges, including limited resources to make the transition to renewable energy and to adapt to climate change impacts. Most recently, the economic and health impacts from the COVID-19 pandemic and state revenue reductions have stalled much of the momentum toward implementation of the borough's climate change mitigation program. If resources and funding can be found for supporting private and public projects such as district heat for the downtown core, expanded shore power for large cruise ships, expansion of electric vehicle charging and residential and commercial air source heat pumps, and innovative programs like carbon offset, Juneau can contribute its part to lower GHG and reduce the impact of climate change.

FIGURE 20. TIMELINE OF CBJ CLIMATE CHANGE POLICIES AND ACTIONS

CBJ's major policies and actions timeline with the five milestones the CBJ adapted from the International Council for Local Environmental Initiatives (ICLEI).



N. Residents taking action

ANDY ROMANOFF & JIM POWELL

Local nonprofit organizations and partnerships are taking action to adapt to and reduce the impact of climate change

Several local nonprofit organizations have emerged during the past decade to actively fight climate change and increase access to Juneau's abundant clean, fish-friendly hydroelectric power. These nonprofits contribute to community awareness, raise funds through innovative means, and advocate for local and state climate change policy.

Education and awareness

- Organize free climate and energy education forums with expert speakers and performers
- Organize climate change rallies at the steps of the Capitol and other locations in town
- Promote clean and efficient heat pumps as an alternative to fossil fuel heating in homes and businesses

Funding and resources

- Established the Juneau Carbon Offset Fund, a carbon impact solution that directs offset purchases, grants, and donations to the replacement of fossil fuel heating systems with air source heat pumps in qualified lower income homes
- Created Juneau's first clean energy financing program by establishing a low-interest heat pump loan
- Partnered with private enterprise and the CBJ to install a system of free electric vehicle charging stations across the borough

Policy

- Advocated, educated, and worked with local decision makers and residents associated with the CBJ's Juneau Renewable Energy Strategy
- Launched Alaska's first Thermalize Campaign, an innovative program designed to accelerate adoption of air source heat pumps through a neighborhood, bulk purchasing, and streamlined process
- Advocate for the state's Permanent Fund board of directors to divest its investments in fossil fuel holdings
- Advocate for divesting the State of Alaska's retirement program funds from fossil fuel holdings
- Raise awareness of health and climate issues underpinning the urgency of electrifying Juneau's cruise ship docks to prevent large cruise ships engines from idling while in port
- Advocate for the electrification of both residential and municipal vehicle fleets, including the Capital Transit bus system
- Advocate for vulnerable people and communities most heavily impacted by climate change.

See the Appendix for a list of these organizations with their contact information.

Photo: Alaska Heat Smart

Summary and recommendations

Climate change presents a clear and present danger to our world, and local communities have a large role and responsibility to lead in reducing and adapting to its impacts. The scientific information presented in this report is intended for use by the general public and local decision makers in formulating mitigation strategies and measures.*

List of recommendations for CBJ consideration

Energy

- Develop a suite of climate change indicators to be reported to the public on progress made toward Juneau's goal of 80% renewable energy use by 2045.
- Implement recommendations included in CBJ's Renewable Energy Strategy.
- Support centralized renewable energy plants such as district heating.
- Provide financial incentives for installing residential and commercial air source heat pumps.
- Adapt the 2021 International Energy Conservation Code (IECC) standards.

Large cruise ship emissions

- Implement the recommendations of the CBJ's Tourism Working Group, including the installation of shore power for 100% of large cruise ships.
- Limit the number of cruise ships in port at one time to five.
- Measure, monitor, and publicly report GHG emissions of large cruise ships while in port.

Food security

- Increase awareness of known successful food growing and processing practices.
- Study and better understand the natural, economic, and societal impacts of climate change, such as food insecurity and supply chain issues, as well as the potential agricultural opportunities climate change may bring.
- Create initiatives to make local food growing more affordable.
- Maximize the use of inexpensive hydroelectricity for indoor and other controlled-environment food production.
- Identify and develop CBJ or other land for commercial agriculture and additional community gardens.
- As the regional hub, support local food production research, demonstrations, education, and incubation programs to positively impact current and future food cultivators throughout Southeast Alaska.

*The following recommendations represent the views of the authors and are not necessarily supported by the University of Alaska Southeast.

References

Welcome (Tom Thornton)

[1] United Nations Environment Programme. (2022). GOAL 13: Climate action. UNEP - UN Environment Programme. https://unstats.un.org/sdgs/report/2020/goal-13/

Introduction (Bruce Botelho)

[1] Keeling, C. D. (1958). The concentration and isotopic abundances of atmospheric carbon dioxide in rural areas. *Geochimica et Cosmochimica Acta, 13*(4), 322–334. https://doi.org/10.1016/0016-7037(58)90033-4

What we're experiencing: Atmospheric, marine, terrestrial, and ecological effects

A.4. Less snow (Eran Hood)

[1] Shanley, C. S., Pyare, S., Goldstein, M. I., Alaback, P. B., Albert, D. M., Beier, C. M., Brinkman, T. J., Edwards, R. T., Hood, E., MacKinnon, A., McPhee, M. V., Patterson, T. M., Suring, L. H., Tallmon, D. A., & Wipfli, M. S. (2015). Climate change implications in the northern coastal temperate rainforest of North America. *Climatic Change, 130*(2), 155–170. https://doi.org/10.1007/s10584-015-1355-9

[2] Nolin, A. W., & Daly, C. (2006). Mapping "At Risk" Snow in the Pacific Northwest. *Journal of Hydrometeorology, 7*(5), 1164–1171. https://doi.org/10.1175/JHM543.1

B.1. Surface uplift and sea level rise (Eran Hood)

[1] Motyka, R., Larsen, C. F., Freymueller, J. T., & Echelmeyer, K. A. (2007). Post Little Ice Age Glacial Rebound in Glacier Bay National Park and Surrounding Areas. *Alaska Park Science, 6(*1), 36-41. https://www.nationalparkstraveler.org/sites/default/files/legacy_files/GLBA-Uplift.pdf

