Climate Change in Port Heiden, Alaska

Strategies for Community Health

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Cover photo: coastal erosion near Goldfish lake.
Photo by Richard Buzard

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Summary

There are two components to this document. The first component is the scope of described environmental change and its impacts in Port Heiden Alaska. The second component is a list of priorities to be addressed that will help Port Heiden achieve its vision for the future. Each priority area incorporates local knowledge with available climate science and takes the expected future changes in to consideration.

"(I was) born and raised here, but change has been constant. People are accepting that change more."

—Gerda Kosbruk

Child drives a snowmachine around Meshik, where many residents lived before moving inland to Port Heiden.
Historic photo provided by Gerda Kosbruk

Introduction

The Alaska Peninsula community of Port Heiden is experiencing a variety of environmental impacts related to a changing climate. Overall, temperatures and precipitation levels are increasing, influencing a change in the length of the growing season, annual snowpack, and wildfire risk. As with many types of change, consequences can have both positive and negative impacts on the community. The reconfiguration of Chistiakof Island in to a barrier spit, broadly influenced by changes in sea ice cover as well as frequency and intensity of Bristol Bay storms, allows waves and storm surges to erode the once sheltered coast between the ocean and Goldfish Lake. The abundance of clam and cockles have fluctuated, as has the abundance, and health of salmon harvested from the Meshik River. The warmer temperatures, however, have benefitted local gardens by increasing the growing season, and creating an environment where a more diverse variety of vegetables can grow. Port Heiden has capitalized on this benefit by building raised garden beds along the side of the community center, and plans to grow fodder crop to feed livestock at the Meshik Farm.

In 2017, the Bristol Bay Native Association (BBNA), with funding from the Bureau of Indian Affairs, initiated this assessment to understand the scope, and impacts, of environmental change from the perspective of Port Heiden residents. The assessment is followed by an adaptation plan, which integrates past observations, comments expressed by community members, and future climate projections while planning next steps to achieve the community vision for the future. Project collaborators include the Village of Port Heiden, the Alaska Native Tribal Health Consortium (ANTHC), the Alaska Climate Adaptation Science Center, the Western Alaska Landscape Conservation Cooperative (WALCC), University of Alaska Fairbanks, the Alaska Division of Geological and Geophysical Surveys (DGGS), and Alaska Sea Grant (ASG).

During May of 2017 representatives from ANTHC, WALCC, and BBNA met in Port Heiden to discuss project goals with community members, and to gather information about observed environmental changes and the impacts of those changes on daily life. Information for this assessment was drawn primarily from residents' comments made during interviews and during a community meeting. Additional information was collected from agency reports, published scientific resources, and observations of environmental change submitted to the Local Environmental Observer (LEO) Network. ANTHC and ASG facilitated a follow-up meeting in April 2018 to present draft findings, add additional comments from community members, and discuss long-term community priorities. Available temperature and precipitation projections were collected in collaboration with the Alaska Climate Adaptation Science Center. These projections were discussed by community members in the April 2018 meeting and used to understand how future environmental change may affect community priorities. A list of community priorities and objectives follows this assessment report.

Community

Port Heiden is a coastal community on the north side of the Alaska Peninsula, near the mouth of the Meshik River. The community is located approximately 15 miles from Mount Aniakchak, a caldera volcano which was historically active during the early post-glacial period of the Holocene, depositing pumice and other volcanic material that characterize the area geology today. A collapse of the Aniakchak volcano, occurring 3,430 years ago, created the 6-mile wide caldera known as the Aniakchak Crater. The most recent eruption of Aniakchak occurred during 1931, which rained volcanic rock on to Meshik, where Port Heiden residents lived before relocating inland (Bacon et al. 2004). The vegetation around Port Heiden is characterized by predominantly moist tundra and beach vegetation in the lowlands, and alpine tundra at higher elevations. In the uplands, willow, alder and grasses are found in areas with well-draining soils. A series of single and interconnected freshwater ponds support fish and marsh vegetation. Free of permafrost, the area geology is composed of volcanic and alluvial outwash, marine terrace deposits, and till. The pumice-rich volcanic deposits along the coast provide little protection against tidal activity, and have eroded significantly in community members' lifetimes (USGS, 1995, Kinsman and Gould, 2014). Analysis of sea level change near Port Heiden indicates that levels have remained stable between 1957 and 2013 (Kinsman and Gould, 2013). The Alaska Peninsula experiences significant seismic activity (Bacon et al., 2004), occurring near the Shelf

Rainbow over Meshik School.
Photo by Mike Brubaker


Port Heiden
©Google Earth

Fault Zone along the Alaska Peninsula and Aleutian Islands, as well as deeper earthquakes occurring in the Wadati-Benioff Zone (Alaska Earthquake Center, 2017).

The current community of Port Heiden is situated within 51.4 square miles of land and water (Alaska Peninsula Corporation, Port Heiden, 2017). There has been substantial development since it was incorporated as a Second Class City in 1972. Several HUD housing developments provide homes for the majority of residents, many of whom left their residences at the old village site of Meshik, between the coast and Goldfish Lake, due to coastal erosion. In 2015, the US Census estimated there to be 55 housing units in the community, although at the time of the May 2017 visit, construction of a new duplex had been completed to house teachers and a Village Public Safety Officer (VPSO). Each house has a private well and septic system, and electricity is provided from a city-run diesel generator (Alaska Energy Data Gateway, 2017). Primary transportation to and from the community is by plane, with service provided by Lake Clark Air and Grant Aviation. The population of Port Heiden was estimated to be 73 in 2016, with 66% male and 34% female, and 74% Alaska Native/American Indian. Approximately half of the population is estimated to be under 35 years old (American Community Survey, 2015). Port Heiden falls within the Bristol Bay Native Association and Bristol Bay Area Health Corporation service areas. According to the Alaska Native Tribal Health Consortium Epidemiology Center, the top two causes of injury within the BBAHC service area are falls and ATV related injuries. The leading causes of death in the Bristol Bay region are cancer, heart disease, and unintentional injury (ANTHC Epidemiology Center, Bristol Bay Regional Health Profile, 2017).

Port Heiden has a history of use by the US military. In 1942 the US Army constructed the Fort Morrow air base as an intermediate site between Cold Bay and Kodiak. Several hundred buildings were constructed for military housing and use, all of which were dismantled following the end of WWII. The US Air Force later constructed the White Alice Communication System site during the Cold War, along with 11 other such sites across Alaska. Use of the White Alice site left soil contaminated with polychlorinated biphenyl (PCB), trichloroethylene (TCE), other chlorinated solvents, diesel, and petroleum. Remediation efforts have been ongoing since 1981 through efforts by the US Air Force, US Army Corps of Engineers, and the Alaska Department of Environmental Conservation. (Alaska Department of Environmental Conservation, 2017).

Local government is the primary employer in Port Heiden, followed by construction, education and health services, trade, transportation and utilities, and leisure/hospitality (Department of Labor and Workforce Development 2017). Port Heiden residents commercially fish for salmon in Bristol Bay using drift gillnets. There are commercial set net sites along the beach near the old Meshik village, however their use has been suspended pending the opening of a newly constructed fish processing plant. Commercial fishing is estimated to provide 90% of all locally generated tax revenue for the Lake and Peninsula Borough and is the primary source of cash income for borough residents. In 2017, ten residents of Port Heiden held commercial fishing permits (Commercial Fisheries Entry Commission Permit Database 2018). Sustaining existing cultural and economic priorities emphasizes the need to monitor and plan for continuing environmental changes.

Ecosystem

The tundra-covered landscape of Port Heiden nearly disguises the rolling hills leading east to the volcanic Aleutian Mountain range, and Mount Aniakchak. At lower elevations, the area is mostly treeless tundra, free of permafrost, with clusters of willow and alder in the floodplains and beach vegetation closer to the coast. The Aleutian Mountain Range reaches elevations of up to 8,580 feet above sea level, and feeds lowland rivers and lakes from glaciers held in the high peaks. Near the community, the Meshik River flows for 31 miles west in to Bristol Bay from the headwater on Mount Aniakchak, within the Aniakchak National Monument and Preserve. Lowland topography is dotted and streaked with rivers and lakes, which continuously change the volcanically influenced landscape. Higher altitude tundra areas are considered semi-arid, supporting shrubs, lichens, moss and grass. Lower elevations become increasingly wet, with vegetation transitioning to moist tussock tundra of moss, lichen and tufted hair grass in the valleys and plateaus (Alaska Department of Fish and Game Wildlife Action Plan, 2005). The beach is composed of sand and gravel, primarily sourced from coastal bluffs containing layers of pumice and other volcanic material (Kinsman and Gould, 2014). The nearshore habitat supports zooplankton and a variety of marine invertebrate species and juvenile fish, drawing migrating waterfowl and marine mammals (Alaska Department of Fish and Game Bristol Bay Critical Habitat Areas Draft Management Plan, 2011).

Old houses and fishing boats near the old Meshik village site.
Photo by Mike Brubaker

The northern area of the Alaska Peninsula is considered a Bristol Bay Critical Habitat Area (CHA) (Alaska Department of Fish and Game, Conservation Areas, 2017). The CHAs are co-managed by the Alaska Department of Fish and Game (ADFG) and the Alaska Department of Natural Resources (DNR), who provide guidelines, policies, and regulations for activity that may disturb habitats, fish, and wildlife species. These activities include scientific research, oil and gas exploration, shoreline alteration, as well as dock and boat ramp construction, among others. The Port Heiden CHA encompasses the area just south of the old Meshik Village site, to include the mouth of the Meshik River

A series of lakes north of Port Heiden.
Photo by Anna Ponurkina

and immediate bay, as well as wet tundra south of the lagoon, extending to the coast (Figure 1.) (Alaska Department of Fish and Game Bristol Bay Critical Habitat Areas Draft Management Plan, 2011). These areas support a variety of fish and wildlife species, important to subsistence and area ecology.

Large numbers of migratory waterfowl concentrate in the food rich estuaries, lagoons, river deltas, tidal flats, and lowland ponds during the spring and fall migration periods. These areas provide enough nutrients to sustain the birds through migration and winter survival (Ibid.). Port Heiden is one of five Alaska Peninsula sites

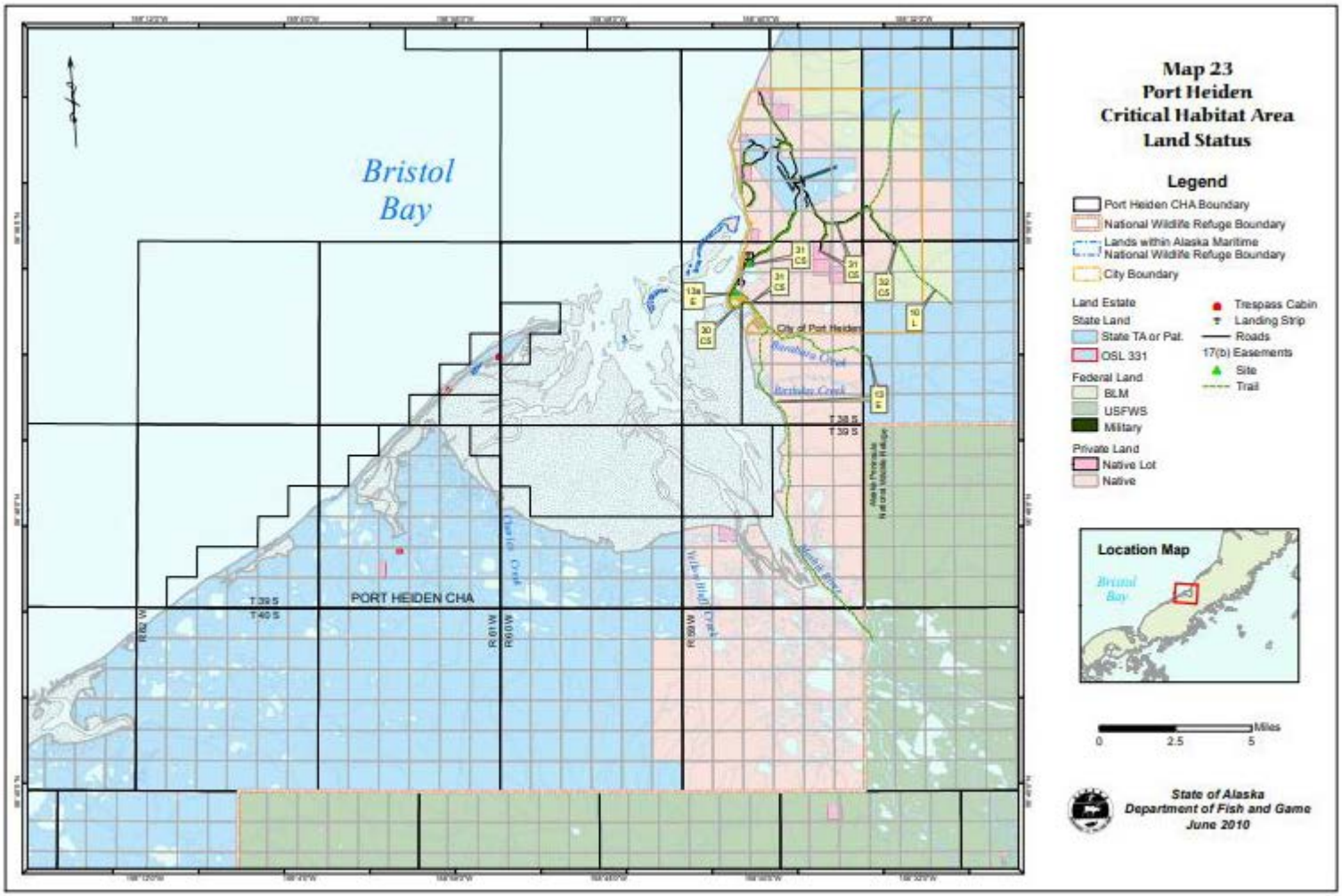


Figure 1: Port Heiden Critical Habitat Area

where around 300,000 shorebirds representing 30-35 species, come to breed between April and May. Other migratory species include Canada Geese, tundra swans, emperor geese, greater white-fronted goose, and Pacific Brant. Although thirty species of seabirds collect in small colonies across the northern Alaska Peninsula, glaucous-winged gulls, black-legged kittiwakes, double-crested and pelagic cormorants, mew gulls, tufted puffins, pigeon guillemots and horned puffins are most commonly sighted (Ibid.). Sea ducks, such as black scoters and Steller's eider in particular, take advantage of the nearshore marine habitat, feeding on vegetation and marine invertebrate species for molting, and as staging areas prior to beginning seasonal migrations. The staging areas between Port Heiden and Izembek Lagoon are particularly important for Steller's eiders, as much of the world's population gather there and molt their flight feathers. The birds depend on healthy invertebrate populations in shallow estuaries during the period of flighlessness (Ibid.).

