Climate Change and the Future of Freshwater Fish Habitat on the Kenai Peninsula

Supplemental document accompanying the Kenai Peninsula Fish Habitat Partnership 2022 Freshwater Conservation Plan

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Contents

Introduction

The 2022 Kenai Peninsula Fish Habitat Partnership Conservation Action Planning workshop generated a great deal of discussion and information regarding climate change and its effects on local ecological systems, so much as to merit this accompanying supplemental document. Here we provide a formal threat description of climate change, a list of observed and ongoing climate-related ecological changes, and a collection of case studies that highlight the state of knowledge on climate change and freshwater fish ecology in the Kenai Peninsula region.

Threat Description of Climate Change

The Climate Change group summarized the challenges and opportunities related to climate change and freshwater fish habitat in the Kenai Peninsula region as follows:

> *Contemporary directional climate change is primarily driven by human impact and is occurring at a much more rapid rate than previously anticipated.*
>
> *The primary threat of climate change can be measured in changes to physical drivers, such as temperature and precipitation, which can then cause wide-ranging system changes. Secondary threats include cascading ecological effects that occur when changing physical drivers act as root causes to other measurable landscape changes. For example, warming air temperatures can create biomes that support new invasive species.*
>
> *Finally, there are both opportunities and threats that arise through an anthropogenic response to climate change. Management that includes adaptive short- and long-term strategies, including resilience and resistance, should be actively pursued and supported by a wide range of partnerships.*

Research, Monitoring, and Observed Effects

In this supplement we build on the work of the previous 2012 workshop; the Partnership's[1] provided "Appendix F: Climate Change Summary" as a way of synthesizing effects of climate change in the Kenai Peninsula region to date. In the intervening years, a suite of additional research synthesis efforts have continued to document regional climate and ecosystem changes that affect fish habitat. In 2017, the U.S. Forest Service published the *Climate Change Vulnerability Assessment for the Chugach National Forest and Kenai Peninsula*[2], an invaluable resource regarding the impacts of climate change and a summary of known and predicted measurements. In addition to research from these federal land managers on the Kenai Peninsula, a plethora of other studies, prominently including Sue Mauger's stream temperature work with Cook Inletkeeper[3–5] (as well as the organization's policy work and role in establishing the local "Drawdown" climate change group[6]); Dr. Susan Loshbaugh's

The History of land use on Alaska's Kenai River and its implications for sustaining salmon[7]; Kachemak Bay National Estuarine Research Reserve aquatic research (particularly groundwater and peatland work, among many publications)[8–10]; University of Alaska's work though the EPSCoR Southcentral Test Case project[11,12]; and Kenai Watershed Forum datasets and work (water quality[13,14], wetlands[15,16], fish passage, stream restoration, invasive species) have shown us that we are experiencing – or can expect to experience – the following environmental changes that have cascading impacts related to fish and fish habitat:

- Wetlands drying at a rate of 6 to 11 percent per decade[17]
- Glaciers receding, including an 11 percent decline in surface area and a 21-meter decline in elevation[18–20]
- Increasing afforestation (i.e. new forest establishment), with tree line shifting nearly 1-meter per year and shrubs receding about 2.8-meters, also annually[21,22]
- Increasing precipitation as rain rather than snow, resulting in less flow during spring and more flow during winter, which may also result in an increase in the availability of overwinter habitat and enhance the survival of juvenile salmon[11,23]
- Increasing snowpack at higher elevations and decreasing snowpack at lower elevations[24]
- Increasing water temperature, including temperatures in non-glacial streams in 2019 exceeding temperatures previously forecasted for 2069[27] and documented fish kills (e.g. Jakalof Creek[25,26])
- Drought in 2019, resulting in drinking water shortages in Nanwalek and Seldovia[27], with annual available water decreasing on the Kenai Peninsula by 60 percent since 1968[22]
- Hatchery pink salmon releases likely negatively affect productivity of some wild salmon populations[28,29]
- Ocean acidification could decrease salmon food supply[30]
- Human footprints will more than double in 50 years; between 2010 and 2020 the human population of the Kenai Peninsula Borough has increased by six percent[31]
- More than a half million acres have burned on the Kenai Peninsula in the past decade, including the 2014 Funny River Fire (200k acres) the 2019 Swan Lake Fire (170k acres), and other significant fires unique for ignitions in unusual fuel types such as the 2015 Stetson Creek Fire (a lighting strike in mountain hemlock), the 2019 Tustumena Lake Fire (a lightning strike in grassland), and the 2019 Swan Lake Fire (burned through alpine)[32,33]
- The renewed spruce bark beetle outbreak since about 2015 has killed nearly 1.2 million acres of unburned forest in Southcentral Alaska north of Tustumena Lake, and particularly north of the Sterling Highway[34]