[2] Hu, Y., & Freymueller, J. T. (2019). Geodetic Observations of Time-Variable Glacial Isostatic Adjustment in Southeast Alaska and Its Implications for Earth Rheology. *Journal of Geophysical Research, 124*(9), 9870–9889. https://doi.org/10.1029/2018JB017028

B.2. Extensive effects of a warming ocean (Heidi Pearson)

[1] Dorn, M., Cunningham, C., Dalton M., Fadely, B., Gerke, B., Hollowed, A., Holsman, K., Moss, J., Ormseth, O., Palsson, W., Ressler, P., Rogers, L., Sigler, M., Stabeno, P., & Szymkowiak, M. (2018). A Climate Science: Regional Action Plan for the Gulf of Alaska. NOAA Technical Memorandum NMFS-AFSC, 376. https://repository.library.noaa.gov/view/noaa/17539

[2] Joh, Y., & Di Lorenzo, E. (2017). Increasing Coupling Between NPGO and PDO Leads to Prolonged Marine Heatwaves in the Northeast Pacific. *Geophysical Research Letters, 44*(22), 11,663-11,671. https://doi.org/10.1002/2017GL075930

[3] Frölicher, T. L., Fischer, E. M., & Gruber, N. (2018). Marine heatwaves under global warming. *Nature, 560*(7718), 360–364. https://doi.org/10.1038/s41586-018-0383-9

[4] Cornwall, W. (2019). Ocean heat waves like the Pacific's deadly "Blob" could become the new normal. *Science*

News, Jan. 21, 8.

[5] Weingartner, T., Eisner, L., Eckert, G. L., & Danielson, S. (2009). Southeast Alaska: oceanographic habitats and linkages. *Journal of Biogeography, 36*(3), 387–400. https://doi.org/10.1111/j.1365-2699.2008.01994.x

[6] Whitney, F. A. (2015). Anomalous winter winds decrease 2014 transition zone productivity in the NE Pacific. *Geophysical Research Letters, 42*(2), 428–431. https://doi.org/10.1002/2014GL062634

[7] L'Heureux, M. L., Takahashi, K., Watkins, A. B., Barnston, A. G., Becker, E. J., Di Liberto, T. E., Gamble, F., Gottschalck, J., Halpert, M. S., Huang, B., Mosquera-Vásquez, K., & Wittenberg, A. T. (2017). Observing and Predicting the 2015/16 El Niño. *Bulletin of the American Meteorological Society, 98*(7), 1363–1382. https://journals.ametsoc.org/view/journals/bams/98/7/bams-d-16-0009.1.xml

[8] Cartwright, R., Venema, A., Hernandez, V., Wyels, C., Cesere, J., & Cesere, D. (2019). Fluctuating reproductive rates in Hawaii's humpback whales, Megaptera novaeangliae, reflect recent climate anomalies in the North Pacific. *Royal Society Open Science, 6*(3), 181463. https://doi.org/10.1098/rsos.181463

[9] Kintisch, E. (2015). Climate crossroads. *Science, 350*(6264), 1016-1017. https://www.science.org/doi/abs/10.1126/science.350.6264.1016

[10] Lorenzo, E. D., & Mantua, N. J. (2016). Multi-year persistence of the 2014/15 North Pacific marine heatwave. *Nature Climate Change, 6*, 1042–1047. https://www.nature.com/articles/nclimate3082

[11] Walsh, J. E., Thoman, R. L., Bhatt, U. S., Bieniek, P. A., Brettschneider, B., Brubaker, M., Danielson, S., Lader, R., Fetterer, F., Holderied, K., Iken, K., Mahoney, A., McCammon, M., & Partain, J. (2018). The High Latitude Marine Heat Wave of 2016 and Its Impacts on Alaska. *Bulletin of the American Meteorological Society, 99*(1), S39–S43. https://doi.org/10.1175/BAMS-D-17-0105.1

[12] van Klink, R., Bowler, D. E., Gongalsky, K. B., Swengel, A. B., Gentile, A., & Chase, J. M. (2020). Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science, 368*(6489), 417–420. https://doi.org/10.1126/science.aax9931

[13] Rogers, L. A., Wilson, M. T., Duffy-Anderson, J. T., Kimmel, D. G., & Lamb, J. F. (2021). Pollock and "the Blob": Impacts of a marine heatwave on walleye pollock early life stages. *Fisheries Oceanography, 30*(2), 142–158. https://doi.org/10.1111/fog.12508

[14] Barbeaux, S. J., Holsman, K., & Zador, S. (2020). Marine Heatwave Stress Test of Ecosystem-Based Fisheries Management in the Gulf of Alaska Pacific Cod Fishery. *Frontiers in Marine Science, 7*, 703. https://doi.org/10.3389/fmars.2020.00703

[15] Piatt, J. F., Parrish, J. K., Renner, H. M., Schoen, S. K., Jones, T. T., Arimitsu, M. L., Kuletz, K. J., Bodenstein, B., García-Reyes, M., Duerr, R. S., Corcoran, R. M., Kaler, R. S. A., McChesney, G. J., Golightly, R. T., Coletti, H. A., Suryan, R. M., Burgess, H. K., Lindsey, J., Lindquist, K., Warzybok, P., Jahncke, J., Roletto, J., & Sydeman, W. J. (2020). Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016. *PLoS ONE, 15*(1), e0226087. https://doi.org/10.1371/journal.pone.0226087

[16] Van Hemert, C., Schoen, S. K., Litaker, R. W., Smith, M. M., Arimitsu, M. L., Piatt, J. F., Holland, W. C., Ransom Hardison, D., & Pearce, J. M. (2020). Algal toxins in Alaskan seabirds: Evaluating the role of saxitoxin and domoic acid in a large-scale die-off of Common Murres. *Harmful Algae, 92*, 101730. https://pubs.er.usgs.gov/publication/70207572

[17] Savage, K. (2017). Alaska and British Columbia large whale unusual mortality event summary report. NOAA Institute Repository: 17715. https://repository.library.noaa.gov/view/noaa/17715