The waters of Bristol Bay provide abundant sources of food for a variety of marine mammals, supporting mollusks, sponges, anemones, ascidians, polychaetes, barnacles, mussels, urchins, scallops, sea cucumbers, shrimp and octopus (Ibid.). Year round, harbor seals haul out on spits and islands in the area to pup. Port Heiden is among three heavily used harbor seal haulouts, hosting anywhere between 4-5,000 seals. Male walrus haulout in seven different locations around Bristol Bay areas in the spring, following mating season (Ibid., Christensen, Lujan, Tcheripanoff, LEO Network 2018, Christensen, Lujan LEO Network Post 2018). Walrus consume clams, snails, anemones, sea cucumbers, tunicates, and other invertebrates, which help restore fat reserves (Alaska Department of Fish and Game Bristol Bay Critical Habitat Areas Draft Management Plan, 2011). As the sea ice moves toward the Bering Sea in fall and winter, the male walrus leave and rejoin the females and pups (Anderson, Douglas, LEO Network

Cockles are an important subsistence resource.
Photo by Anna Ponurkina

Post 2017). Sea otters frequent the Port Heiden waters, and river otters have been seen to gather on shore in large numbers. Although southwestern Alaskan sea otter populations are considered threatened under the U.S. Endangered Species Act, several thousand may periodically collect between Port Moller and Herendeen Bay. Reduced seasonal ice provides easier access to nearshore feeding areas.

All five species of Pacific salmon can be found in the nearshore waters. The Meshik River supports Sockeye (red) and Chinook (king) salmon, while Coho (silver) spawn up North River. Chinook and sockeye runs begin in June, with Chinook tapering off in August and Sockeye in September. Chum (dog) salmon arrive in July, moving on by August, while Coho run from August to October. Other fish species include Dolly Varden, steelhead, and humpback whitefish, overwintering in freshwater lakes. Herring and other forage fish have been documented around Port Heiden, providing an important food source to marine mammals, other fish, and seabirds. Confined freshwater systems host grayling, rainbow trout, burbot, northern pike, and resident populations of humpback whitefish (Alaska Department of Fish and Game Bristol Bay Critical Habitat Areas Draft Management Plan, 2011).

Brown bear populations have fluctuated based on harvest levels, fluctuating salmon returns, and other factors, but they still maintain a presence around Port

Children help fish for salmon in Reindeer Creek, referred to as North River.
Photo by Anna Ponurkina

Heiden. Between October and May, bears den in the land covered by alder, willow and grasses. In April or May, bears emerge with anywhere between one and four cubs, and head to the coastal grass flats to feed on sedge and other early vegetation. In the summer months, bears depend heavily on salmon as a food resource in nearby rivers. Wolves are present around Port Heiden, although populations have fluctuated based on federal wolf control programs, prey fluctuations, and rabies outbreaks (Ibid.).

Furbearing mammals such beaver, coyote, red fox, lynx, mink, muskrat, sea and river otter, and wolverine can be seen darting across the landscape. Although population data for many of these species is lacking, foxes are frequently seen across the tundra between the coast and the upland slopes, following small prey of Alaskan and snowshoe hares, ermine, least weasels, and arctic ground squirrel. Beaver populations are estimated to be increasing, favoring areas of thick willow, birch and cottonwood near lakes and streams (Ibid.).

The Northern Alaska Peninsula Caribou herd ranges from Port Moller to Naknek, moving through the communities of Egegik, Pilot Point, and Port Heiden. The herd utilizes the area around Port Heiden as calving grounds typically between May and June. As winter edges in, the herd migrates north to the area between the Ugashik and Naknek rivers (Ibid.). In the early to mid-1900's, moose began to move southward, increasing populations in the 1950s. Currently, they can be found browsing lower slopes and valleys alongside streams and rivers, where willow, shrub, and other vegetation is abundant. Hunting regulations have periodically

A brown bear sow and two cubs walk the Port Heiden beach.
Photo by Mike Brubaker

Mossberries, or crowberries, are abundant across the tundra.
Photo by Anna Ponurkina

changed to allow for moose range recovery and help maintain over-browsed areas.

For the community, seasons are characterized by subsistence harvest, which include fish, shellfish, caribou, moose, small land mammals, birds, eggs, berries and other vegetation (Fall and Morris, 1987). However, harvest timing is likely to change in accordance with other environmental changes. As characterized in a 1987 subsistence harvest report, Port Heiden residents typically hunted migratory waterfowl, seal, and walrus, dug for shellfish during low tides, and collect gull and tern eggs typically beginning in March and April. Salmon continue to arrive in area waters beginning in late May to early June. Currently, one community member in particular is the first to set his net along the beach near the old village site, and calls the beginning of the run when the first Chinook salmon bobs the cork-line along the top of his net. Salmon fishing continues through the summer; Chinook harvested as they migrate up the Meshik, and silvers as they head up Reindeer Creek. Sockeye salmon, some headed up the Meshik River, and others on to the northern Bristol Bay drainages, are intercepted by set nets from the shore near Goldfish Lake. Harvested salmon are hung to dry, smoked, canned or frozen. Berries typically ripen in mid-July and are harvested through the summer and into the fall when waterfowl hunting resumes (ibid.). Although caribou was a primary subsistence resource in the 1987 report, this has changed over time. Caribou harvests from the Northern Alaska Peninsula Herd have been restricted since 2005 due to extremely low numbers. In the fall of 2016, the Alaska Department of Fish and Game instated a Tier II hunt system, replacing the previous general hunt system. Residents may once again apply for permits to hunt caribou in their area (Alaska Department of Fish and Game, Northern Alaska Peninsula Caribou Herd Update, 2015). The reintroduction of the ability to harvest caribou is significant to the subsistence practice of Port Heiden residents. Because of long-term caribou harvest restrictions, salmon have become more central to the diet of Port Heiden residents.

In an effort to maintain rangifers as a food source during the restriction period for caribou harvest, Port Heiden residents began the Meshik Farm in 2015. Building off a history of community reindeer herding that has been dormant since the 1940s, a total of 39 reindeer were flown to the community farm from Stebbins/St. Michaels. They graze within a fenced area over a tundra segment, adjacent to the village, feeding on the local vegetation and a specialized reindeer pellet. In addition to the reindeer herd, the Meshik Farm also raises rabbits, chickens, and pigs. Animal pens are constructed through creative re-use of materials.

Meshik Farm reindeer.
Photo by Erica Lujan

Observed and Projected Changes

Climate and Weather

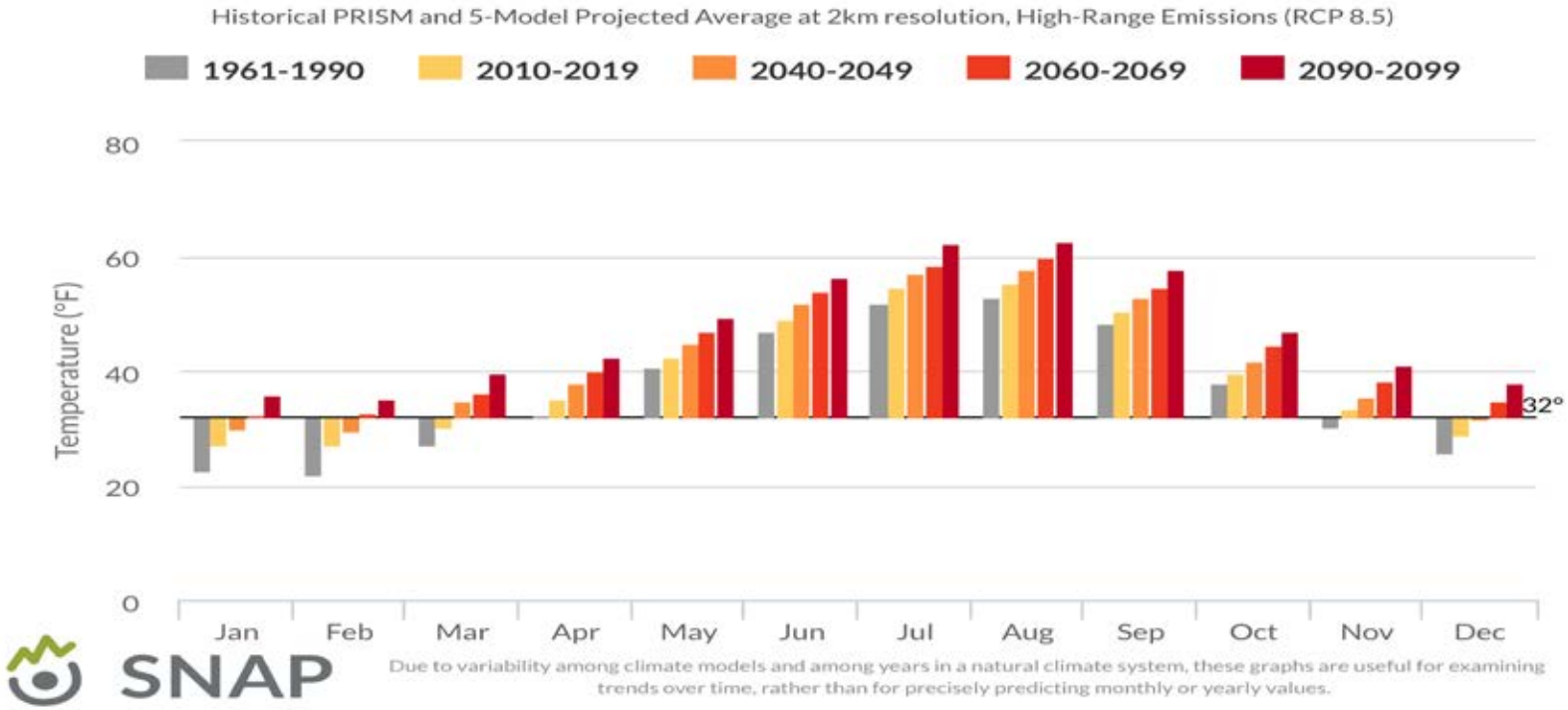
Located on the south slope of the Aleutian Range, Port Heiden's maritime climate is characterized by high humidity, heavy precipitation and frequent cloud cover. The community's coastal location also makes it vulnerable to other severe weather events, including thunderstorms, lightening, hail, heavy and drifting snow, freezing rain and ice storms, extreme cold and high winds, especially during El Nino/La Nina southern oscillation periods (Lake and Peninsula Borough, 2015).

Warm weather has allowed some vegetation to grow taller.
Photo by Anna Ponurkina

An eroding coast will lead to the eventual breach of Goldfish Lake.
Photo courtesy of the Division of Geological and Geophysical Surveys Coastal Hazards Program

The Scenarios Network for Alaska + Arctic Planning (SNAP) Climate Projection Tool estimates that future monthly temperatures for Port Heiden will continue to increase (Figure 2.). The average monthly temperature for Port Heiden in January between 1961 and 1990 was 22.6 degrees Fahrenheit, while the average January temperature between 2010-2019 is estimated to reach 27.3 degrees Fahrenheit (PRISM[1] data). Between 2040 and 2069, the average annual temperature is expected to increase between 5.0 degrees Fahrenheit under a lower emissions scenario (RCP[2] 4.5) and 6.5 degrees Fahrenheit under a higher emissions scenario (RCP 8.5), averaged across five climate models. By 2060 projections show that average monthly temperatures year-round will remain above freezing. Increases are expected to be larger in winter and spring than summer and fall. SNAP projections for future precipitation levels are more varied, but an overall increase in precipitation is expected (Figure 3; SNAP Climate Projection Tool, Alaska Climate Adaptation Science Center).