Expanded Description of Climate Change "Nested" Threats

To conceptualize climate change and its impact on our Partnership, the main thematic threats to fish and fish habitat posed by direct and indirect contemporary climate change have been categorized here in nine "nested" threat categories, i.e. sub-categories of threats within climate change. The nested threat categories are as follows (in no particular order):

i. *Loss of hydrologic connectivity*: Changes in hydrologic connectivity potentially limit the amount of habitat readily available to aquatic organisms and impede the ability to complete their life cycle, especially for anadromous species.
ii. *Wildfire impacts to water quality and quantity:* As the frequency and intensity of wildfires increase, the reduction of vegetative cover will increase sedimentation in waterways and has the potential to alter discharge patterns and affect water quality.
iii. *Discharge volatility from increasing glacial melt*: As glacial mass is reduced due to warming air temperatures, the expulsion of water and sediment from glaciers may produce changes in flood regimes, downstream water temperatures, and other hydrologic conditions that can modify valuable aquatic habitat and damage human infrastructure.
iv. *Discharge volatility from precipitation*: Predicted changes to patterns in precipitation could lead to more extreme rainfall events and higher mean monthly precipitation[35], resulting in an increased occurrence of flood events and scouring that alter important aquatic habitat as well as timing of discharge patterns due to events like rain on snow/ice.
v. *Increased erosion, turbidity, and sedimentation*: As the frequency of events such as wildfires and heavy rainfalls speed up the velocity of overland flow as well as in-stream flow, erosion of soil in riparian areas will increase. This in turn can lead to a sharp spike in turbidity and sedimentation levels altering stream conditions for aquatic organisms.
vi. *Changing intrinsic water quality conditions*: As terrestrial and in-stream ecosystems change, those changes will be reflected in shifting intrinsic water quality conditions including water temperature, conductivity, turbidity, and dissolved oxygen.
vii. *Loss of groundwater recharge*: Extreme rain/flood events where water moves through the system too fast to infiltrate into groundwater systems will limit their ability to recharge. This in turn can decrease the abundance of cold-water seeps that are crucial to maintaining hydrologic conditions necessary for many aquatic species.
viii. *Increased solar radiation*: Increased solar radiation can drive shifts in total available water on the landscape, influencing water budgets for glaciers and wetlands, and in turn influencing downstream aquatic ecosystem drivers (see "Case Study 3: Kenai River (Glacial River)" for an example of how glacial meltwater affects Skilak lake sockeye salmon smolt productivity)[36].
ix. *Changes in ecosystem composition*: Habitat conditions will shift as climate change alters parameters such as temperature and precipitation, thus likely shifting species compositions and having an effect on overall ecosystem function (e.g. forest vs. grassland). This can be further broken down into three categories:
    a. *Changes to species abundance, such as a loss of ecosystem diversity, but an increase in species diversity*: As conditions change due to climate change, they

may become more suitable for certain species that will alter communities and the presence of contemporary native species.

b. *Shifting native species baselines*: As new species proliferate or old species adapt due to changes in climatic conditions, the baseline for what defines native species, or how many are present at a given moment in time in an ecosystem, will be subject to change.

c. *Changing species diversity*: Habitat conditions will shift as climate changes alter parameters such as temperature and precipitation, making them more suitable to certain non-native species. This in turn will change how certain ecosystems' function as they move further from how they traditionally operated.