[18] Neilson, J. L., Gabriele, C. M., & Taylor-Thomas, L. F. (2018). Humpback Whale Monitoring in Glacier Bay and Adjacent Waters 2017: Annual progress report. (NPS/GLBA/NRR—2018/1660). National Park Service. https://irma.nps.gov/DataStore/DownloadFile/602012

[19] Neilson, J. L., & Gabriele, C. M. (2020). Glacier Bay & Icy Strait Humpback Whale Population Monitoring: 2019 Update. National Park Service Resource Brief. Gustavus, Alaska. https://irma.nps.gov/DataStore/DownloadFile/640111

[20] McDowell Group. (2020). Economic Analysis of Whale Watching Tourism in Alaska. Prepared for NOAA Fisheries (Alaska). https://media.fisheries.noaa.gov/2020-11/Economic-Analysis-Whale-Watching-Tourism-Alaska.pdf?VersionId=null

[21] Grémillet, D., Fort, J., Amélineau, F., Zakharova, E., Le Bot, T., Sala, E., & Gavrilo, M. (2015). Arctic warming: nonlinear impacts of sea-ice and glacier melt on seabird foraging. *Global Change Biology, 21*(3), 1116–1123. https://doi.org/10.1111/gcb.12811

[22] Hazen, E. L., Abrahms, B., Brodie, S., Carroll, G., Jacox, M. G., Savoca, M. S., Scales, K. L., Sydeman, W. J., & Bograd, S. J. (2019). Marine top predators as climate and ecosystem sentinels. *Frontiers in Ecology and the Environment, 17*(10), 565–574. https://doi.org/10.1002/fee.2125

[23] Ward, E. J., Adkison, M., Couture, J., Dressel, S. C., Litzow, M. A., Moffitt, S., Hoem Neher, T., Trochta, J., & Brenner, R. (2017). Evaluating signals of oil spill impacts, climate, and species interactions in Pacific herring and Pacific salmon populations in Prince William Sound and Copper River, Alaska. *PLoS ONE, 12*(3), e0172898. https://doi.org/10.1371/journal.pone.0172898

B.3. Increasing ocean acidification (Robert Foy)

[1] Caldeira, K., & Wickett, M. E. (2003). Anthropogenic carbon and ocean pH. *Nature*, 425, 365. https://doi.org/10.1038/425365a

[2] Fabry, V., McClintock, J., Mathis, J., & Grebmeier, J. (2009). Ocean Acidification at High Latitudes: The Bellwether. *Oceanography, 22*(4), 160–171. https://doi.org/10.5670/oceanog.2009.105

[3] Pilcher, D. J., Siedlecki, S. A., Hermann, A. J., Coyle, K. O., Mathis, J. T., & Evans, W. (2018). Simulated Impact of Glacial Runoff on CO_2 Uptake in the Gulf of Alaska. *Geophysical Research Letters, 45*(2), 880–890. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL075910

[4] Alaska Ocean Observing System. https://aoos.org/

[5] Alaska Ocean Acidification Network. (2019). Ocean Acidification: an annual update on the state of ocean acidification in Alaska. https://aoos.org/wp-content/uploads/2019/12/2019_OA_Science_Update_medres.pdf

[6] Cai, W.-J., Feely, R. A., Testa, J. M., Li, M., Evans, W., Alin, S. R., Xu, Y.-Y., Pelletier, G., Ahmed, A., Greeley, D. J., Newton, J. A., & Bednaršek, N. (2021). Natural and Anthropogenic Drivers of Acidification in Large Estuaries. *Annual Review of Marine Science, 13*(1), 23–55. https://doi.org/10.1146/annurev-marine-010419-011004

[7] Long, W.C., Swiney, K. M., & Foy, R. J. (2013). Effects of ocean acidification on the embryos and larvae of red king crab, *Paralithodes camtschaticus*. *Marine Pollution Bulletin, 69*(1–2), 38–47. https://doi.org/10.1016/j.

marpolbul.2013.01.011

[8] Long, W. C., Swiney, K. M., Harris, C., Page, H. N., & Foy, R. J. (2013). Effects of Ocean Acidification on Juvenile Red King Crab (*Paralithodes camtschaticus*) and Tanner Crab (*Chionoecetes bairdi*) Growth, Condition, Calcification, and Survival. *PLoS ONE, 8*(4), e60959. https://doi.org/10.1371/journal.pone.0060959

[9] Bednaršek, N., Feely, R. A., Howes, E. L., Hunt, B. P. V., Kessouri, F., León, P., Lischka, S., Maas, A. E., McLaughlin, K., Nezlin, N. P., Sutula, M., & Weisberg, S. B. (2019). Systematic Review and Meta-Analysis Toward Synthesis of Thresholds of Ocean Acidification Impacts on Calcifying Pteropods and Interactions With Warming. *Frontiers in Marine Science, 6*, 227. https://doi.org/10.3389/fmars.2019.00227

[10] Doubleday, A. J., & Hopcroft, R. R. (2015). Interannual patterns during spring and late summer of larvaceans and pteropods in the coastal Gulf of Alaska, and their relationship to pink salmon survival. *Journal of Plankton Research, 37*(1), 134–150. https://doi.org/10.1093/plankt/fbu092

[11] Williams, C. R., Dittman, A. H., McElhany, P., Busch, D. S., Maher, M. T., Bammler, T. K., MacDonald, J. W., & Gallagher, E. P. (2019). Elevated CO_2 impairs olfactory-mediated neural and behavioral responses and gene expression in ocean-phase coho salmon (*Oncorhynchus kisutch*). *Global Change Biology, 25*(3), 963–977. https://doi.org/10.1111/gcb.14532

[12] Mathis, J. T., Cooley, S. R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T., Hauri, C., Evans, W., Cross, J. N., & Feely, R. A. (2015). Ocean acidification risk assessment for Alaska's fishery sector. *Progress in Oceanography, 136*, 71–91. https://doi.org/10.1016/j.pocean.2014.07.001

[13]Evans, W., Lebon, G. T., Harrington, C. D., Takeshita, Y., Bidlack, A. (2022) Marine CO2 system variability along the northeast Pacific Inside Passage determined from an Alaskan ferry. *Biogeosciences, 19,* 1277–1301. https://doi.org/10.5194/bg-19-1277-2022