Figure 2: Average Monthly Temperature for Port Heiden, Alaska

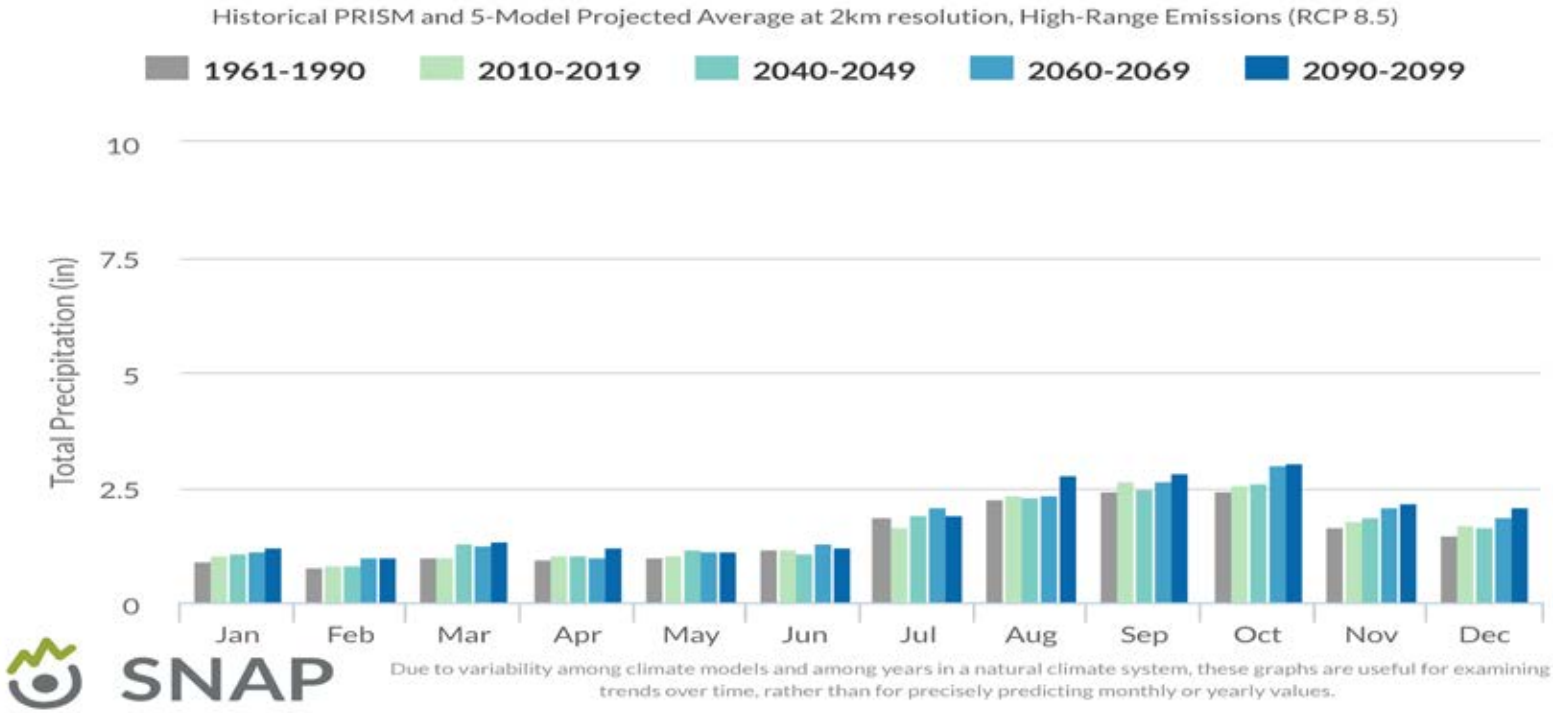


[1] Parameter Elevation Regression on Independent Slopes Model
[2] Representative Concentration Pathways: Consistent sets of projections of greenhouse gases that result from emissions scenarios. These are used to describe possible climate futures.

The average monthly precipitation measurement for Port Heiden for January 1961-1990 was 2.09 inches. The average annual precipitation for Port Heiden for 1970-1999 was about 20.8 inches (PRISM data). This is expected to increase by approximately 10% for the period 2040-2069 under a lower emissions scenario (RCP 4.5) and 13% under a higher emissions scenario (RCP 8.5), averaged across 5 climate models.

Residents have begun to see more variability in winter weather, noting that the winters have become more wet with less snowpack (Scott Anderson). A LEO Network post by Barbara O'Domin, documented a lack of snow, and temperatures in the upper 40-degree range during, early December of 2013. December temperatures in the upper 40's during 2013 represented an approximately 20-degree Fahrenheit difference than the average temperature documented by SNAP for the same month. In January of 2013, Delores Anderson posted

Figure 3: Average Monthly Precipitation for Port Heiden, Alaska



an observation of an active brown bear that may have left its den due to warm temperatures and winter precipitation, flooding or poor health.

> ***"This is a rare sighting to observe a brown bear in January. I believe he's starving so he was forced out of hibernation."***
>
> *— Delores Anderson, Port Heiden*

The Alaska Climate Adaptation Science Center snowpack vulnerability projection model (Appendix II, Figure 4) estimates that between the years 2030-2059, the Port Heiden community will see between 60%-80% of its annual precipitation falling as rain rather than as snow. The mountainous area to the east however, will continue to experience snow dominant precipitation. Historically (1970-1999), about two thirds (67.3%) of the precipitation falling between October and March was entrained, or trapped, in the April 1st snowpack for the watershed above Port Heiden. For the 2040-2069 period, the snowfall is projected to decrease by 25% under a lower emissions scenario (RCP 4.5). Under a higher emissions scenario the snowfall is projected to decrease by 37% resulting in less than half (RCP 8.5) of the October to March precipitation entrained, or trapped, in spring snowpack (Appendix II, Figure 5).

Increasing temperatures and reduced snowpack may lead to periods of drought during the warm summer months, and affect drinking water quantity, recreation, navigation, and aquatic ecosystems (Lake and Peninsula Borough, 2015). Decreased water production from snowpack also has consequences for the health of the tundra, related plants, and wildlife. Residents reported that during low snow years, the tundra vegetation dies back, and rodent populations flourish. The roots of berry bushes feed the growing populations of small animals, and plants are unable to produce enough berries to meet the needs of community members. Residents reported seeing owls hunt during the day during years of large rodent populations (Tisha Kalmakoff, Amber Christensen-Fox, Billie Schraffenberger).

Warming temperatures, changes in precipitation, and uncertain weather patterns have led the Lake and Peninsula Borough to consider it likely that a tundra or wildland fire will break out in the near future. Wildfires occurring in the area since 1953 are mostly the result of lightning strikes (Lake and Peninsula Borough, 2015). The Alaska Center for Climate Adaptation Science Center used a SNAP model to develop estimates of historical and projected differences in rate of wildfires for this region (Appendix II, Figure 6). The model projects that wildfire rates for the area around Port Heiden will see none-to-moderate increases in the number of fires from the year 2000 to the year 2099, as compared

to the years 1990-1999. A moderate-to-substantial increase is projected for the areas west of Port Heiden, which may cause air quality concerns in the future from wildfire smoke.

Residents of Port Heiden have also noticed a change in the severity, and frequency of storms. Intense windstorms that used to occur once every few years now occur twice in a single year (Jimmy Christensen). Increasing windstorms, some bringing warm temperatures from the southeast, contribute to rapid snowmelt (Jaclyn Christensen). According to residents, wind speeds have also increased (Gerda Kosbruk). Some homes have experienced storm related damage, including windows blown out from the force of the wind.

The frequency of extreme precipitation events is expected to increase in Southwest Alaska by a factor of 2 to 3 under a low emissions scenario (RCP 2.6), and by a factor of 4 to 6 under a high emissions scenario (RCP 8.5) (Walsh and Wuebbles et al., 2014). This means that extreme precipitation events which occurred once in a 20 year period, may now occur once in 7-10 years under low emission scenarios and occur once in 3.5 to 5 years under high emissions scenarios. The amount of precipitation on the wettest days, above the 99th percentile, is also expected to increase from approximately 2"- 3" to 3.5" – 4.5" (Sun et al., 2015). An increase in the frequency of severe precipitation events, and in the amount of rainfall, may also increase localized flood risk in the winter months, especially if the ground is frozen and does not allow for adequate drainage. Residents reported that during winter precipitation/ ground-surface thaw events, standing water collects over septic leach fields. This poses a health risk if people, pets or livestock are exposed to septic overflow or if water infiltrates neighboring water wells (Scott Anderson, Tisha Kalmakoff, Jaclyn Christensen). There is currently no regular testing for bacteriological presence/absence in private well water.

Warmer winters may also be contributing to reduced indoor air quality. Residents report indoor mold, mildew and rot problems that did not exist in earlier, drier years. Environmental Coordinator Scott Anderson commented that when he moved to Port Heiden in 1994, he was amazed that the buildings, despite having no paint, were dry with no moisture or rot problems due to the cold, dry winters. Now, he says, even the southeast wind is wet.

"The winters have changed; it is wetter than it used to be. Might be why we have mold in the houses now, and in the dump."

—Scott Anderson, Port Heiden

Erosion

The current rate of shore erosion that Port Heiden experiences is the result of both changes in climate and changes in the coastline and surrounding landforms, which have influenced the amount of wave energy that reaches the coast. The geology of the Alaska Peninsula is largely composed of volcanic deposit, leaving layers of unconsolidated and non-welded pumice and coarse ash, which erode easily when ocean waves make contact. Bristol Bay is prone to extratropical cyclones that originate in the Bering Sea and result in storm surge and wind driven waves along the coast. These waves are the primary driver of erosion near the community.

Historically, the southernmost extent of Bering Sea winter sea ice reached Bristol Bay, providing some protection to the coast from wave swells during the winter. However, the sea ice has gradually retreated, forming as much as a month later than normal (Kinsman and Gould, 2014). In a January 2014 LEO Network post, Linda Anderson wrote that residents observed sea ice for only a couple of days during the winter. Previously, ice would begin to appear in November. She wrote that community members were concerned, because the sea ice helped prevent coastal erosion. At the same time, there has been an

Coastal erosion near Goldfish Lake.
Photo by Anna Ponurkina

increase in the frequency and severity of storms in the Northern Pacific. This trend coincides with a shift in the Pacific Decadal Oscillation (PDO), a long-term pattern of climate variability over the Pacific Ocean (NOAA, 2018), affecting typical wind speeds and precipitation levels, among other variables (Hartmann and Wendler, 2005 in Kinsman and Gould, 2014). Changes in sea ice coverage, frequency and intensity of Pacific storms, and a shift in climate patterns, have likely contributed to an increase in the relative amount of wave energy along the coast near Port Heiden (Kinsman and Gould, 2014).

The change in wave energy has reshaped the coastline and nearshore landforms. The most consequential change was the movement of Chistiakof Island, a barrier island that protected the Port Heiden coast from waves. Through a process of erosion and accretion, the island gradually moved between 1973 and 1983, forming a spit to the north of the island's previous location. The change in the land form has altered long shore currents towards previously sheltered bluff areas and increased the rate of erosion in Port Heiden. In 2013, the Alaska Division of Geological & Geophysical Surveys (DGGS), Coastal Hazards Program and the University of Alaska Fairbanks (UAF) installed community-based erosion monitoring sites along the bluff to track change over time. Since 2013, DGGS and UAF has recorded erosion of approximately 30 feet per year, and up to 80 feet in one location.

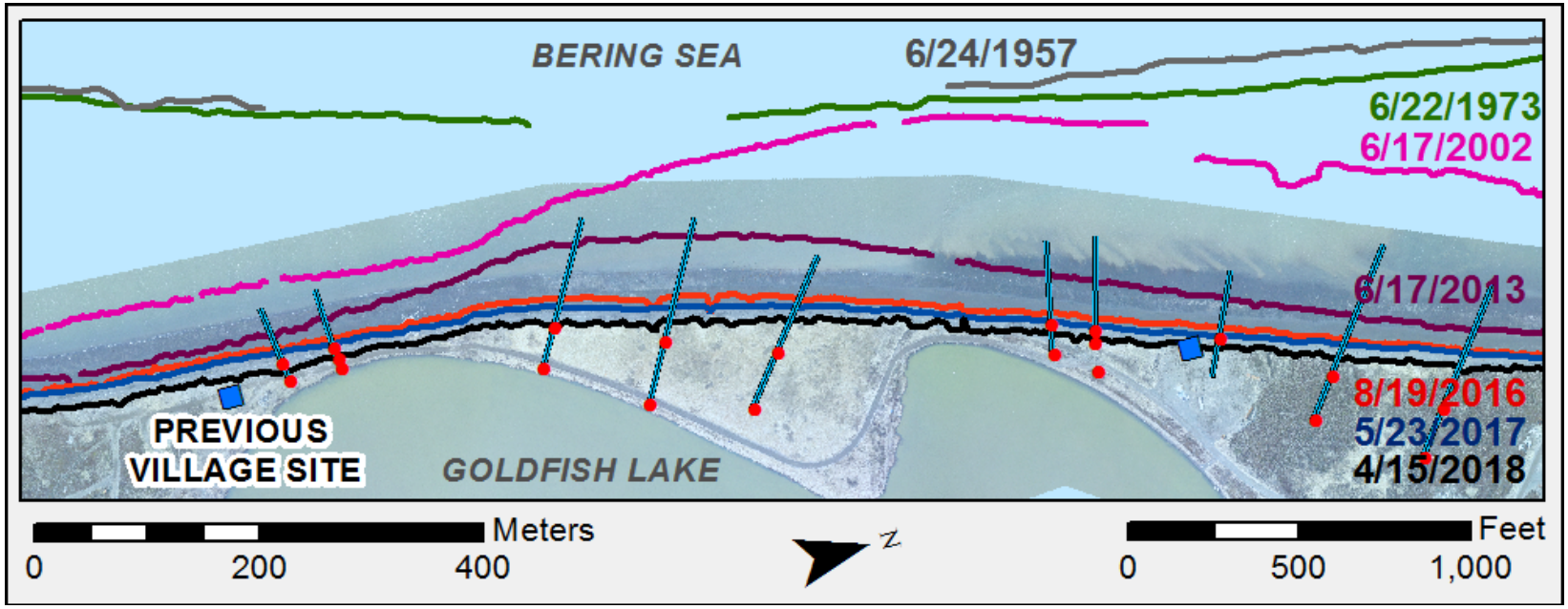
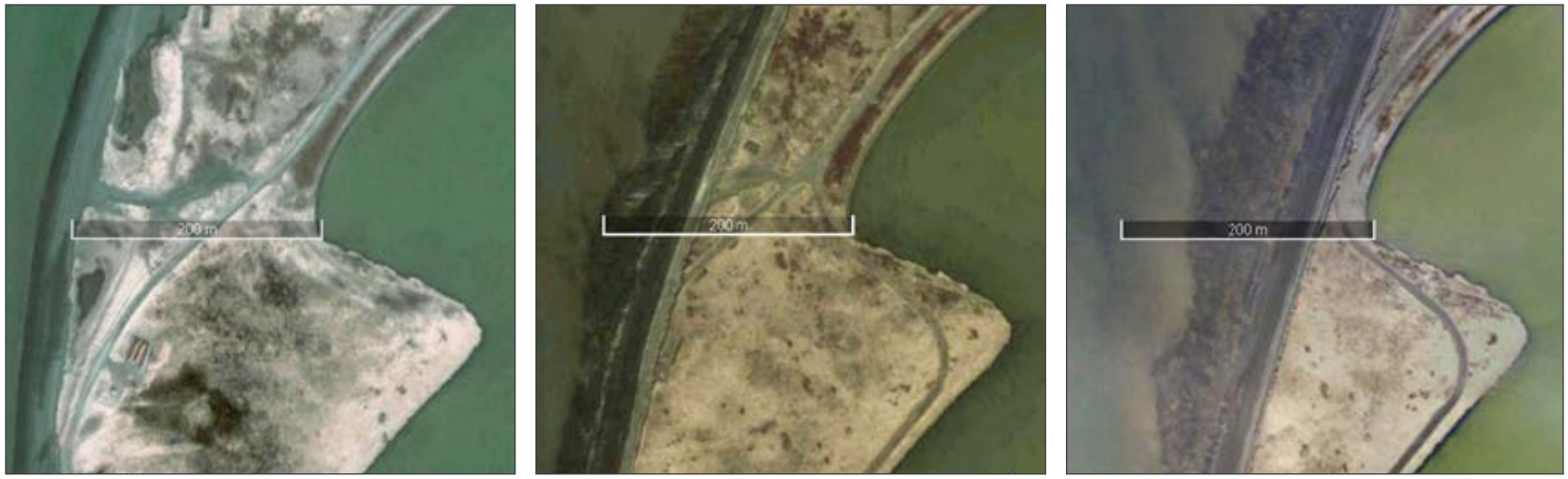


Figure 7: Shoreline Change in Port Heiden, Division of Geological and Geophysical Surveys and University of Alaska Fairbanks, 2018



Shoreline change between 2004, 2011, and 2017.
Photo courtesy of the Division of Geological and Geophysical Surveys Coastal Hazards Program

expected to erode an additional 10-20 feet, leaving a thin strip of land between the coast and Goldfish Lake. In some areas of the bluff that face the coast, freshwater can be seen seeping from the lake, increasing risk of breach during a severe storm or tidal event. According to residents, the lake is approximately 4 feet deep, while the bluff drops approximately 10 feet to the beach. When the lake breaches, it will likely drain because of the elevation difference, and become a smaller pond. It is possible that the lake breach would lead to more erosion, unless there is peat underlying the lake, as peat is less susceptible to erosion than the unconsolidated volcanic material.