Case Studies

Case Study 1: Kenai Peninsula, Alaska

The Kenai Peninsula was highlighted as a case study in the 2012 National Fish, Wildlife and Plants Climate Adaptation Strategy[37] because the effects of a warming climate were already dramatic and forecasted to become even more so. Since then, it has been used in additional case studies for ways of thinking about climate change adaptation[38,39]. Numerous observed effects of climate change on forests, glaciers, and wildlife have been recorded and are described in detail above ("Introduction"). Some additional observations and trends in regional climate change and their effects on fish habitat are described below.

Observed Ecosystem Changes
In the early 2000s the peninsula was the epicenter of a spruce bark beetle outbreak that devastated 400,000 ha of Sitka, white and Lutz spruce forest in southcentral Alaska over a 15-year period, sustained by consecutive summers of above-average temperatures[40]. As the climate has warmed and dried over the past half century, available water declined 55%[22]. Concomitantly, tree line and shrub line rose 1 m per yr[41] and 2.8 m per yr[17], respectively, in the Kenai Mountains; wetlands in the Kenai Lowlands decreased 6–11% per decade in surface area[17,22]; and the Harding Icefield decreased 5% in surface area and 21 m in average elevation[18,19] while its rate of thinning increased by 55% in the 1990s to 0.72 m per yr[20]. Although data have yet to indicate a change in mean fire return interval[40], the fire regime seems to be changing from late summer canopy fires in spruce to spring fires in *Calamagrostis canadensis* grasslands; the Alaska fire season's official start was changed from May 1 to April 1 in 2006 for this reason[42].

Lightning strikes, once rare on the Kenai Peninsula, have ignited fires with increasing frequency during the past 20 years[11]; in fact, lightning-caused wildfires in mountain hemlock in 2005 and 2015, and grasslands in 2019, are well outside any historic fire regime. Water temperatures in some non-glacial streams routinely exceed physiological thresholds for salmon during July[3]. Increasing glacial melt during the 1990s reduced sockeye salmon fry abundance, size and overwinter mortality in the second largest lake on the Kenai Peninsula through the cascading effects of increasing silt, decreasing euphotic zone, and decreasing copepod biomass[36].

The online database *e*Bird has recorded 13 new bird species on the Kenai Peninsula since 2012 as well as earlier arrival and later departure dates, respectively, for at least 33 and 38 species of migratory birds[43].

Modeled Ecosystem Changes
Spatial modeling predicts dramatic changes to Kenai Peninsula landscapes by the end of this century , but these models come with a degree of uncertainty. Some alpine tundra will likely be replaced by forests, but forecasts for lower elevations range from more hardwood cover to almost catastrophic deforestation[34]. However, those effects are not equitably distributed over the peninsula. Coastal influence and the Kenai Mountains create a rain shadow on the western peninsula that increases climatic variability. All empirical and modeling evidence to date suggests that although both biomes will warm for the remainder of this century, the eastern peninsula will remain a rainforest while the western side is likely to transition to mixed hardwood forests and grasslands.

During the next half century, directional change associated with warming temperatures and increased precipitation will result in dramatic reductions in snow cover at low elevations, continued retreat of glaciers, substantial changes in the hydrologic regime for an estimated 8.5% of watersheds, and potentially an increase in the abundance of pink salmon[2]. In contrast to some portions of the planet, apparent sea level rise is likely to be low for much of the Partnership region owing to interactions between tectonic processes and sea conditions. Shrubs and forests are projected to continue moving to higher elevations, reducing the extent of alpine tundra and potentially further affecting snow levels. Opportunities for alternative forms of outdoor recreation and subsistence activities that include sled-dog mushing, hiking, hunting, and travel using over-snow vehicles will change as snowpack levels, frozen soils, and vegetation change over time. There is a projected 66% increase in the estimated value of human structures (e.g. homes, businesses) that are at risk to fire in the next half century on the Kenai Peninsula, and a potential expansion of invasive plants, particularly along roads, trails, and waterways[2].