C.1. More landslides (Sonia Nagorski and Aaron Jacobs)

[1] Tetra Tech. (2021). Downtown Juneau Landslide and Avalanche Assessment, 3rd draft. May 28. (Commissioned by City and Borough of Juneau) File: ENG.EARC03168-01. https://juneau.org/wp-content/uploads/2021/07/Downtown_Juneau_Landslide_and_Avalanche_Assessment_IFR_Report_Third%20Draft_Reduced.pdf

[2] Bogaard, T. A., & Greco, R. (2016). Landslide hydrology: From hydrology to pore pressure. *WIREs Water, 3*(3), 439–459. https://doi.org/10.1002/wat2.1126

[3] Sharma, A. R., & Déry, S. J. (2020). Contribution of atmospheric rivers to annual, seasonal, and extreme precipitation across British Columbia and Southeastern Alaska. *Journal of Geophysical Research: Atmospheres, 125*(9). https://doi.org/10.1029/2019JD031823

[4] Waliser, D., & Guan, B. (2017). Extreme winds and precipitation during landfall of atmospheric rivers. *Nature Geoscience, 10*(3), 179–183. https://doi.org/10.1038/ngeo2894

[5] Tan, Y., Zwiers, F., Yang, S., Li, C., & Deng, K. (2020). The Role of Circulation and Its Changes in Present and Future Atmospheric Rivers over Western North America. *Journal of Climate, 33*(4), 1261–1281. https://journals.ametsoc.org/view/journals/clim/33/4/jcli-d-19-0134.1.xml

[6] McFarland, H., Walsh, J., & Thoman, R. (2019). Alaska's changing environment: documenting Alaska's physical and biological changes through observations. https://doi.org/10.13140/RG.2.2.24481.15209

[7] Lader, R., Bidlack, A., Walsh, J. E., Bhatt, U. S., & Bieniek, P. A. (2020). Dynamical Downscaling for Southeast Alaska: Historical Climate and Future Projections. *Journal of Applied Meteorology and Climatology, 59*(10), 1607–1623. https://doi.org/10.1175/JAMC-D-20-0076.1

C.2. Mendenhall Glacier continues to retreat (Jason Amundson)

[1] Motyka, R. J., O'Neel, S., Connor, C. L., & Echelmeyer, K. A. (2003). Twentieth century thinning of Mendenhall Glacier, Alaska, and its relationship to climate, lake calving, and glacier run-off. *Global and Planetary Change, 35*(1–2), 93–112. https://doi.org/10.1016/S0921-8181(02)00138-8

[2] Larsen, C. (2020). IceBridge UAF Lidar Scanner L1B Geolocated Surface Elevation Triplets, Version 1. [Data set]. NASA National Snow and Ice Data Center DAAC. https://doi.org/10.5067/AATE4JJ91EHC

[3] USGS Earth Resources Observation and Science (EROS) Center. (2018). USGS EROS Archive—Digital Elevation—Interferometric Synthetic Aperture Radar (IFSAR)—Alaska. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-interferometric-synthetic-aperture-radar

[4] Farinotti, D., Huss, M., Fürst, J. J., Landmann, J., Machguth, H., Maussion, F., & Pandit, A. (2019). A consensus estimate for the ice thickness distribution of all glaciers on Earth. *Nature Geoscience, 12*(3), 168–173. https://www.nature.com/articles/s41561-019-0300-3

[5] Kienholz, C., Pierce, J., Hood, E., Amundson, J. M., Wolken, G. J., Jacobs, A., Hart, S., Wikstrom Jones, K., Abdel-Fattah, D., Johnson, C., & Conaway, J. S. (2020). Deglacierization of a Marginal Basin and Implications for Outburst Floods, Mendenhall Glacier, Alaska. *Frontiers in Earth Science, 8*, 137. https://doi.org/10.3389/feart.2020.00137

C.3. Tongass Forest Impacts and Carbon (Dave D'Amore)

[1] U.S. Forest Service. Addressing Climate Change on the Tongass. Issue Paper, June 2010. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5252603.pdf

[2] Bisbing, S. M., Cooper, D. J., D'Amore, D. V., & Marshall, K. N. (2016). Determinants of conifer distributions across peatland to forest gradients in the coastal temperate rainforest of southeast Alaska. *Ecohydrology, 9*(2), 354–367. https://doi.org/10.1002/eco.1640

[3] Hennon, P. E., D'Amore, D. V., Schaberg, P. G., Wittwer, D. T., & Shanley, C. S. (2012). Shifting Climate, Altered Niche, and a Dynamic Conservation Strategy for Yellow-Cedar in the North Pacific Coastal Rainforest. *BioScience, 62*(2), 147–158. https://doi.org/10.1525/bio.2012.62.2.8

[4] D'Amore, D. V., Hennon, P. E., Schaberg, P. G., & Hawley, G. J. (2009). Adaptation to exploit nitrate in surface soils predisposes yellow-cedar to climate-induced decline while enhancing the survival of western redcedar: A new hypothesis. *Forest Ecology and Management, 258*(10), 2261–2268. https://doi.org/10.1016/j.foreco.2009.03.006

[5] Schaberg, P. G., D'Amore, D. V., Hennon, P. E., Halman, J. M., & Hawley, G. J. (2011). Do limited cold tolerance and shallow depth of roots contribute to yellow-cedar decline? *Forest Ecology and Management, 262*(12), 2142–2150. https://doi.org/10.1016/j.foreco.2011.08.004

[6] Krapek, J., Hennon, P. E., D'Amore, D. V., & Buma, B. (2017). Despite available habitat at range edge, yellow-cedar migration is punctuated with a past pulse tied to colder conditions. *Diversity and Distributions, 23*(12), 1381–1392. https://doi.org/10.1111/ddi.12630

[7] USDA Forest Service. (2020). Forest Health Conditions in Alaska – 2020. U.S. Department of Agriculture,

Forest Service, Alaska Region. Publication R10-PR-46. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd903361.pdf