The erosion has been the most substantial change the community has experienced in recent memory (Melissa O'Domin, Hank Matson). As the increasing rate of erosion began to threaten Meshik Village in the 1970s, the community developed plans to relocate inland (Hank Matson). The first new subdivision was built in the early 1980s, and residents began to move in to their new homes. As the coast continued to retreat, the community mobilized to remove and relocate structures that were in the path of the receding shoreline. A series of military fuel tanks and drums were moved between 1990 and 2007, as was a Russian Orthodox church and at least two grave sites. A landfill with both municipal and military waste was lost to Bristol Bay by 2013 (Kinsman and Gould, 2014). Another piece of important infrastructure was the fuel header used to transfer barge delivered fuel to on shore storage tanks. As documented in a LEO Network post by Linda

Anderson, the header was undercut by the receding shoreline to the point of failure (Anderson 2014). The city decommissioned the fuel header in January of 2014. A jute fabric, used as ground cover during soil remediation of a former drum disposal area, along with variety of abandoned underground utilities from the Meshik village site, is actively being exposed by the retreating coast and washed in to the bay. The last remaining structures at the old Meshik village site were moved inland during the summer of 2018. Residents still remain wary of the impact that the coastal storms have on the current community infrastructure. In a LEO Network post from March, 2013, Shannon Matson wrote that the erosion, occurring during a severe storm, was impacting the public roads, electrical transformers, and water wells. She explained that if the erosion continued, it would be expensive to repair the roads. The associated flooding may also ruin the electrical transformers and seep in to the water wells (Matson, 2013).

"A high wind out of the west can take as much as 30 feet of shoreline in a single storm. Big tides, high winds, and no ice around Thanksgiving can cause a lot of erosion. Lots of pumice."

—Scott Anderson, Port Heiden

Debris from Meshik village erode out of the bluff.
Photo by Richard Buzard

A substantial impact from the coastal erosion is the loss of a protected lagoon where commercial fishers used to launch their boats. The protective barrier has now washed away, and the road between the beach and Goldfish Lake has become too thin to transport boats and other heavy equipment (Scott Anderson). Boats are now launched in open water. Each year, residents use heavy machinery to build a dirt road from the bluff down to the beach in order to get the boats to water. Each year, this temporary road is eroded away. Waves make launching boats more dangerous, risking damage to the boat at the beginning of fishing seasons (Jimmy Christensen). The dangers of launching in open water also create a greater risk of physical injury to fishers themselves.

Water

According to the Port Heiden Environmental Office, the changes in well water quality is considered to be the most significant environmental issue that the community currently faces. In 2003, the State of Alaska Department of Environmental Conservation (DEC) Village Safe Water Program conducted a Sanitation Improvement Feasibility Study, in which DEC staff explored the hydrology of the Port Heiden area, and tested the quality of the groundwater used for household use. Although there are numerous fresh water sources, including creeks, lakes, and wetlands, few qualify as acceptable drinking water sources because of the tidal influence, and high concentrations of iron (Ditterman et al., 1981 in DEC 2004, Burns Consulting, 2004).

Examining the hydrology, DEC found the upper geologic strata below the organic mat to be composed of pumice and sand, reaching to depths of 15-25 feet. The next strata is composed of silt/clay and silt/gravel, which extends down to 50-90 feet below ground surface. Beginning at approximately 60 feet, DEC found a water bearing strata of coarse sand and gravel, which is the primary water source for almost all household drinking water wells. This aquifer is thought to be recharged either by the hills to the west of the community (DEC 2004) or through vertical infiltration (Burns Consulting 2004). The US Geological Survey notes that the confined

Each home in Port Heiden utilizes a household well and septic system.
Photo by Erica Lujan

beds are localized (USGS, 1995, Burns Consulting 2004). A more consistent confined aquifer may begin at a depth of 200 feet, based on limited data from the Meshik School and hardware store wells, drilled at 220 and 165 feet below ground surface (bgs), respectively (Burns Consulting, 2004).

"After the earthquakes, some people were complaining about their water. At Trina Bishop's house, the water turned her tub orange. At my mom's house, she has changed the inline filter every two weeks."

—Melissa O'Domin, Port Heiden

Water quality from household wells in Port Heiden is variable, as all household wells may not all draw from confined aquifer beds. The "A Limited Drinking Water Quality Assessment" prepared by Keres Consulting Inc. in 2003, on behalf of the U.S Army Corps of Engineers, documents residential well depths ranging from 47 feet to 109 feet bsg. Keres tested 40 Port Heiden residential wells and the Meshik School (with well depth of 202 feet bsg) for inorganic contaminants: Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Copper (CU), Iron (Fe), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se), and Thallium (Th). Additionally, Keres tested wells for organic contaminants: gasoline range organics, diesel range organics, pesticides, PCBs, polynuclear aromatic hydrocarbons and volatile organic compounds. Polynuclear, or polycyclic, aromatic hydrocarbons are naturally occurring chemicals found in coal, crude oil and gasoline (CDC- Polycyclic Aromatic Hydrocarbons (PAHs), 2018). Volatile organic compounds (VOC) are chemicals associated with fuel contamination, such as toluene (EPA – Technical Overview of Volatile Organic Compounds, 2018).

Test results showed that iron was the only element found to be in excess of the federal and Alaska maximum contaminant level goal of 0.33 milligrams per liter (mg/l). However, iron does not pose any threat to human health, and falls under a set of secondary maximum contaminant levels focused on maintaining the appearance and taste of drinking water (EPA – Secondary Drinking Water Standards: Guidance for Nuisance Chemicals, 2018). Of the tested household wells, 27 of the 40 wells showed high iron levels ranging from .423 mg/l to 16.4 mg/l. The school showed iron levels at 0.495 mg/l. Four wells returned results with multiple VOCs above the federal maximum contaminant levels, including 1,2 dichloroethane, Methylene Chloride, Chloromethane, and Styrene. Two households returned low, but detectable, levels of naphthalene, a polynuclear aromatic hydrocarbon obtained from either coal tar or

petroleum distillation, in excess of the method reporting limit of 0.022 micrograms/liter (µg/l). One household also returned low but detectable levels of diesel range organics in excess of the method reporting limit of 0.320 milligrams per liter. The levels detected in the water samples from homes were at low levels and below any action level that is considered to be a health risk. The Meshik School returned no detectable levels of organic contaminants.

There is some variability in the construction of household wells, which may contribute to contamination of the aquifer. In some households wells, Burns Consulting notes the lack of an effective seal between the well bore and casing, which may allow contaminated groundwater to enter the well. In 2012, DEC outfitted homes in Port Heiden with point-of-entry filter systems to remove the iron and hydrogen sulfide/sulfur smells. However, the high iron levels continue to discolor the water, pipes, and appliances, and leave a strong metallic aftertaste. Sudden changes in water quality are frequently experienced following earthquakes (Scott Anderson, Melissa O'Domin). Residents reported sudden increases in iron content and sediment, requiring some homes to frequently change their inline filters.

Since April of 2016, Port Heiden has experienced an increase in seismic activity (Alaska Earthquake Center in APRN, LEO Network). Earthquakes have been known to change groundwater levels and water quality. The degree of impact depends on the geologic conditions of the aquifer and the distance from the earthquake epicenter, as well as the magnitude and depth of the earthquake (USGS Fact Sheet 096-03, personal communication with Natalia Ruppert, Alaska Earthquake Center, 2017).

According to the Alaska Earthquake Center, seismic activity around the Alaska Peninsula is the result of three different tectonic features. The strongest earthquakes in this area are due to the Aleutian megathrust. Megathrust earthquakes occur when one tectonic plate is forced underneath another, in areas called a subduction zones (IRIS). Additional earthquakes occur as the subducting plate (the tectonic plate being forced underneath another plate) reaches the earth's mantle. In the Alaska Peninsula region, these intermediate-depth earthquakes occur in the Wadati-Benioff Zone, between 20 and 150 feet below the surface. Thousands of earthquakes occur at these intermediate depths, however many are often too small and too deep to be felt on the surface. Crustal seismic activity occurs near the underwater Shelf Fault Zone and the volcanic arc along the Alaska Peninsula, which follows the Aleutian Range and the Aleutian Islands.

Wildlife and Vegetation

Approximately 30 years ago, "Emma" clams, or littleneck clams, were readily available on the Port Heiden beach, providing an important subsistence resource. Today, Emma clams and cockles are now difficult to find (Scott Anderson, Annie Christensen, Hank Matson). Some in the community attribute this to a change in sea mammal abundance and behaviors. A 2015 LEO Network post by Charles O'Domin Sr. and Oxcenia O'Domin (ANTHC), documented a decrease in the number of seals near the shoreline. However, more sea otters have been seen in recent years, some hauling out with harbor and ring seals. (Scott Anderson, Jaclyn Christensen, LEO Network Post May, 2017). The clams that residents have been able to harvest were sent to the State of Alaska lab in 2015 for testing. That test batch returned with levels below the US Food and Drug Administration limit for PSP toxins (Scott Anderson), considered to be 80 micrograms per 100 grams of shellfish tissue (SeaGrant, 2017). Saxotoxin is a neurotoxin produced by Alexandrium algea blooms (commonly known as red tide), which can lead to paralytic shellfish poisoning. Ingestion of saxotoxin will result in numbness or tingling around the mouth or in the fingers. Symptoms may progress to paralysis and difficulty breathing, which can be fatal (Southeast Alaska Tribal Ocean Research, 2017). Large clam feeds, commonplace in many memories, are no longer held in the community (Annie Christensen).

Changes to the marine ecosystem are also evident in both subsistence and commercial salmon fishing. Overall, residents consider salmon abundance to have increased since 2002, when permit prices dipped along with the price of fish, allowing more residents an

Blue mussel and cockle shells.
Photo by Mike Brubaker

opportunity to enter into the industry through permit purchase (Scott Anderson). Salmon are harvested in the subsistence fishery as well as commercially, and residents can also retain commercial salmon for home use. While the salmon have become more plentiful, residents notice changes in the timing of the runs. The Fourth of July holiday has historically been a busy fishing time. Today, residents begin preparing fishing boats and gear during May and June, as the run timings creep earlier in to the year (Sarah Anderson). Commercial fishers have reported changing their fishing areas and seeking fish that swim in the deeper, cooler waters (Jimmy Christensen).

A series of changes have also occurred in the rivers near the community. The largest of these is the Meshik River, which originates from the southern slope of Mount Aniakchak, and serves as an important salmon fishing location. Fishers report lower water levels and more sandbars (Jimmy Christensen, Annie Christensen). Residents wonder if sediment from the coastal erosion is building up near the mouth of the river, with the potential to prevent fish or boat passage in the future. The river north of the community, Reindeer Creek, also has changed within

Meshik beach subsistence set net site.
Photo by Erica Lujan

recent memory, with residents reporting that it is becoming 'shorter' (Jaclyn Christensen).

> ***"When we first moved here the mouth of the river seemed far away, had to really drive to it, and there was a swimming lake right next to it. Every year that river changes and it seems like it's becoming shorter."***
>
> *—Jaclyn Christensen, Port Heiden*

Fishers also report seeing physical abnormalities in salmon. Some fish have white spots on the skin, and at times it is more difficult to find healthy looking fish (Gerda Kosbruk). Documented in a LEO Network post, salmon caught in the Meshik during the summer of 2015 were found to have a mushy texture to the meat and a putrid smell when cut open, despite a healthy outward appearance (Jimmy Christensen, Erica Lujan, Jayde Ferguson, LEO Network Post 2015). These physical abnormalities may be attributed to the parasitic infection Kudoa thyrsites, characterized by a softening of the flesh. Fish that were harvested with odd-looking white spots, or with a poor meat quality, and were thrown out. King salmon caught from beach set nets have been increasing in number and size, but those in the Meshik River are found to be smaller and fewer in number (Nefuti Orloff, Hank Matson). Sandbars and shallow water prevent access to the river, and boats are only able to travel about 10-20 miles up stream (Jaclyn Christensen).