Community Response to Change
Agencies and communities have responded differently to these non-uniformly distributed ecological changes. Over 75% of the peninsula is managed within three federal conservation units: Kenai National Wildlife Refuge, Chugach National Forest, and Kenai Fjords National Park. The remaining non-federal lands are managed by a host of state agencies, tribes, the Kenai Peninsula Borough, communities and private landowners.

Generally, most changes have been accepted, either because they are infeasible to manage (e.g., changes in bird migration) or they haven't been impactful enough to warrant financial investment (e.g., afforestation). However, some examples where communities have responded with action are worth highlighting:

- In response to extensive tree mortality from spruce bark beetle attack, the Borough and Ninilchik Native Association have reforested > 1,000 hectares with both native (e.g., white spruce) and nonnative species (e.g., lodgepole pine), and the Alaska Division of Forestry has offered tree seedlings of varying nativity to the public[44].

- "All Lands-All Hands"[45], an interagency fire management working group on the Kenai Peninsula, evaluated control treatments for *Calamagrostis* grass, a highly flammable spring fine fuel that has replaced beetle-killed spruce along the wildland-urban interface. This group has also created linear fuel breaks around local communities to increase the likelihood that wildfire will run in adjacent wilderness.
- In response to rising temperatures in the Anchor River, an anadromous stream with waters of non-glacial origin, Cook Inletkeeper has partnered with the Kachemak Heritage Land Trust to acquire lands that harbor cold water refugia detected from aerial thermal infrared imagery[46].
- Local communities, rural landowners, and farmers have responded to rapidly increasing temperatures and growing days by planting exotic tree species for landscaping and fruit production. Various species of fruit trees have been successfully cultivated: Manchurian apricot, Ussurian pear, nonnative serviceberry and multiple varieties of apples, crabapples, and cherries. Hardwoods include red and burr oaks, green ash, Siberian elm, five species of maple, two species of basswood, Russian olive, Norway poplar, European mountain ash, two nonnative birches and eleven species of willow. Amur maples, native to northern Asia, seem to do particularly well. Softwoods include white and western red cedars, nine firs (balsam, Douglas, grand, Korean, Sakhalin, Shasta red, silver, subalpine, and white), Metasequoia, eastern hemlock, juniper, four larches, eleven pines (Austrian, bristlecone, eastern and western white, lodgepole, limber, Manchurian, mugo, Ponderosa, Scotch, Siberian) and five nonnative spruces[47].
- Salmon "ranching" is becoming more common in waters surrounding the Kenai Peninsula. This practice supplements wild populations with hatchery-raised fry that grow to maturity in the wild at sea. Hatchery-origin salmon accounted for one-third of the salmon commercially harvested in Alaska over the past decade, 56% of which return to Prince William Sound and 2% to Cook Inlet[48]. Recent studies show substantial proportions of strayed hatchery-origin fish on wild spawning grounds[49,50], genetic introgression into wild populations[51], and competition between hatchery-origin and wild fish in the ocean. Low stream flows driven by climate change or human-caused water diversions increase the risk of hypoxia, making wild spawners more sensitive to the density of hatchery-origin fish[52]. As the ocean warms during this century, Chinook and sockeye salmon are projected to face greater metabolic constraints than other salmon species[53], and these stresses could be exacerbated by greater competition with hatchery-enhanced pink salmon populations. Large-scale hatchery releases involve important policy tradeoffs, including potential reductions in the resilience of wild salmon to climate and landscape changes[11].
- Various organizations have carried out direct management of select invasive species including *Elodea spp.,* white sweetclover *(Melilotus alba),* bird vetch *(Viccia cracca)*, and reed canary grass (*Calamagrostis canadensis*)[54].
- Some agencies have discussed climate-focused strategies for management of foundation species, or species that disproportionately influence the structure of their ecological communities by creating or maintaining an ecosystem that would

otherwise not persist[55]. Beavers (*Castor canadensis*) are one such example of a foundation species, as they frequently restructure freshwater fish habitat.