[8] Leighty, W. W., Hamburg, S. P., & Caouette, J. (2006). Effects of Management on Carbon Sequestration in Forest Biomass in Southeast Alaska. *Ecosystems, 9*(7), 1051–1065. https://doi.org/10.1007/s10021-005-0028-3

[9] Jackson, R. B., Lajtha, K., Crow, S. E., Hugelius, G., Kramer, M. G., & Piñeiro, G. (2017). The Ecology of Soil Carbon: Pools, Vulnerabilities, and Biotic and Abiotic Controls. *Annual Review of Ecology, Evolution, and Systematics, 48*(1), 419–445. https://doi.org/10.1146/annurev-ecolsys-112414-054234

[10] Schmidt, M. W. I., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D. A. C., Nannipieri, P., Rasse, D. P., Weiner, S., & Trumbore, S. E. (2011). Persistence of soil organic matter as an ecosystem property. *Nature, 478*(7367), 49–56. https://doi.org/10.1038/nature10386

[11] McNicol, G., Bulmer, C., D'Amore, D., Sanborn, P., Saunders, S., Giesbrecht, I., Arriola, S. G., Bidlack, A., Butman, D., & Buma, B. (2019). Large, climate-sensitive soil carbon stocks mapped with pedology-informed machine learning in the North Pacific coastal temperate rainforest. *Environmental Research Letters*, 14(1), 014004. https://iopscience.iop.org/article/10.1088/1748-9326/aaed52

[12] Fellman, J. B., D'Amore, D. V., Hood, E., & Cunningham, P. (2017). Vulnerability of wetland soil carbon stocks to climate warming in the perhumid coastal temperate rainforest. *Biogeochemistry, 133*(2), 165–179. https://www.fs.fed.us/pnw/pubs/journals/pnw_2017_fellman001.pdf

[13] Edwards, R. T., D'Amore, D. V., Biles, F. E., Fellman, J. B., Hood, E. W., Trubilowicz, J. W., & Floyd, W. C. (2021). Riverine Dissolved Organic Carbon and Freshwater Export in the Eastern Gulf of Alaska. *Journal of Geophysical Research: Biogeosciences, 126*(1). https://doi.org/10.1029/2020JG005725

[14] Sergeant, C. J., Bellmore, J. R., McConnell, C., & Moore, J. W. (2017). High salmon density and low discharge create periodic hypoxia in coastal rivers. *Ecosphere, 8*(6). https://doi.org/10.1002/ecs2.1846

D.1. Terrestrial vertebrates in Áak'w & T'aakú Aaní (Richard Carstensen)

[1] Carstensen, R., Wilson, M., & Armstrong, R. (2003). Habitat use of amphibians in northern Southeast Alaska. *Juneau Nature*. http://juneaunature.discoverysoutheast.org/content_item/habitat-use-of-amphibians-in- northern-southeast-alaska/

[2] White, K., Levi, T., Breen, J., Britt, M., Merondun, J., Martchenko, D., Shakeri, Y., Porter, B., & Shafer, A. (2021). Integrating Genetic Data and Demographic Modeling to Facilitate Conservation of Small, Isolated Mountain Goat Populations. *Journal of Wildlife Management, 85*(2), 271-282. https://doi.org/10.1002/jwmg.21978

[3] Morris Animal Foundation. (2020). New Probiotic Solution Could Treat Amphibian Fungal Disease in Boreal Toads. (June 9) https://www.morrisanimalfoundation.org/article/new-probiotic-solution-could-treat-amphibian-fungal-disease-boreal-toads

[4] Goulson, D. (2019). The insect apocalypse, and why it matters. *Current Biology, 29*(19), R967–R971. https://www.sciencedirect.com/science/article/pii/S0960982219307961

[5] van Klink, R., Bowler, D. E., Gongalsky, K. B., Swengel, A. B., Gentile, A., & Chase, J. M. (2020). Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science, 368*(6489), 417–420. https://doi.org/10.1126/science.aax9931

D.3. Insects (Bob Armstrong)

[1] Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE, 12*(10), e0185809. https://doi.org/10.1371/journal.pone.0185809

What we're doing: Community response

E. Upgrading infrastructure and mitigation (Katie Koester)

[1] KTOO News Department. (2020). Record rain brings floods and mudslides to Juneau. December 2. https://www.ktoo.org/2020/12/02/record-rain-brings-floods-and-mudslides-to-juneau/

[2] Federal Emergency Management Agency. (2021). Preliminary Damage Assessment Report. FEMA-4585-DR. https://www.fema.gov/sites/default/files/documents/PDAReport_FEMA4585DR-AK.pdf

[3] City and Borough of Juneau. (2011). Juneau Climate Action and Implementation Plan. https://juneau.org/wp-content/uploads/2017/03/CAP_Final_Nov_14.pdf

[4] Juneau Commission on Sustainability. (2017). Juneau Renewable Energy Strategy (JRES) Draft Plan 2017. (July 7). https://juneau.org/community-development/jcos-deprecated/renewable-energy-strategy

[5] Tetra Tech. (2021). Downtown Juneau Landslide and Avalanche Assessment, 3rd draft. May 28. (Commissioned by City and Borough of Juneau) File: ENG.EARC03168-01. https://juneau.org/wp-content/uploads/2021/07/Downtown_Juneau_Landslide_and_Avalanche_Assessment_IFR_Report_Third%20Draft_Reduced.pdf

G. Growing demand for hydropower (Duff Mitchell)

[1] Federal Energy Regulatory Commission. (2016). *Final Environmental Impact Statement for the Sweetheart Lake Hydroelectric Project* (P-13563-003) (May 31). https://www.ferc.gov/final-environmental-impact-statement-sweetheart-lake-hydroelectric-project-p-13563-003-issued-may

[2] Juneau Commission on Sustainability. (2017). Juneau Renewable Energy Strategy (JRES) Draft Plan 2017. (July 7). https://juneau.org/community-development/jcos-deprecated/renewable-energy-strategy

[3] Mai, T. T., Jadun, P., Logan, J. S., McMillan, C. A., Muratori, M., Steinberg, D. C., Vimmerstedt, L. J., Haley, B., Jones, R., & Nelson, B. (2018). *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71500, 1459351. https://www.nrel.gov/docs/fy18osti/71500.pdf