Residents historically collected gull eggs on Chistiakof Island, which has now eroded away (Annie Christensen, Nefuti Orloff). As gull eggs have become a less common food in the community, the taste for these eggs among younger residents is waning, indicating a decline in the local use of a nutritious food source. Erosion around Goldfish Lake has caused residents to look elsewhere for waterfowl hunting, often heading across the bay to Strogonof Point (Annie Christensen).

The warmer temperatures and changing precipitation patterns have led to observed changes in the timing of vegetation cycles and the abundance of certain plant species. The Alaska Center for Climate Science projects an increase in the length of the growing season by 45 days between 2030 and 2059 (Appendix 1.) Willow bushes and other vegetation have become taller in areas across the tundra, providing ample moose browse. However, with some plants reaching approximately 30 feet, moose hunting can become more complicated. Although the animals have not changed their

distribution, they are more difficult to access for some who cannot easily navigate the heavily vegetated hill areas (Tisha Kalmakoff, Billie Schraffenberger). Wetland areas have changed, and tall grasses have replaced swamps. As the grasses regenerate, the tundra builds upon itself, layer by layer of vegetation (Jimmy Christensen). Two cycles of wild parsley, known as Putchki, and two cycles of dandelions can be seen over the course of one summer. As far as local gardening, residents have primarily root vegetables, which are more stable in the cool temperatures and windy environment. However, warming temperatures are allowing for a greater variety of garden vegetables that residents are able to grow, such as tall celery and leafy greens. Small raised bed and greenhouse gardens are becoming more common in the community, in an effort to take advantage of warmer temperatures and diversify the garden harvest (Tisha Kalmakoff, Billie Schraffenberger).

Garden plot near Ray's place.
Photo by Erica Lujan

Subsistence foods and a healthy traditional diet are essential in maintaining the health of rural Alaskan residents, and Port Heiden is no exception. Fluctuations in the abundance and accessibility of caribou, salmon and other traditional foods have caused residents to rely more heavily on market foods purchased from the store. Despite the necessity, commercially sold meats are very expensive (Annie Christensen). Community Health Aids have noticed an increase in allergic reactions to food coloring and food preservatives, as well as low iron levels in children. Physical activity previously associated with more frequent subsistence activity has decreased, and weight issues have become more prevalent. Pollen allergies from longer growing seasons may also be keeping people inside (Trisha Christensen, Billie Schraffenberger).

Residents also expressed concern that wild berries may be impacted by contaminated soil. While not thought to be influenced by climate change, legacy sites with PCBs and other chemicals are an environmental health concern and harvest from areas identified as contaminated should be avoided. Contaminated sites around Port Heiden are largely the result of the U.S. Air Force radio relay station, constructed in 1942. While the station was in operation, contaminants were released in to the soil from spills, leaks, and other events. Included in these were polychlorinated biphenyls (PCBs), Trichloroethylene (TCE),

other chlorinated solvents, diesel fuel, and petroleum constituents. PCBs are a broad category of manufactured chemicals used in electrical and hydraulic equipment, plasticizers in paints, plastics, and rubber products, among others. PCBs are "persistent" meaning they remain in the environment, cycling between air, water and soil and wildlife and when consumed in elevated levels can affect the health of people (EPA – Polychlorinated Biphenyls, 2017). TCEs are also manufactured chemicals, used in adhesives, as well as grease and paint removers, which can also impact human health through short term or prolonged exposure (DEC, 2017, EPA, 2017). After the station was deactivated in 1978, the barracks, the radio station, the antennae, and other equipment and buildings were demolished and buried in landfills (Health Consultation: PCB Evaluation Associated with Former Fort Morrow, Port Heiden, Alaska, 2014).

The Alaska Department of Environmental Conservation, Contaminated Sites Program, has documented sixteen contaminated sites around Port Heiden. Five of these sites have been completely cleaned, and three additional sites are considered cleaned with institutional controls. Seven sites are currently open, and one site remains in the informational stage[3]. The active sites are clustered around the Radio Relay Station Facility area, along the former pipeline corridor, which stretched between the radio relay station and the airstrip, along airport road between the airport and the marine terminal area, and the coastal marine terminal. Beginning in 1981, the Air Force 5099th Civil Engineering and Operations Squadron began removing hazardous material and contaminated soils, and oversaw the demolition of the radio relay station facility. Between 1995 and 2005, the Air Force and Army Corp of Engineers sampled soils and determined the extent of the contamination. Contracts for cleanup activity were awarded in 2007, and cleanup efforts have continued since (DEC Port Heiden Radio Relay Station Site Summary).

Military use of the area surrounding Port Heiden left contaminated soil.

[3] An "informational" listing is used when the DEC is tracking a site where the nature and extent of contamination is not known. (Personal communication with Christy Howard, DEC).

Near the coast, remnants from previous cleanup efforts are beginning to appear as the coast continues to erode. In 2007, the U.S. Army Corps of Engineers removed approximately 2,500 metal drums and other debris from the Port Heiden coast. During the drum excavation, around 3,000 cubic feet of soil was removed, of which 84 cubic yards were shipped to Oregon for disposal. The remaining soil tested below the Alaska Department of Environmental Conservation Method Two cleanup criteria. A jute (coconut fiber) liner, approximately 180 feet long, and 60 feet wide, was laid down to protect the coast from wind and water induced erosion as the area was revegetated. The jute liner is now eroding out of the bluff due to coastal erosion and washing into the coastal waters. As a result of this process however, there are no longer any FUDS-era drums or contaminated soils in the area, and according to ADEC, no remaining risk to human health or the environment in this area (personal communication with Louis Howard, Department of Environmental Conservation).

The DEC acknowledges that there are still detectable levels of PCB, TCE, chlorinated solvents, diesel and other petroleum constituents in the soil and groundwater surrounding the former radio relay facility. Exposure to these contaminants could occur through contact with contaminated soil and water, or through ingestion of fish and wildlife with bio-accumulated amounts of PCBs. In 2014, a report by the U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, found that there would be low risk of PCB exposure if residents avoid eating berries growing from contaminated sites. Small land mammals hunted in the areas showed low levels of PCBs, however no tests have been done to cockles, and other shellfish and are a recommended next step in ensuring food safety (USDA, 2014).

The Port Heiden Environmental Program has excellent capacity to re-use and recycle material. Two 250,000-fuel storage tanks salvaged from the old village have been moved and repurposed as a small airplane hangar and the community recycling facility. Here, old appliances and utility wires are processed, and aluminum is crushed, in preparation for recycling. A roll up garage door was installed to facilitate vehicle repair, and salvage. The environmental program employs community members, and builds valuable skills among the youth.

One 250,000 gallon fuel storage tank reused as an airplane hangar.
Photo by Mike Brubaker

Conclusion

"We lost our safe boat harbor. Launching is particularly a problem. We have to build ramps, and the waves are risky and it's hard on equipment. We have had boats that sink in the lagoon."

—Scott Anderson, Port Heiden

Environmental changes in Port Heiden are apparent in many different aspects of the ecosystem and community life, and are linked to climate change in varying degrees. Most significantly, changes in coastal morphology, caused in part by changing sea ice conditions, have allowed storms to erode the bluffs with greater frequency and intensity. As a result, Port Heiden experiences severe erosion of its pumice-rich coast, which has washed away miles of bluff, a small island in Bristol Bay important to subsistence, and a land barrier creating a protected lagoon. After losing the calmer waters of the lagoon, commercial fishers are launching their boats in unprotected waters, risking injury and damage to boats. The commercial fishing season in Bristol Bay is beginning earlier with continued abundant runs, but some salmon harvested from the Meshik River near Port Heiden are observed to have physical abnormalities. The abundance of clam and cockles on the beach has diminished, as has the practice of collecting gull eggs from the now-eroded Chistiakof Island. However, warmer temperatures have extended the growing season, increasing the crop possibilities for community gardens and the Meshik Farm, but has also lengthened the seasonal allergy periods. Warmer temperatures and winter precipitation events, which are expected to increase in the future, currently cause localized flooding over septic leach fields during the winter, risking contamination in neighboring wells that may not be adequately sealed. Seismic activity in the area is associated with frequent changes to well water quality, by increasing iron levels, and requiring frequent filter changes.

As conditions continue to change, Port Heiden residents are integrating scientific climate projections with traditional knowledge and local observations as they plan for the future. This report is intended to highlight both the positive and negative aspects of environmental change in Port Heiden, and to frame the changes and impacts so that they may be understood during adaptation planning.

Warm winter temperatures cause localized flooding on top of household septic fields.
Photo by Scott Anderson, Port Heiden Environmental Department

Every year, Port Heiden residents use heavy machinery to build a temporary boat ramp used launch boats in to Bristol Bay at the beginning of commercial fishing season.
Photo by Erica Lujan

Adaptation Planning

Information from the climate change assessment was used in an adaptation-planning workshop in Port Heiden, facilitated by ASG, ANTHC, and BBNA, during April of 2018. During the workshop, Port Heiden residents described the vision they had for their community in the future. One of the primary goals that came out of the workshop was to strengthen the foundation of community health by addressing the water quality issues with the current water system, as well as the high cost of energy, and further developing the Meshik Farm so that it can provide healthy foods to the community while remaining as self-sufficient as possible. The second goal is for the community to become a regional hub, through the construction of a safe harbor and airport building, and begin operations at the completed fish processing plant, the Meshik Processing Center. Eventually, the community would also like to support tourism to Aniakchak National Monument and Preserve. Although these have been long-standing goals for the community, they are now being re-examined in the context of a changing climate using the climate information provided by the Alaska Climate Adaptation Science Center.

The goals to strengthen community health will also play a fundamental role in the development of Port Heiden as a regional hub. A reliable source of adequate clean water is necessary for the health of residents as well as that of visitors. The type of water infrastructure in place will influence the construction of future buildings, such as the planned airport terminal, and for the operation of the fish processing plant. The Alaska Department of Environmental Conservation has outlined several possibilities for future water-system improvements that may be revisited. Information such as changes in precipitation, snow-water equivalent, snowpack vulnerability and sea level rise need to be taken in to consideration when evaluating the best option for future improvements. Increases in precipitation levels may increase the risk of groundwater contamination from dissolved solids on the surface in wells without an effective seal. Additionally, changes precipitation and snowpack may impact the ability of households wells to recharge and prevent saltwater intrusion as sea levels rise.

Similarly, affordable energy lowers household bills, and prevents an increase in the cost for goods and services provided through the fish processing plant, airport and other tourism related activities. Associated costs for these three revenue sources need to be kept low, as they are also expected to create jobs for Port Heiden residents. The community has explored alternative energy sources such as hydro and wind power. Feasibility studies for wind and pumped hydro power have been completed by the Alaska Energy Authority (AEA) and Tanadgusix (TDX). Changing temperatures may impact the results of the feasibility assessments.

Port Heiden community discussion about observed changes in the environment.
Photo by Mike Brubaker

Growing reliance on store-bought foods also presents a high household expense. Further development of the Meshik Farm is intended to provide residents with a reliable source of healthy foods, as well as a source of revenue for the village through food sales. The ability of the farm to support enough vegetable and fodder crop to supply food to both livestock and residents will be heavily impacted by changes in temperature and water availability. Changes in these aspects may determine what types of vegetation can be grown in the area, as well as the total yield. This may impact the amount of livestock that the farm can support, if those animals cannot also browse the natural vegetation in the area. Collaboration with other farm projects around the state may provide a set of best-practices that can be taken in to consideration with the climate information as plans are made for further growth of the Meshik Farm.

Construction of a boat harbor, construction of an airport terminal, and the operation of the Meshik Processing Center both could have a significant economic impact for the community. Goldfish Lake is expected to breach during 2018, providing a potential space for the future harbor. The harbor will allow fishers to launch their boats in an area protected from heavy wave swells in open water, which may damage boats at the onset of the season. There is no other safe harbor from Port Moller to Pilot Point along the Alaska Peninsula. Additionally, it will promote Port Heiden as a place for other area fishers to stop and make purchases from the local store and Meshik Farm, generating revenue for the village. Construction of the harbor is also necessary for fishers to quickly and safely offload their harvest for transport to the Meshik Processing Center, before getting flown out of the community to fulfill customer orders. The operation of the processing center is expected to create at least 10 jobs for community members, as well as enhance income for local commercial fishers. The airport terminal is also expected to create jobs through airport and tourism related services. Feasibility of the harbor construction and maintenance is heavily dependent on information about the drivers of coastal erosion in the area and projected measurements. The dataset created from the community-based erosion monitoring project is imperative to consider, along with other climate information, such as temperature change, that may impact the frequency and severity of coastal storms.

Each community priority outlines the public health and economic impacts the community currently faces, and the expected benefits from meeting these goals. In addition, general short and long-term actions have been identified to help meet each community priority.

Summary Climate Change Assessment Findings:

TEMPERATURE & PRECIPITATION	*Overall, temperatures and precipitation is increasing.* Increased moisture may be related to the recent occurrence of mold inside homes, which affect indoor air quality. Winter precipitation events, and early surface thaw, have caused localized flooding around homes.
SEVERE STORMS	*Local accounts report that severe storms are becoming more frequent.* Reduced sea and shore ice and increased wave action generated during storm events contributes to severe coastal erosion, which threatens Goldfish Lake, and the coastal road.
WATER QUALITY	*Community members reported sudden changes in well water quality.* Changes in well water quality are often characterized by sudden changes in taste and color. These changes may possibly be associated with earthquakes and severe storms. *Localized flooding around wells risk contamination due to lack of drainage.* During winter precipitation and/or periods of mid-winter thaw, water accumulates over some household septic leach fields, risking contamination of neighboring wells.
VEGETATION	*Temperature increase during the summer months has led to a longer growing season.* Warmer summers open up more possibilities for the variety of crops that can be grown in community gardens, but also allow willow and alder to grow taller. Pollen allergy season has lengthened. *Temperature changes that promote vegetation growth are affecting subsistence.* Tall brush impact the ability of hunters to spot and harvest moose and caribou.
INFRASTRUCTURE	*Debris from the Meshik village site are in danger of eroding in to Bristol Bay due to severe coastal erosion.* Underground utilities and jute fiber lining from previous cleanup efforts is emerging from the bluff between the coast and the bank of Goldfish Lake. *Coastal erosion may increased the risk of injury.* Coastal erosion has forced commercial fishermen from Port Heiden to launch their boats in open water, as the sheltered boat launch has fully eroded. Launching in unprotected open water risks both damage to the boats and human injury. Residents also risk injury when traveling the road between the coast and Goldfish Lake. The eroded bluff facing the coast is seeping freshwater from Goldfish Lake, increasing risk of breach during a severe storm or tidal event.
FOOD SECURITY	*Subsistence resources are changing.* Commercial and subsistence fishermen have reported unusual fish behavior, parasites and changes to the quality of meat, which they believe is related to warming water temperatures. Many residents consume cockles and other shellfish, which should be regularly tested for PSP. Changes in the availability of subsistence resources has caused residents to consume commercially produced food, which is not as nutritional as traditional subsistence foods.