A list of additional references that address topics related to climate change and ecology in the Kenai Peninsula region is accessible in an online supplemental reference list[56].

Case Study 2: Salmon (or not) in the Anthropocene

Like much of Alaska, the Kenai Peninsula is rapidly changing in response to a warming climate. Annual available water on the western peninsula has decreased 62% since 1968 as mean July temperatures have increased four degrees Fahrenheit and annual precipitation has decreased slightly[22,57]. The Harding Icefield in the Kenai Mountains lost 11% of its surface area and 21 m in average elevation since the 1950s even as the thinning rate of glaciers increased 55%[19]. Wetlands in the Kenai Lowlands decreased 6–11% per decade in surface area over this same period.

The Kenai Peninsula has 1,800 miles of anadromous streams and rivers that flow from 374 outlets into the surrounding saltwater[58]. Aside from the commercial, recreational and subsistence values of salmon, hooligan, and Dolly Varden, these fish play an outsized role in bringing exogenous nutrients from the seas to terrestrial ecosystems[59]. Marine-derived nutrients stored in their bodies and roe energize a complex food web that includes phytoplankton, benthic invertebrates, predators, scavengers, riparian vegetation, and even songbird populations. Adult chum salmon returning to spawn each contain 130 grams of nitrogen and 20 grams of phosphorus on average[60]. Using that as a model, the 20-year average late run of 3.6 million sockeye in the Kenai River[61] translates to a potential input of one million pounds of nitrogen and 160,000 pounds of phosphorus into the 1.3-million-acre watershed every year.

This nutrient multiplier effect carries over to riparian vegetation, a beneficiary of scavenging and fishing eagles, bears, ravens, gulls, river otters, and mink, all of which leave salmon carcasses on stream banks. For example, 15–18% of nitrogen in white spruce within 500 meters of Mystery Creek and the Killey River, two anadromous streams on the Kenai Peninsula, were marine-derived. On Chichigof Island in southeast Alaska, Sitka spruce grew three times faster on spawning sites than non-spawning sites[62]. Furthermore, on salmon streams in coastal British Columbia, breeding densities of birds (winter wren, Swainson's thrush, varied thrush, Pacific-slope flycatcher, and golden-crowned kinglet) were two times higher on stream reaches below waterfalls (with salmon) than those above waterfalls (without salmon)[63].

Whether a stream originates from glacial or non-glacial sources has real implications for salmon. For non-glacial streams, water temperatures vary with air temperatures and they are more vulnerable to changing precipitation and the form it takes (snow vs rain). In contrast, glacially-fed streams are robust against varying air temperatures and, to a certain extent, varying precipitation as long as the glacier remains; however, glaciers in Alaska are expected to decrease 30–70% by 2100[64].

The Alaska Department of Environmental Conservation published these criteria in 1999 regarding water temperature and salmonids[65]:

> Maximum temperatures not to be exceeded in anadromous waters:
>
> - egg & fry incubation = 13°C (55° F)
> - spawning areas = 13°C
> - migration routes = 15°C (59 °F)
> - rearing areas = 15°C
> - and may not exceed 20°C (68° F) at any time

Warming thermal regimes can influence salmon life cycles in complex ways including changes to body growth rate, migration timing, and habitat occupancy.

Case study 3: Kenai River (Glacial River) (see summary paper by Schoen et al. 2017)[11]

Certainly the largest example of a mostly glacial system is the 115-mile-long Kenai River, which receives water from both the Harding and Sargent Icefields in its upper watershed. Further downstream, it receives substantial non-glacial input from the Killey, Funny and Moose Rivers. As with most glacial streams, its flow peaks in mid-summer, coinciding with the late run of sockeye salmon.