[4] Environmental and Energy Study Institute (EESI). (n.d.). Beneficial Electrification. https://www.eesi.org/electrification/be

[5] Blackshear, B., Crocker, T., Drucker, E., Filoon, J., Knelman, J., & Skiles, M. (2011). Hydropower Vulnerability and Climate Change: A Framework for Modeling the Future of Global Hydroelectric Resources. Middlebury College Environmental Studies Senior Seminar. https://www.academia.edu/3119763/Hydropower_Vulnerability_and_Climate_Change

[6] Markoff, M. S., & Cullen, A. C. (2008). Impact of climate change on Pacific Northwest hydropower. *Climatic Change, 87*(3–4), 451–469. https://doi.org/10.1007/s10584-007-9306-8
[7] U.S. Dept of Energy. (2017). 2nd Report to Congress on Effects of Climate Change on Federal Hydropower.

https://www.energy.gov/sites/prod/files/2017/01/f34/Effects-Climate-Change-Federal-Hydropower-Program.pdf

[8] Cherry, J. E., Walker, S., Fresco, N., Trainor, S., & Tidwell, A. (2010). Impacts of Climate Change and Variability on Hydropower in Southeast Alaska: Planning for a Robust Energy Future. NOAA IR 17388. https://repository.library.noaa.gov/view/noaa/17388

[9] Amir Jabbari, A., & Nazemi, A. (2019). Alterations in Canadian Hydropower Production Potential Due to Continuation of Historical Trends in Climate Variables. *Resources, 8*(4), 163. https://doi.org/10.3390/resources8040163

[10] Jacobs, A., & Thoman, R. (n.d.). Drought in A Rainforest...How Can That Be?? Alaska Center for Climate Assessment and Policy, PowerPoint presentation. https://www.climatehubs.usda.gov/sites/default/files/Aaron%20Jacobs%20Drought%20in%20a%20Rainforest.pdf

[11] Leffler, J. (2019). SEAPA approves $850,000 for Petersburg and Wrangell diesel use. KSTK. June 20. https://www.kstk.org/2019/06/20/seapa-approves-850000-for-petersburg-and-wrangell-diesel-use/

[12] U.S. Government Accountability Office. (2021). Electricity Grid Resilience: Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions. GAO-21-46. https://www.gao.gov/assets/gao-21-346.pdf

[13] Ibid.

[14] Chang, J. & Pfeifenberger, J. (2016). Well-Planned Electric Transmission Saves Customer Costs: Improved Transmission Planning Is Key to the Transition to a Carbon Constrained Future. The Brattle Group, PowerPoint presentation. https://www.brattle.com/wp-content/uploads/2017/10/7235_well-planned_electric_transmission_saves_customers_costs_ppt.pdf

[15] Elgqvist, E. (2021). Battery Storage for Resilience. *Resilient Energy Platform*. NREL/TP-7A40-79850, National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy21osti/79850.pdf

[16] U.S. EPA. (2020) Environmental Annual Environmental Justice Progress Report FY 2020. https://www.epa.gov/sites/default/files/2021-01/documents/2020_ej_report-final-web-v4.pdf

[17] Wilson, R. & Biewald, B. (2013). Best Practices in Electric Utility Integrated Resource Planning. Regulatory Assistance Project (RAP). Synergy Energy Economics, Inc. https://www.raponline.org/knowledge-center/best-practices-in-electric-utility-integrated- resource-planning/

H. Leading a shift in transportation (Duff Mitchell)

[1] Gross, B. K. (2020). 2030: At least 1 in 5 vehicles must be EV. What will it take? Rocky Mountain Institute. https://www.cargroup.org/wp-content/uploads/2020/09/Britta-Presentation.pdf

[2] Domonoske, C. (2021). From Amazon To FedEx, The Delivery Truck Is Going Electric. NPR, March 17. https://www.npr.org/2021/03/17/976152350/from-amazon-to-fedex-the-delivery-truck-is-going-electric

[3] Forsgren, M., Östgren, E., & Tschiesner, A. (2019). Harnessing Momentum for electrifying heavy machinery and equipment. McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/harnessing-momentum-for-electrification-in-heavy-machinery-and-equipment

[4] Infineon. (2021). Why ships of the future will run on electricity. https://www.infineon.com/cms/en/discoveries/

electrified-ships/#:~:text=One%20advantage%20of%20battery%20operation,reach%20%2420%20billion%20by%202027

[5] Washington State Ferries System Electrification Plan. (2020). WSDOT. https://wsdot.wa.gov/sites/default/files/2021-11/WSF-SystemElectrificationPlan-December2020.pdf

[6] Sterling, I. (2019). New funding secured for cleaner, greener ferries. WSDOT. https://wsdot.wa.gov/about/news/2019/new-funding-secured-cleaner-greener-ferries

[7] Banks, K. (2021). In an exclusive interview, BC Ferries CEO Mark Collins outlines his plan to convert at least half of the operator's 36-vessel fleet to electric, updates his pitch for government support, and reflects on a disappointing lack of interest from Canadian shipyards. Electric Autonomy Canada. https://electricautonomy.ca/2021/09/11/bc-ferries-new-hybrid-electric-vessels/

[8] Schisler, C. (2021). BC Ferries aims to have 12-14 fully electric vessels by 2032. *Oak Bay News*, August 21. https://www.oakbaynews.com/news/bc-ferries-aims-to-have-12-14-fully-electric-vessels-by-2032/

[9] BC Ferries. (2020). Island Class Ferries 2020. https://www.bcferries.com/in-the-community/projects/island-class-ferries-2020

[10] Chan, K. (2021). BC Ferries proposes building 7 additional electric-battery ships in Canada. *Daily Hive,* February 2. https://dailyhive.com/vancouver/bc-ferries-island-class-vessels-electrification-canada-strategy

[11] Renewable Juneau. (2021). Juneau All Aboard with Creation of a 'No Idle Zone' for Ships. https://renewablejuneau.org/2021/07/29/juneau-all-aboard-with-creation-of-a-no-idle-zone-for-ships/