Summary Findings: Health Impacts

TOPIC	DESCRIPTION	OBSERVED CHANGE	COMMUNITY IMPACTS	HEALTH CONCERNS	RECOMMENDATIONS
Weather	Precipitation	Increase in annual precipitation levels and winter rain events	Localized winter flooding	Flooding affects home septic systems	Evaluate drainage around homes with septic systems. Develop water-monitoring protocol to test for possible contamination from neighboring septic leach fields.
	Temperature	Increase in air temperature	Longer growing season, ability for a wider variety of crops to grow	Extended pollen season	Monitor changes to air quality using LEO, construct greenhouse to shelter gardens from wind and other storms
Air	Indoor Air Quality	Increase in air temperature and moisture levels	Increased incidence of mold and mildew inside homes	Respiratory health (sneezing, coughing, wheezing), headache, fatigue, and other associated symptoms	Perform home assessment to identify indoor air improvements, monitor indoor humidity levels, ensure adequate ventilation
Water	Quality/Availability	Change quality of well water following earthquakes and severe storms.	Changes in water quality affect taste and appearance, raising safety concerns.	Supply shortages of palatable drinking water, increase cost of changing water filters and replacing stained appliances	Systematic well water to determine variables associated with changing water quality. Creation of community water plan to accommodate variability in well water quality
	Recreation	Severe erosion between the coast and Goldfish Lake that will lead to a lake breach	Loss of recreation area	Reduced level of physical activity	Creation or identification of alternative recreation sites
Land	Infrastructure/ Economy	Severe storms and wave activity have eroded the safe boat launch	Boats are launched in open water, vulnerable to wave swells	Risk of injury and property damage, potential for delayed launch.	Explore all future construction relating to adaptation using a common set of design engineering parameters
Wildlife	Food Security	Some salmon have discolored skin, and unusual smells in the flesh, potential for shellfish to accumulate PSP toxin	Disruption of subsistence practice and nutritious food consumption	Nutritional deficiency from market food, weight gain	Monitor changes to subsistence resources using LEO Network, test shellfish for PSP in light of temperature changes

Meshik village structures waiting for removal.
Photo by Erica Lujan

"Moving away from the beach, people used to be able to have their nets out and now it's harder to get down. Erosion changed the beach and where people put their nets out. And now people can't always fish or clam."

—Hank Matson, Port Heiden

Community Priorities

Community Water Goal: Identification of alternative water source

PUBLIC HEALTH IMPACT

- Residents currently experience sudden changes in the taste and color of household well water following earthquakes.
- Floodwater from mid-winter precipitation events collects on top of septic leach fields, risking posing a health risk if people, pets or livestock are exposed to septic overflow or if water infiltrates neighboring water wells.
- Flood waters collect around electrical transformers, risking damage to the transformers and electrical grid.

ECONOMIC IMPACT

- A reliable water source is crucial for providing services as a hub community, for the Meshik Processing Center, and to support tourism to Aniakchak National Monument.

Short Term Actions:

- Dig culverts to re-route winter floodwaters and make sure culverts stay clear during winter.
- Raise electrical transformers onto gravel pads to protect them from inundation.
- Implement a well water testing protocol for coliform bacteria contamination, iron and manganese levels.

Long Term Actions:

- Conduct an updated area-wide hydrological assessment to determine the best alternative water source and create a prioritized list of sources based on reliability and cost.
- Follow-up with a feasibility assessment for prioritized new water sources.
- Develop the new water source that benefits the commercial activity of the community and community health and safety.

High iron content in well water stains household appliances.
Photo by Erica Lujan

Community Energy Goal: Identification of reliable, affordable, energy source

PUBLIC HEALTH IMPACT

- There is a need for LED street lighting to enhance resident safety.
- The current high cost of energy means a stagnant growth in the economy and investment in infrastructure that benefits better community wellbeing.

ECONOMIC IMPACT

- The cost of electricity is much higher in Port Heiden compared to urban areas in Alaska ($0.75kWh non-PCE, $0.28 kWh PCE, which increases the cost of infrastructure that use high amounts of energy (i.e. fish processing plant and harbor).
- Current electrical generators are over-sized and operate at a low part-load capacity. The amount of diesel fuel needed to run the oversized generator limits efficiency and increases cost.
- Current power quality is poor, resulting in outages and damages to electrical equipment.

Short Term Actions:

- Housing assessments to determine enhancements that could reduce household energy consumption while benefiting indoor air quality.
- Weatherization of existing housing and public facilities.
- Review results from the Alaska Energy Authority (AEA) and Tanadgusix (TDX) Anemometer wind studies, pumped hydro storage study.
- Conduct a feasibility study for ground source heat pumps and other sources of geothermal power generation.
- Determine the best alternative, or suite of alternatives that could be implemented as a package and conduct a site assessment.

Long Term Actions:

- Purchase a smaller more efficient generator, or potentially a generator that is modular, and can work with alternative sources of power.
- Renovate a salvaged house from Meshik to act as a location for wood pellet fabrication.
- Contract feasibility studies for alternative energy sources.
- Develop the new energy source or suite of sources.

Inline fuel pump.
Photo by Mike Brubaker

Economic Infrastructure Goal: Construction of a Safe Harbor

PUBLIC HEALTH IMPACT:

- The protected lagoon where commercial fishers launched their boats has eroded. As a result, commercial fishers are launching fishing boats in open water, where they are vulnerable to sudden wave swells. This increases the risk of personal injury and damage of boats.
- There is currently no harbor between Port Moller and Pilot Point. Fishers who are injured, sick, or caught in a storm, cannot easily access medical care.

ECONOMIC IMPACT:

- By launching in open water, fishers risk damage to their fishing boats at the beginning of the season.
- Lack of a harbor prevents fishers from outside of Port Heiden from offloading their commercial harvest for transport to the Meshik Processing Center, and visiting the Port Heiden store during fishing season.
- It is costly to re-build the landing every year for the barge and to launch the commercial fishing boats.

ECONOMIC BENEFIT

- A harbor would reestablish Port Heiden as a regional hub community greatly enhancing the economy as well as fisher safety.

Short Term Actions:

- Identify potential location for future harbor.
- Conduct a feasibility study for a potential harbor development.
- Identify certifications necessary for local employment

Long Term Actions:

- Identify potential funding sources for harbor construction
- Contract construction company

Commercial fishing is an important source of revenue for Port Heiden.
Photo by Mike Brubaker

Economic Activity Goal: Begin Operation of Meshik Processing Center

- The success of the Meshik Processing Center corresponds with the construction of a harbor.
- In conjunction with development of a reliable clean water source and reliable power the fish processing plant will be more economically viable.

PUBLIC HEALTH IMPACT:

- Variability in subsistence salmon harvest and species abundance has caused residents to rely more heavily on shelf-stable foods and meat flown in from urban areas at a high cost.

PUBLIC HEALTH BENEFIT:

- An operational processing center would provide a reliable source of healthy meat at a reduced cost.

ECONOMIC BENEFIT:

- A tribally owned fish processing center creates a longer fishing season for area fishers, with the intention to operate beginning with Chinook runs and ending with Coho runs.
- The fish processing center currently creates jobs. In conjunction with a harbor the processing activities could be expanded further employing additional residents.

Short Term Actions:

- Identify steps to get the correct certifications on community-constructed electrical and plumbing systems.
- Finalize plans for freezing equipment and methodology for maximum cost effectiveness.
- Finish the business plan acquiring all certifications and licenses.

Long Term Actions:

- Construct a safe boat harbor to enhance and expand the Meshik Processing Center.

Constructed Meshik Fish Processing Center.
Photo by Erica Lujan

Economic Infrastructure Goal: Construct Airport Building to Support Airline Partnerships

PUBLIC HEALTH/ECONOMIC IMPACT:

- Significant variability in flight schedule impacts the ability of people to travel to urban areas to receive medical care.
- Freight cost and frequency of flights limits the ability to bring in goods to the community.
- Lack of an airport building limits large passenger planes from flying into the community which has larger faster planes and set schedules.
- Lack of a building means no welcome center for tourists to provide them with services and educate them on the hazards of backcountry travel in the area.

PUBLIC HEALTH BENEFIT:

- More flights and increased competition between carriers will increase the amount and variety of foods and other goods flowing in to the community.
- There will be more reliable transportation to urban areas for medical care.

ECONOMIC BENEFIT:

- More flights will increase the flow of goods that may be marketed to commercial fishers.
- Competition could potentially drive down the cost of air travel by attracting multiple air carriers.
- A welcome center at the airport will increase the potential for tourist travel to Anaikchak National Monument & Preserve.
- Commercial fishers could dock their boats at the new harbor paying dock fees and use the airport during breaks in the season.
- An airport will create jobs for ticket agents, baggage carriers, etc.

CURRENT ACTIVITY:

- The City of Port Heiden is currently leasing land and selling fuel, but it is not generating a significant amount of revenue.

Short Term Actions:

- Develop a building plan and associated cost assessment for construction.
- Develop a business plan for airport and tourism related services.

Long Term Actions:

- Develop a business partnership with additional air service providers.

Port Heiden is currently served by Lake Clark Air and Grant Aviation.
Photo by Bailey Richards

Food Security Goal: Increase the availability of cost effective, healthy foods by increasing Meshik Farm yield

PUBLIC HEALTH IMPACT:

- The overall decrease in subsistence harvest due to abundance, variability, and species health has caused residents to rely more heavily on shelf-stable foods and meat flown in from urban areas at a high cost.

PUBLIC HEALTH BENEFIT:

- The creation and expansion of vegetable gardens provides a source of produce at a commercial level to be available in the community.
- Barley and other fodder crops decrease the cost of raising livestock and increase livestock yield (i.e. meat, milk, eggs)
- Healthy foods are readably available for purchase at low cost.
- Healthy foods are available for elder lunches at the community center.
- Partnering with the school to start vegetables in the classroom in the spring can provide an education for children on health, chemistry, etc. and provide older kids with an income in the summer as they follow their starts to production.

ECONOMIC BENEFIT:

- The sale of produce and animal products can support local jobs.
- Produce could lower the cost school lunches as well as community events such as elder lunches.

Short Term Action:

- Network with other communities supporting gardens to develop best-practices such as the Tyonek Grown Program.
- Work with Cooperative Extension Staff to identify best greenhouse design for windy environments.
- Seek education in growing requirements and soil composition for garden crops.

Long Term Action:

- Identify funding source for greenhouse construction and transport of garden supplies.
- Develop a business plan that makes the farm economically sustainable.

Meshik Farm chickens.
Photo by Erica Lujan

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Melissa O'Domin holds a GPS used to measure coastal erosion rates.
Photo by Richard Buzard

Historical and Projected Climate and Derived Variables for the Port Heiden Region

Appendix I

Historical and projected climate variables were obtained from SNAP (UAF) in raw gridded format. Fine scale (771m) decadally averaged gridded temperature (Temp) and precipitation (Precip) derived from were used to develop a historical 30 year climatology for 1970-1999, derived from PRISM and CRU TS 3.1. Future climate model projections downscaled to the same 771m grid historical were develop for two climatologies: the 2050s – 2040-2069 and the 2080s – 2070-2099. These projections represent the average of five different climate models (CMIP5/AR5 generation) and are presented for two emission scenarios, medium emissions RCP 4.5 and high emissions RCP 8. Littell et al. (2018) used SNAP temperature, precipitation and snow-day fraction (McAfee et al. 2014) to develop snowfall water equivalent – how much water falls as snow – as an index of snowpack for the same climate models and emissions scenarios. Snow index (SNI, the ratio of snowfall water equivalent to total precipitation between October and March) is also presented. Finally, we used length of growing season (days between last spring freeze and first fall freeze from single model (CGCM3, A2 emissions) used to drive the SNAP Integrated Ecosystem Model (IEM). All climatic variables were spatially averaged by HUC12 watersheds across Alaska, and are reported for watersheds for communities in the Port Heiden region below.