While glacial waters help refrigerate the Kenai River, more glacial meltwater is not necessarily a positive outcome of a warming climate. A 17-year study by ADF&G showed that sockeye recruitment in Skilak Lake was depressed by the additional input of glacial meltwater during the 1990s. Higher air temperatures meant more water, more silt, higher turbidity, reduced light penetration (decreasing euphotic zone), reduced phytoplankton abundance, reduced copepod biomass and, finally, reduced sockeye smolt abundance and size, which in turn was related to overwinter morality of fry[36].

Although the Harding Icefield is likely to persist for centuries, it is diminishing quickly. Many short, high-gradient mountain streams flowing into Resurrection Bay (near Seward) that originate from snow fields or glaciers in satellite imagery taken three decades ago now appear to be discontinuous from anything white during the summer months[66]. Not surprisingly, this accelerating ice melt is due to rapidly warming air temperatures. However, watermelon or red snow, which is caused by an algal species (*Chlamydomonas nivalis*), has a positive feedback on glacial melt. Watermelon snow reflects less light than plain snow and therefore heats more in the summer sun. This means, of course, more meltwater and larger algal blooms, which in turn heats the snow even more. Watermelon snow, which covers more than a third of the Harding Icefield, increases total snowmelt by 17%[67].

Additionally, faster glacial melting is contributing to more frequent releases of ice dams from Skilak Glacier and the Snow River[68]. Depending on the time of year and the condition of ice on the Kenai River, these releases can be damaging to both bank infrastructure (docks, stairs) and spawning habitat.

To accept these ecological trajectories in the short term likely means more glacial silt and reduced sockeye recruitment, as well as more ice dam releases. In the long term, glacial input is likely to decrease as the Harding and Sargent Icefields shrink back, with reduced stream flow and presumably a much lower carrying capacity for salmonids.

Case Study 4: Anchor River (Non-glacial) (see papers by Mauger et al. 2017[3] Whigham et al. 2017[8])

The largest non-glacial stream on the peninsula is the 42-mile-long Anchor River, which receives its inputs from precipitation, groundwater and surrounding peatlands. As with most non-glacial streams, its flow peaks in spring after the snowpack melts and declines thereafter. In Limpopo Creek, an Anchor River tributary, 55% of the flow during the dry season originates from adjacent peatlands[69]. Peat stores water well and so buffers against dry seasons and drought. However, wetlands in the Kenai lowlands have lost 6–11% of their surface area per decade since the 1950s[17]. Sphagnum peatlands that have been sphagnum peatlands for at least 8,000 years have been invaded by dwarf birch and other woody shrubs over the past 40 years[22].

Forty-seven of 48 non-glacial streams monitored on the Kenai Peninsula and in the Mat-Su Valley routinely experience temperatures in July that can cause sub-lethal stress in salmon[3]. During the 2019 drought, when the entire peninsula was deemed in severe drought (D2) or extreme drought (D3) by early September, maximum weekly water temperatures in all streams monitored exceeded values forecasted for 50 years into the future[70] (see Figure 1). Water temperature in the Anchor River reached 73° F (23° C) on July 7, the highest since monitoring began in 2002. On the Deshka River in the Mat-Su Valley, water temperatures reached 82° F (28° C).

Non-glacial streams are likely more vulnerable than glacial streams to climate warming in the short term. Not only are air temperatures increasing rapidly, but shorter periods of ice cover mean extended periods for those waters to receive solar radiation. Also, spruce trees killed by spruce bark beetles and thin-leaf alder defoliated by exotic green alder sawflies mean less canopy cover and more solar radiation in riparian areas, with cascading ecological effects to fish habitat[71].

To accept these trajectories in the short term likely means reduced recruitment and increasing fish kills from lethal temperatures. In the long term, low-gradient non-glacial streams could cease being productive waters for salmonids, perhaps even becoming intermittent during low-flow periods.