[12] Hurtigrutin Expeditions. (n.d.). Hybrid Electric–Powered Ships. https://www.hurtigruten.com/our-ships/ms-roald-amundsen/hybrid-electricpowered-ship/

[13] Sterling, I. (2019). New funding secured for cleaner, greener ferries. WSDOT. https://wsdot.wa.gov/about/news/2019/new-funding-secured-cleaner-greener-ferries

[14] Schisler, C. (2021). BC Ferries aims to have 12-14 fully electric vessels by 2032. *Oak Bay News*, August 21. https://www.oakbaynews.com/news/bc-ferries-aims-to-have-12-14-fully-electric-vessels-by-2032/

I. Maintaining mental health through community and recreation (Linda Kruger and Kevin Maier)

[1] Cianconi, P., Betrò, S., & Janiri, L. (2020). The Impact of Climate Change on Mental Health: A Systematic Descriptive Review. *Frontiers in Psychiatry, 11*(74). https://doi.org/10.3389/fpsyt.2020.00074

[2] Kruger, L. (Ed.). (2010). Healthy Communities: Improving Health and Well-Being. *Rural Connections, 5*(1). Western Rural Development Center. https://www.usu.edu/wrdc/files/news-publications/RC-Sept-2010.pdf

[3] Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn Jr, P. H., Lawler, J. J., Levin, P. S., Tandon, P. S., Varanasi, U., Wolf, K. L., & Wood, S. A. (2017). Nature Contact and Human Health: A Research Agenda. *Environmental Health Perspectives, 125*(7), 075001. https://doi.org/10.1289/EHP1663

J. Food security (Darren Snyder and Jim Powell)

[1] Orttung, R. W., Powell, J., Fox, J., & Franco, C. (2019). Strengthening Food Security Near the Arctic Circle: Case Study of Fairbanks North Star Borough, Alaska. *Sustainability, 11*(10), 2722. https://doi.org/10.3390/su11102722

[2] Caster, C. D. (2011). Assessing Food Security in Fairbanks, Alaska: A Survey Approach to Community Food Production. University of Alaska. Senior Theses, ST 2011-01. http://hdl.handle.net/11122/3186

[3] Juneau dairy farms, ca. 1890-1950's. (n.d.). https://researchworks.oclc.org/archivegrid/collection/data/53966883

[4] Azadi, H., Movahhed Moghaddam, S., Burkart, S., Mahmoudi, H., Van Passel, S., Kurban, A., & Lopez-Carr, D. (2021). Rethinking resilient agriculture: From Climate-Smart Agriculture to Vulnerable-Smart Agriculture. Journal of Cleaner Production, 319, 128602. https://doi.org/10.1016/j.jclepro.2021.128602

K. Large cruise ship air emissions (Jim Powell)

[1] Rain Coast Data. Southeast Alaska by the Numbers 2021. (2021). https://www.raincoastdata.com/project/southeast-alaska-by-the-numbers-2021/

[2] Pemberton, J. (2021). The last cruise ship of Juneau's short, reduced season has come and gone. Alaska Public Media, October 21. https://www.alaskapublic.org/2021/10/21/the-last-cruise-ship-of-juneaus-short-reduced-season-has-come-and-gone/#:~:text=E%2DNewsletters-,The%20last%20cruise%20ship%20of%20Juneau's%20short,season%20has%20come%20and%20gone&text=On%20Wednesday%2C%20the%204%2C000%2Dpassenger,big%20ships%20visiting%20Southeast%20Alaska

[3] Jonson, J. E., Gauss, M., Schulz, M., Jalkanen, J.-P., & Fagerli, H. (2020). Effects of global ship emissions on European air pollution levels. *Atmospheric Chemistry and Physics, 20*(19), 11399–11422. https://doi.org/10.5194/acp-20-11399-2020

[4] Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kågeson, P., Lee, D., Buhaug, Ø., Lindtsad, H., Roche, P., Humpries, E., Graichen, J., Cames, M., & Schwarz, W. (2009). Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport. Institute for Biodiversity and Ecosystem Dynamics (IBED). Pub. No. 09.7731.78 https://dare.uva.nl/search?identifier=7252edce-88b0-440f-9f2b- 8343d55a1b76

[5] Lamers, M., Eijgelaar, E., & Amelung, B. (2015). The environmental challenges of cruise tourism: Impacts and governance. In D. Scott, S. Gossling, & C. M. Hall (Eds.) *The Routledge Handbook of Tourism and Sustainability* (pp. 430–439). Routledge.

[6] Alaska Department of Environmental Conservation, Division of Air Quality. (2020). ***Summary Report for the Juneau Saturation Study***. April – October 2019. https://media.ktoo.org/wp-content/uploads/2021/03/juneau-cruise-ship-project-2019-report-june-2020.pdf

[7] Howitt, O. J. A., Revol, V. G. N., Smith, I. J., & Rodger, C. J. (2010). Carbon emissions from international cruise ship passengers' travel to and from New Zealand. ***Energy Policy***, 38(5), 2552–2560. https://doi.org/10.1016/j.enpol.2009.12.050

[8] Lloret, J., Carreño, A., Carić, H., San, J., & Fleming, L. E. (2021). Environmental and human health impacts of cruise tourism: A review. ***Marine Pollution Bulletin***, 173, Part A, 112979. https://doi.org/10.1016/j.marpolbul.2021.112979

[9] International Maritime Organization. (2018). IMO Annex 11. Resolution MEPC.304(72). Initial IMO Strategy on Reduction of GHG Emissions from Ships. Adopted April 13, 2018. https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304(72).pdf

L. Tourists' views on climate change mitigation (Jim Powell)

[1] Jones, E. (2021). Sustainable Travel Survey 2021—Importance & Sentiment to Fight Climate Change When Booking Travel. *The Vacationer*, April 26. Updated March 31, 2022. https://thevacationer.com/sustainable-travel-survey-2021/

M. Lowering greenhouse gas emissions (Jim Powell)

[1] Cadman, T., Maguire, R., & Sampford, C. (Eds.). (2018). *Governing the Climate Change Regime: Institutional integrity and integrity systems*. Routledge.