Historical temperature and projected changes by scenario

Community	HUC12 Watershed	1970-1999 Temp (F)	RCP 4.5 2050s (F)	RCP 4.5 2080s (F)	RCP 8.5 2050s (F)	RCP 8.5 2080s (F)
Chignik	190207021505	38.1	4.9	6.2	6.3	8.2
Dillingham	190303031108	35.1	5.6	7.2	7.3	9.5
Egegik	190302031109	36.6	5.3	6.7	6.9	8.9
Koliagnek	190303012008	34.5	5.6	7.2	7.3	9.6
Naknek	190302041503	35.7	5.4	6.9	7.1	9.2
Nondalton	190302051402	34.4	5.5	7.0	7.2	9.4
Pedro Bay	190302060901	31.8	5.4	6.9	7.0	9.2
Pilot Point	190302021107	36.8	5.2	6.6	6.7	8.7
Port Heiden	190302010305	36.1	5.0	6.4	6.5	8.4
Togiak	190303050904	33.9	5.7	7.3	7.4	9.6

Historical precipitation and projected changes (percent) by scenario

Community	HUC12 Watershed	1970-1999 Precip (in)	RCP 4.5 2050s (%)	RCP 4.5 2080s (%)	RCP 8.5 2050s (%)	RCP 8.5 2080s (%)
Chignik	190207021505	69.9	7.1	12.9	13.1	19.8
Dillingham	190303031108	25.0	3.5	16.1	16.5	26.7
Egegik	190302031109	20.1	2.2	13.3	13.7	22.0
Koliagnek	190303012008	30.9	4.7	18.3	18.1	28.3
Naknek	190302041503	19.6	2.4	14.5	14.7	23.3
Nondalton	190302051402	24.0	3.7	18.5	17.2	27.9
Pedro Bay	190302060901	54.2	7.6	17.4	15.8	26.4
Pilot Point	190302021107	18.7	2.0	12.6	13.6	21.2
Port Heiden	190302010305	20.8	2.1	11.6	13.0	19.9
Togiak	190303050904	30.6	4.4	16.6	17.5	28.3

Historical snow water equivalent (SWE) and projected changes (percent) by scenario

Community	HUC12 Watershed	1970-1999 SWE (in)	RCP 4.5 2050s (%)	RCP 4.5 2080s (%)	RCP 8.5 2050s (%)	RCP 8.5 2080s (%)
Chignik	190207021505	16.7	-30.5	-38.8	-41.4	-55.4
Dillingham	190303031108	6.4	-19.0	-28.1	-31.3	-47.8
Egegik	190302031109	3.8	-25.5	-33.7	-36.9	-52.0
Koliagnek	190303012008	8.3	-17.6	-26.0	-29.5	-46.1
Naknek	190302041503	4.2	-22.4	-30.6	-33.9	-49.5
Nondalton	190302051402	6.0	-20.8	-28.2	-31.5	-47.5
Pedro Bay	190302060901	16.2	-20.6	-27.5	-31.0	-47.1
Pilot Point	190302021107	3.6	-25.8	-34.0	-36.8	-51.5
Port Heiden	190302010305	6.2	-24.9	-34.7	-37.3	-55.6
Togiak	190303050904	8.6	-13.8	-23.3	-26.2	-44.8

Historical snow index (SNI) and projected future values by scenario. Snow index is the amount (%) of October-March total precipitation that falls as snow and is used to approximate April 1 snow available for melt. Greater than 40% is snow dominated; between 40% and 10% is transitional; less than 10% is rain-dominated.

Community	HUC12 Watershed	SNI 1970-1999 (%)	RCP 4.5 2050s (%)	RCP 4.5 2080s (%)	RCP 8.5 2050s (%)	RCP 8.5 2080s (%)
Chignik	190207021505	40.7	25.2	21.4	21.3	15.7
Dillingham	190303031108	59.8	41.0	34.8	34.7	25.2
Egegik	190302031109	48.5	31.4	26.5	26.5	19.2
Koliagnek	190303012008	62.3	43.6	37.2	37.3	27.1
Naknek	190302041503	54.7	36.6	31.1	31.1	22.6
Nondalton	190302051402	60.5	41.3	35.4	35.7	25.9
Pedro Bay	190302060901	65.2	45.0	39.0	39.1	28.5
Pilot Point	190302021107	45.5	29.5	25.0	25.1	18.4
Port Heiden	190302010305	67.3	44.6	37.2	37.3	25.6
Togiak	190303050904	72.7	52.4	44.7	44.8	32.2

Projected change in length of growing season between 1970-1999 historical and 2030-2059 (2040s) future for CGCM3 under an A2 (higher) emissions scenario.

Community	HUC12 Watershed	2040s* Change in Length of Growing Season (days)
Chignik	190207021505	51
Dillingham	190303031108	34
Egegik	190302031109	40
Koliagnek	190303012008	35
Naknek	190302041503	37
Nondalton	190302051402	30
Pedro Bay	190302060901	21
Pilot Point	190302021107	39
Port Heiden	190302010305	45
Togiak	190303050904	28

Alaska Climate Adaptation Science Center Climate Maps: Port Heiden

Figure 4

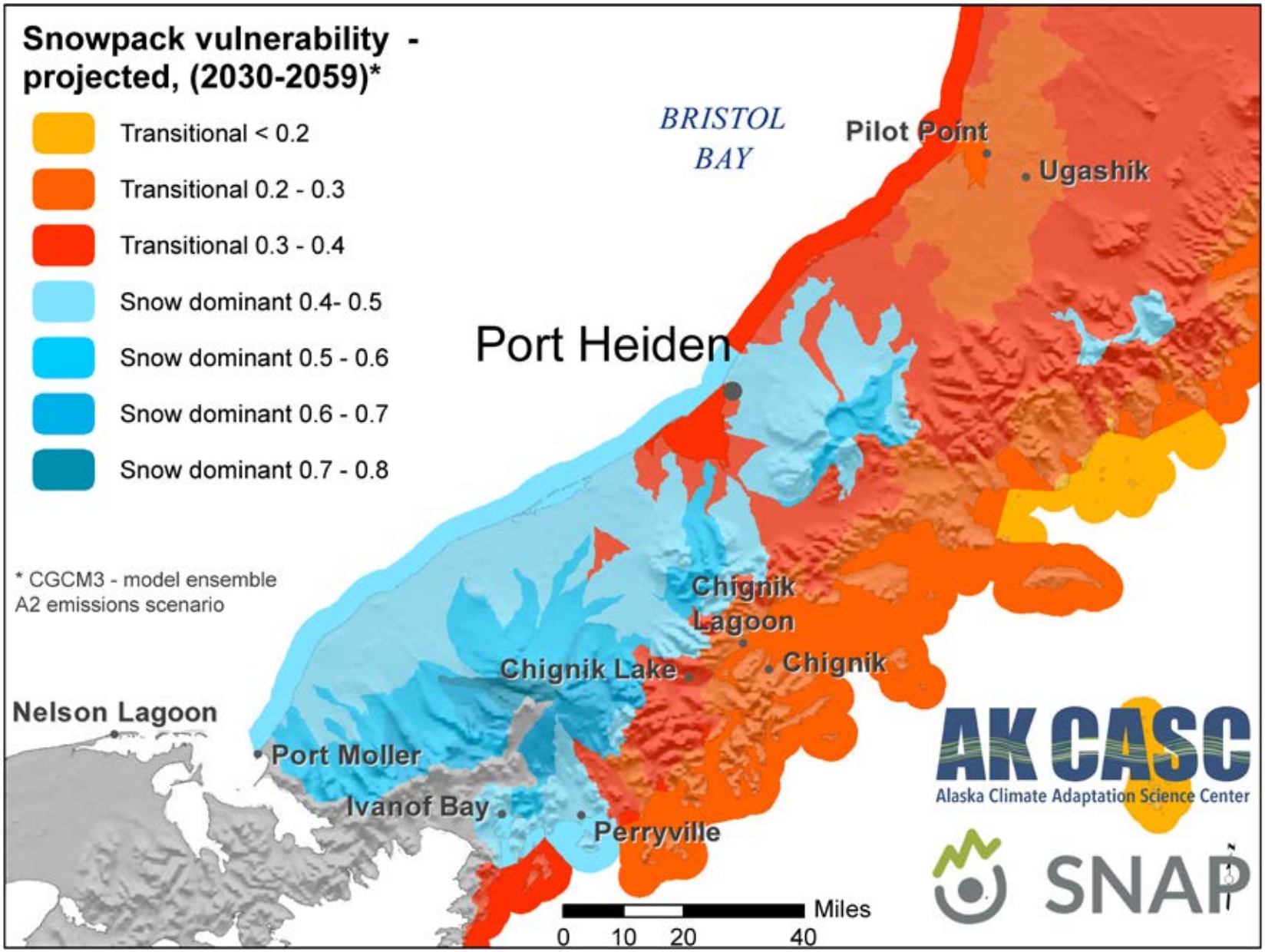


Figure 5

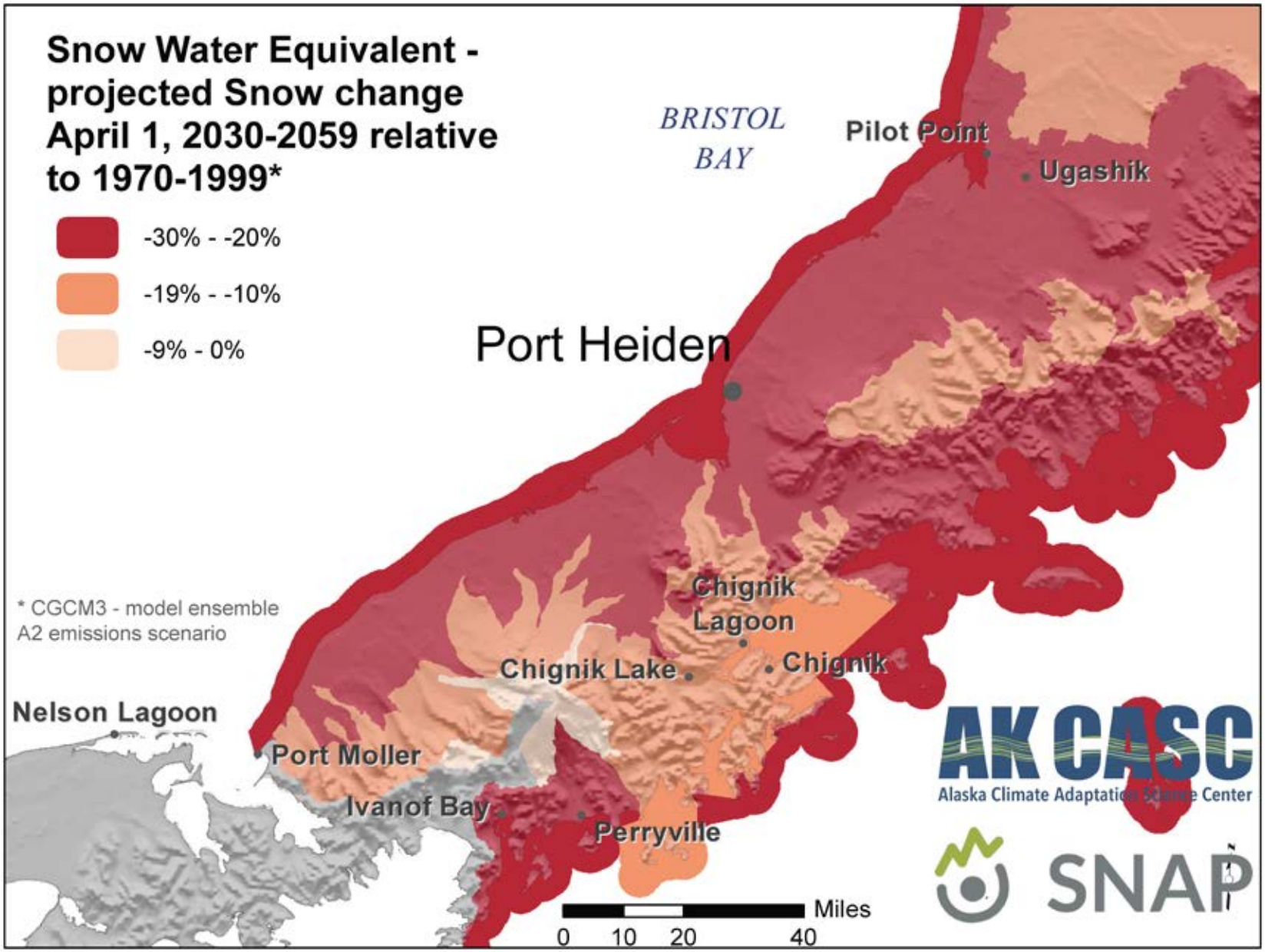
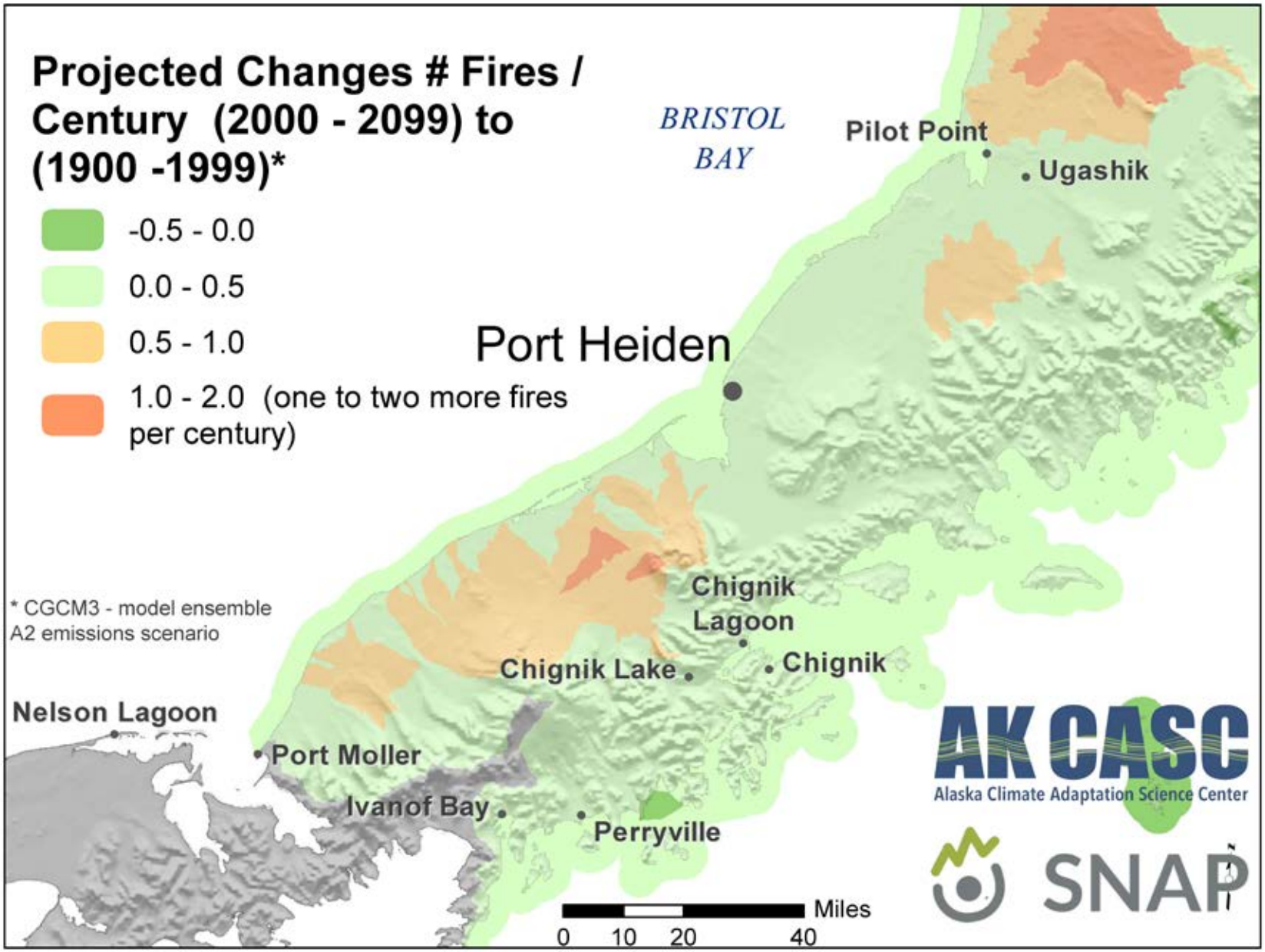