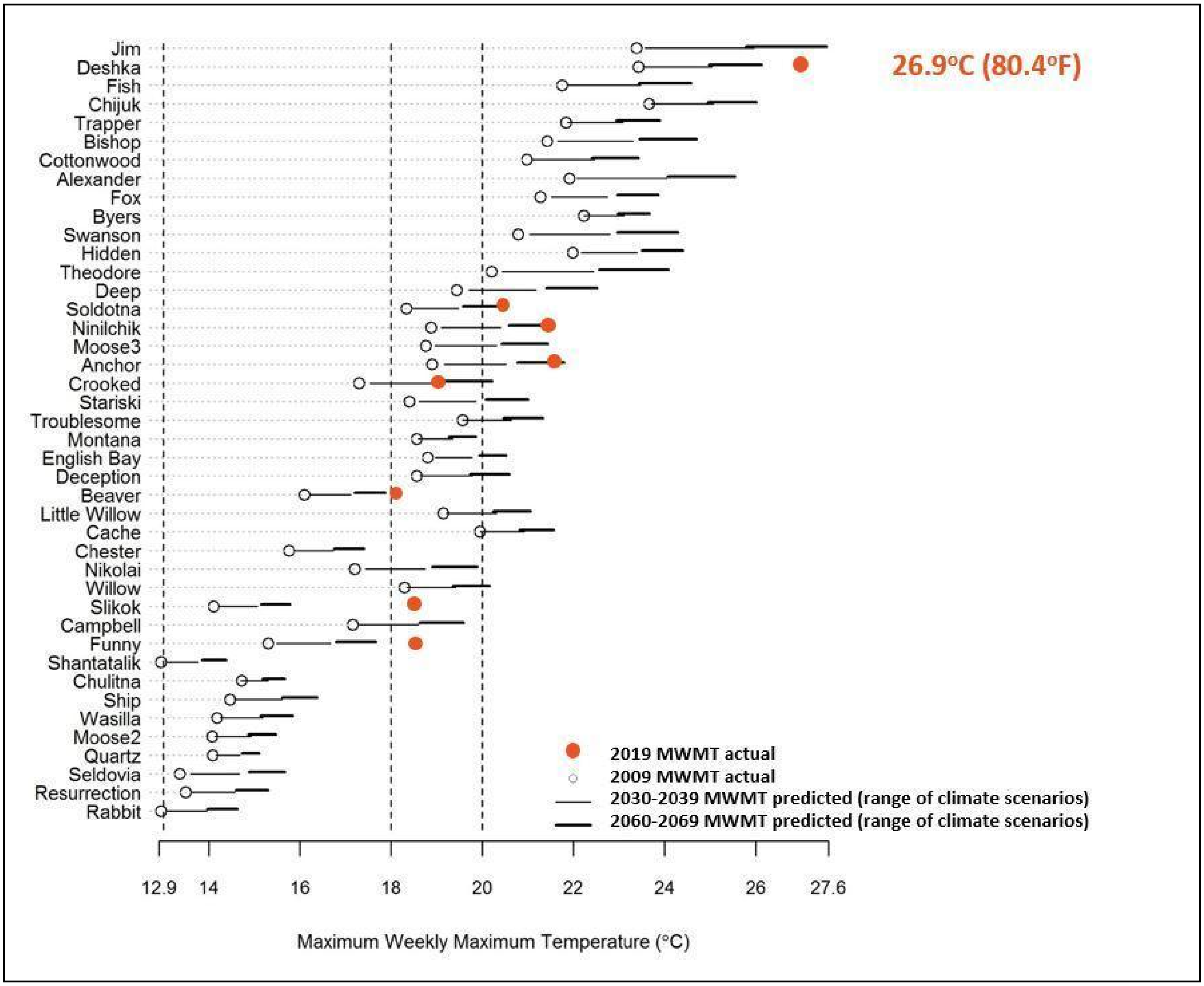

Figure 1. Maximum Weekly Maximum Temperature (MWAT), e.g., the highest weekly maximum water temperature in the year, for a selection of rivers and streams in the Cook Inlet drainage. Circles show observed temperatures (white for 2009, orange for 2019) and projected temperature ranges (thin line for 2030-2039, thick line for 2060-2069). Adapted from Mauger et al 2017.

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