[2] Bulkeley, H., & Betsill, M. (2006). *Cities and Climate Change: Urban sustainability and global environmental governance*. Routledge.

[3] Betsill, M., & Bulkeley, H. (2007). Looking Back and Thinking Ahead: A Decade of Cities and Climate Change Research. *Local Environment, 12*(5), 447–456. https://doi.org/10.1080/13549830701659683

[4] Satterthwaite, D. (2008). Cities' contribution to global warming: Notes on the allocation of greenhouse gas emissions. *Environment and Urbanization, 20*(2), 539–549. https://doi.org/10.1177/0956247808096127

[5] Unlocking Climate Action in Megacities. (2016). C40. https://www.c40knowledgehub.org/s/article/Unlocking-Climate-Action-in-Megacities?language=en_US

Graphics and data sources

What we're experiencing: Atmospheric, marine, terrestrial, and ecological effects.

A.2 More precipitation
Figure 1: Rick Thoman, Alaska Center for the Climate Assessment and Policy (ACCAP) (Data source: NOAA/NSIA)

A.3 Higher temperatures
Figure 2: Rick Thoman, ACCAP (Data source: NOAA/NSIA)

A.4 Less snowfall
Figure 3: Eran Hood, UAS Alaska Coastal Rain Forest Center (ACRC) (Data source: National Weather Service, Juneau)

Figure 4: Eran Hood, UAS Alaska Coastal Rain Forest Center (ACRC) (Data source: National Weather Service, Juneau)

B.1 Surface uplift and sea level rise
Figure 5: Eran Hood, UAS ACRC (Data source: adapted from Hu, Y., & Freymueller, J. T. (2019). Geodetic Observations of Time-Variable Glacial Isostatic Adjustment in Southeast Alaska and Its Implications for Earth Rheology. *Journal of Geophysical Research, 124*(9), 9870–9889.)

Figure 6: Eran Hood, UAS ACRC (Data source: adapted from NOAA (2021)

B.2 Extensive effects of a warming ocean

Figure 7: Heidi Pearson, UAS (Data source: Dorn, M., Cunningham, C., Dalton M., Fadely, B., Gerke, B., Hollowed, A., Holsman, K., Moss, J., Ormseth, O., Palsson, W., Ressler, P., Rogers, L., Sigler, M., Stabeno, P., & Szymkowiak, M. (2018). A Climate Science: Regional Action Plan for the Gulf of Alaska. NOAA Technical Memorandum NMFS-AFSC, 376.)

Figure 8: Kristin Timm, UAF, Source: Adapted from "Icefield to Ocean" by Kristin Timm, licensed under CC BY 4.0

B.3 Increasing ocean acidification
Figure 9: Evans, W., Lebon, G. T., Harrington, C. D., Takeshita, Y., Bidlack, A. (2022) Marine CO2 system variability along the northeast Pacific Inside Passage determined from an Alaskan ferry. *Biogeosciences, 19,* 1277–1301. https://doi.org/10.5194/bg-19-1277-2022

C. 1 More landslides
Figure 10: Sonia Nagorski, UAS, ACRC. Days per year of precipitation greater then .50. (Data Source: NOAA, NWS)

C.2 Mendenhall Glacier continues to retreat
Figure 11: Amber Chapin and Michael Penn. Mendenhall Visitor Artistic Rendering

Figure 12: Jason Amundson, UAS ACRC. Glacial lake outburst floods in Juneau.

C.3 Tongass Forest impacts and carbon
Figure 13: McNicol, G., Bulmer, C., D'Amore, D., Sanborn, P., Saunders, S., Giesbrecht, I., Arriola, S. G., Bidlack, A., Butman, D., & Buma, B. (2019). Large, climate-sensitive soil carbon stocks mapped with pedology-informed machine learning in the North Pacific coastal temperate rainforest. *Environmental Research Letters, 14*(1), 014004. https:// doi.org/10.1088/1748-9326/aaed52

D.2 Three animals as indicators of change
Figure 14: White, K. S., Gregovich, D. P., & Levi, T. (2017). Projecting the future of an alpine ungulate under climate change scenarios. *Global Change Biology, 24(*3), 1136-1149.

What We're Doing: Community Response

E. Upgrading infrastructure and mitigation
Figure 15: Katie Koester, CBJ Engineering and Public Works. 30-day average of effluent volume and precipitation (Data source: CBJ Mendenhall Waste Treatment).

F. Upgrading utilities and other energy consumers
Figure 16: Alec Mesdag, Alaska Energy, Light, and Power. Juneau's major energy sources and use. (Data source: CBJ Renewable Energy Strategy).

G. Growing demand for hydropower
Figure 17: Duff Mitchell. Juneau Hydro. Electricity Share of Final Energy doubles from 2016 to 2050 under the high scenario. (Data source: Mai, T. T., Jadun, P., Logan, J. S., McMillan, C. A., Muratori, M., Steinberg, D. C., Vimmerstedt, L. J., Haley, B., Jones, R., & Nelson, B. (2018). Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71500, 1459351.)

H. Leading a shift in transportation
Figure 18: Duff Mitchell, Juneau Hydro. Electric vehicle use in Juneau. (Data source: Alaska Department of Motor Vehicles).

K. Large cruise ship air emissions

Figure 19a: Jim Powell, UAS, ACRC, Juneau Cruise Ship Port Calls. (Data source: Rain Coast Data. Southeast Alaska by the numbers 2021.)

Figure 19b: Pemberton, J. (2021). The last cruise ship of Juneau's short, reduced season has come and gone. Alaska Public Media, October 21.

M. Lowering greenhouse gas emissions
Figure 20: Jim Powell, UAS, ACRC. (Data source: CBJ Archives.)

Appendix: Juneau's nonprofit climate change organizations

Renewable Juneau (https://renewablejuneau.org) and its Juneau Carbon Offset Fund (https://juneaucarbonoffset.org)

350 Juneau.org (https://350juneau.org)

Alaska Heat Smart - AHS (https://akheatsmart.org)

Interfaith Power and Light
(https://www.uri.org/who-we-are/cooperation-circle/alaska-interfaith-power-and-light)