Snow Water Equivalent - projected Snow change April 1, 2030-2059 relative to 1970-1999*
-30% - -20%
-19% - -10%
-9% - 0%
* CGCM3 - model ensemble A2 emissions scenario
BRISTOL BAY
Pilot Point
Ugashik
Port Heiden
Chignik Lagoon
Chignik Lake
Chignik
Nelson Lagoon
Port Moller
Ivanof Bay
Perryville
AK CASC
Alaska Climate Adaptation Science Center
SNAP
Miles
0 10 20 40
Data Sources: https://www.snap.uaf.edu/ https://casc.alaska.edu/

Figure 6



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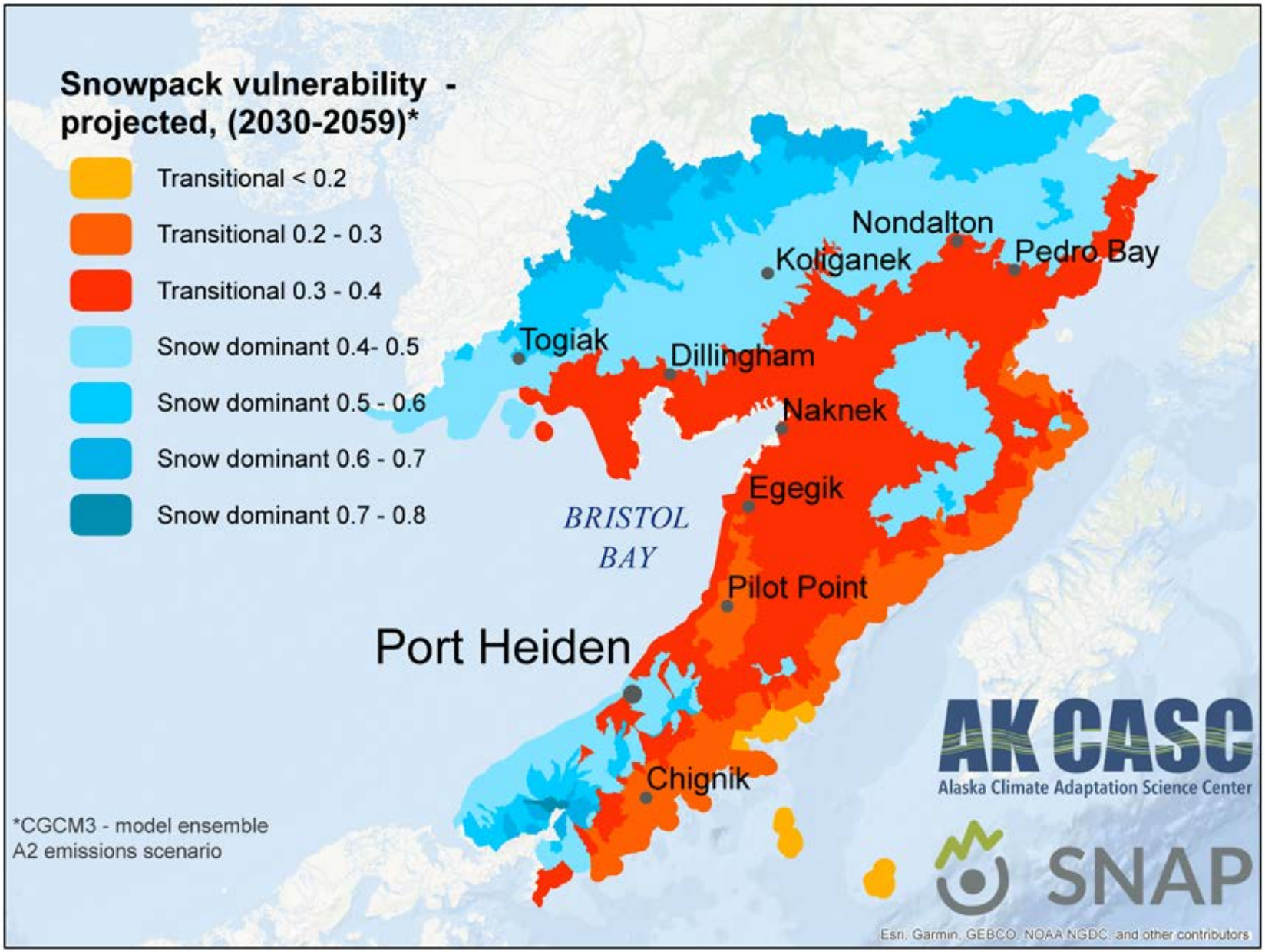
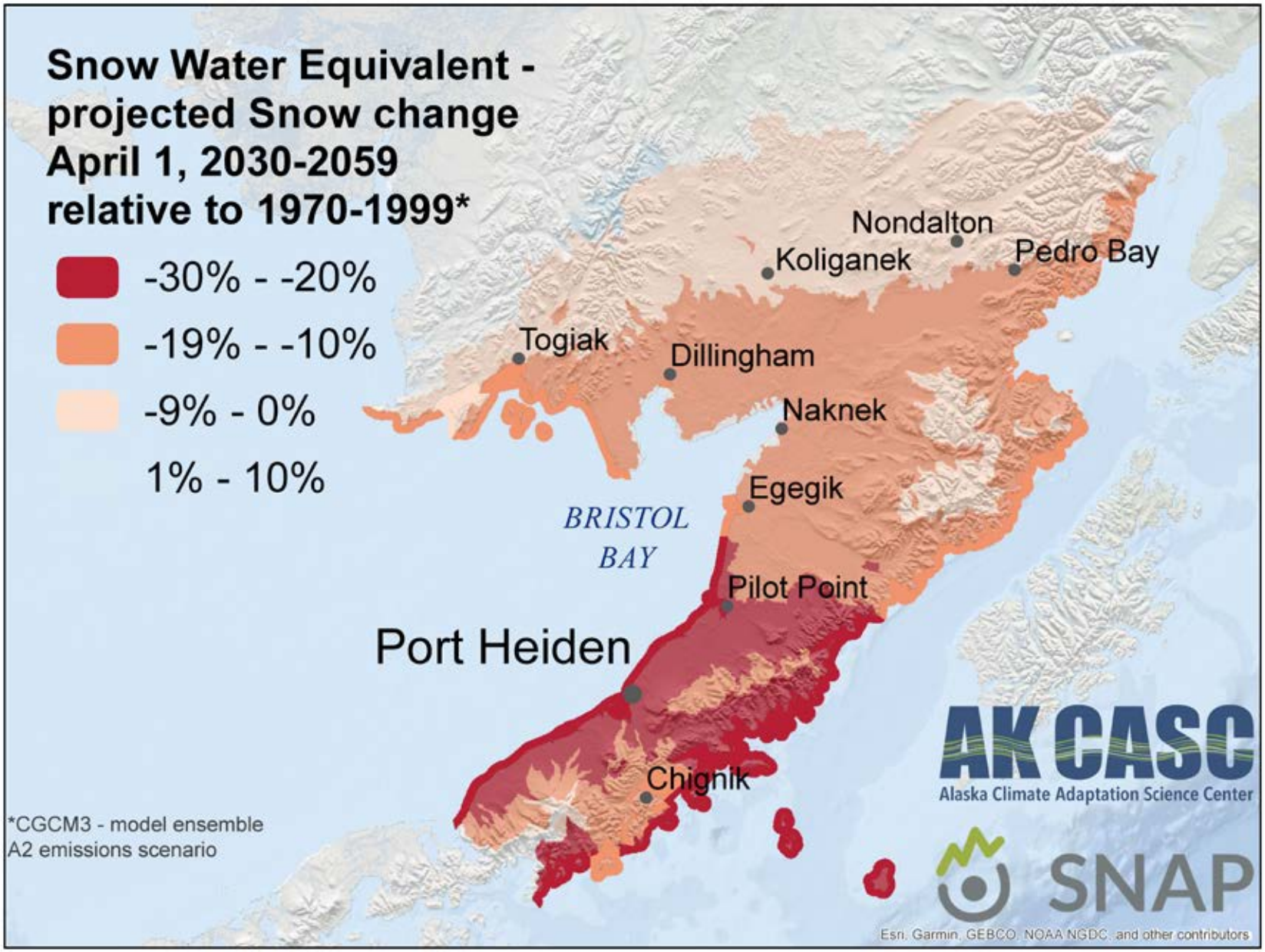
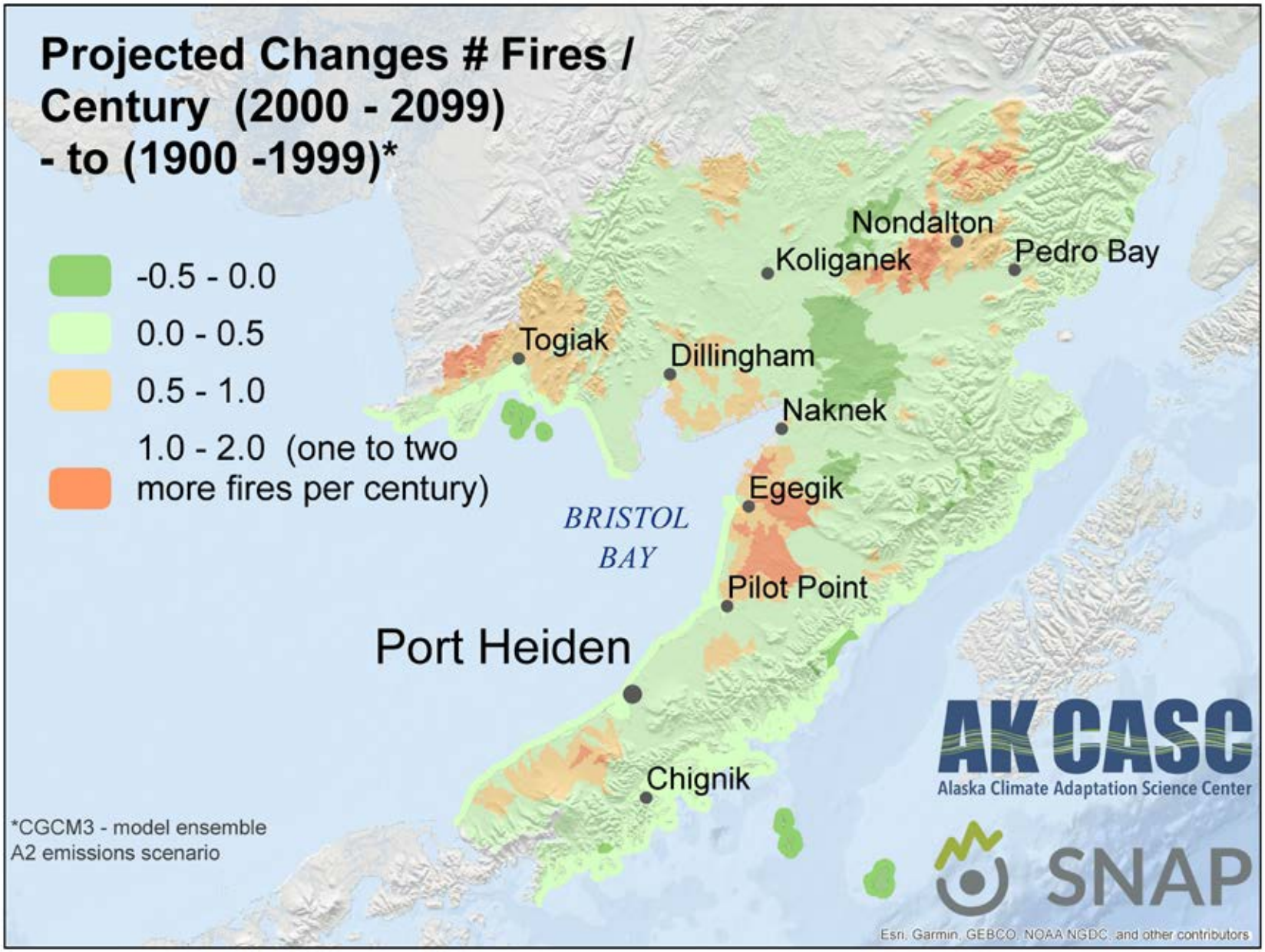


Data Sources: https://www.snap.uaf.edu/ https://casc.alaska.edu/



Data Sources: https://www.snap.uaf.edu/ https://casc.alaska.edu/



Data Sources: https://www.snap.uaf.edu/ https://casc.alaska.edu/

We would like to express our appreciation to our partners in the tribal governments and tribal organizations in the Port Heiden Region for making this project possible.

Alaska Native Tribal Health Consortium

U.S. Department of the Interior Bureau of Indian Affairs 1824

Bristol Bay Native Association

Native Village of Port Heiden