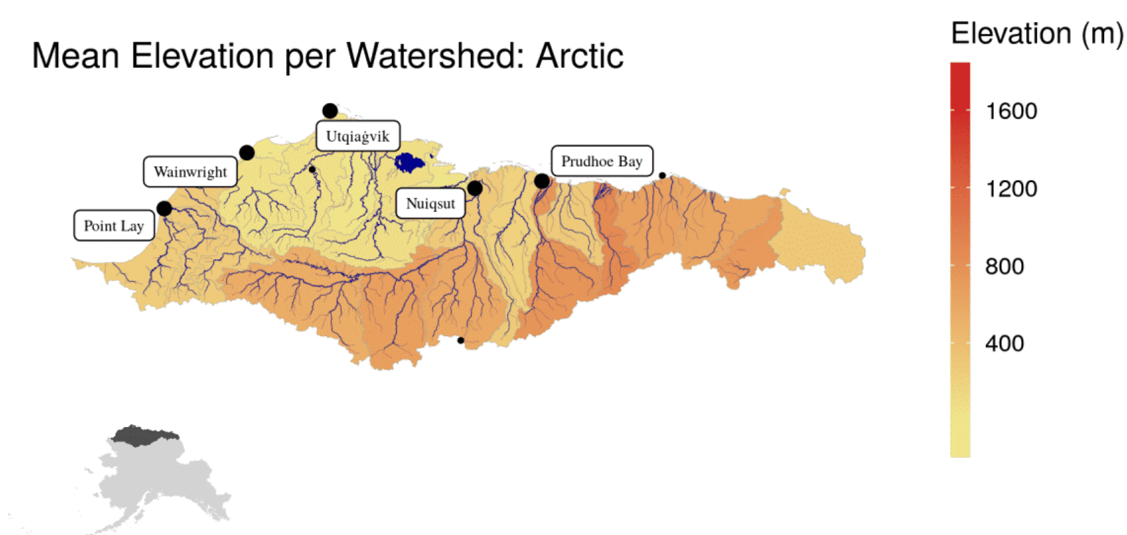
ARCTIC

Geography

How does one define the Arctic? One way is to define the Arctic as an invisible northern polar region northward of 66° 34' N latitude where the sun fails to crest the horizon during the winter solstice and never sets during the summer solstice. Alternatively, the Arctic is sometimes defined as northern regions where the average temperature of the warmest month of the year is less than 10°C, or where boreal forest ecosystems give way to brilliant tundra landscapes.

For the purposes of this report and project, we categorize 221,190 km² (11% of land area of Alaska) from the coasts of the Chukchi and Beaufort Seas inland to the Brooks Range as the Arctic region. We acknowledge that substantial portions of the Kotzebue and Yukon regions fall above the Arctic circle, but describe those regions separately given their distinct biophysical, cultural, and economic characteristics.



Jared Kibele, Rachel Carlson, and Marie Johnson. 2018. Elevation per SASAP region and Hydrologic Unit (HUC8) boundary for Alaskan watersheds. Knowledge Network for Biocomplexity. doi:10.5063/F1D798QQ.

Early people and salmon systems

The Arctic region has been inhabited for thousands of years by the Iñupiaq people and their predecessors (Langdon 2002). Today, communities in Arctic Slope region of Alaska include: Anaktuvuk Pass, Atqasuk, Kaktovik, Nuiqsut, Point Hope, Point Lay, Utqiaġvik, and Wainwright.

Traditional hunting and fishing is the lifeblood of the region. Communities of the Arctic Slope region have sustained dynamic yet stable cooperative social networks, which structure harvests and sharing (BurnSilver et al. 2016).

Subsistence production in the Arctic Slope region remains among the highest in the state, and both the current levels of harvest and social ties among community members have been found to be similar to historic levels, suggesting the persistence of a mixed economy in the Arctic Slope region even among high-income households (BurnSilver et al. 2016; Brown et al. 2016).

Sheenjek River in the Arctic Refuge, Photo Credit: Alexis Bonogofsky

The Iñupiaq peoples of the Arctic Slope depend on marine mammals, caribou, and a variety of fish species. Salmon have been a relatively unimportant resource in most

Arctic communities. For example, subsistence harvests of salmon in 2014 made up only 1-3% of the wild foods harvested among the Arctic Slope communities of Utqiaġvik, Nuiqsut, and Anaktuvuk Pass (Brown et al. 2016). Of the salmon, chum salmon and pink salmon are the most commonly harvested and encountered species in this region, which is consistent with known extent of salmon rearing and spawning habitat in the region. Summarized data compiled from the Anadromous Waters Catalog indicate 3,185 km of known salmon rivers (of any species, not double counting stream length where multiple species are present) in the Arctic region representing 2.6% of the 118, 692 km of anadromous waters documented in Alaska as a whole. In terms of length of habitats (km), chum salmon are known to occur in 2,813 km of river, pink salmon in 2,668 km, sockeye salmon in 43 km, Chinook salmon in 40 km, and coho salmon in just 10 km. However, it is unclear whether these reflect self-sustaining established populations.

Why are pink and chum salmon apparently the most common species of Pacific salmon currently in the Arctic? It is likely not a coincidence that only pink salmon and chum salmon have life histories that do not include spending a winter in freshwater as juveniles (Nielsen et al. 2012). This life history strategy of migrating to sea before the first winter in freshwater may be beneficial to avoid potentially lethally-cold temperatures, dynamic ice conditions, and a lack of feeding options during inhospitable winter months. That being said, freshwater residents such as Arctic grayling are able to successfully overwinter and self-sustain populations in the region. The winter freshwater ecology of salmonids throughout their range is not well known (see Huusko et al. 2007, Brown et al. 2011 for reviews) and there is a stark knowledge gap for Pacific salmon in the Arctic.

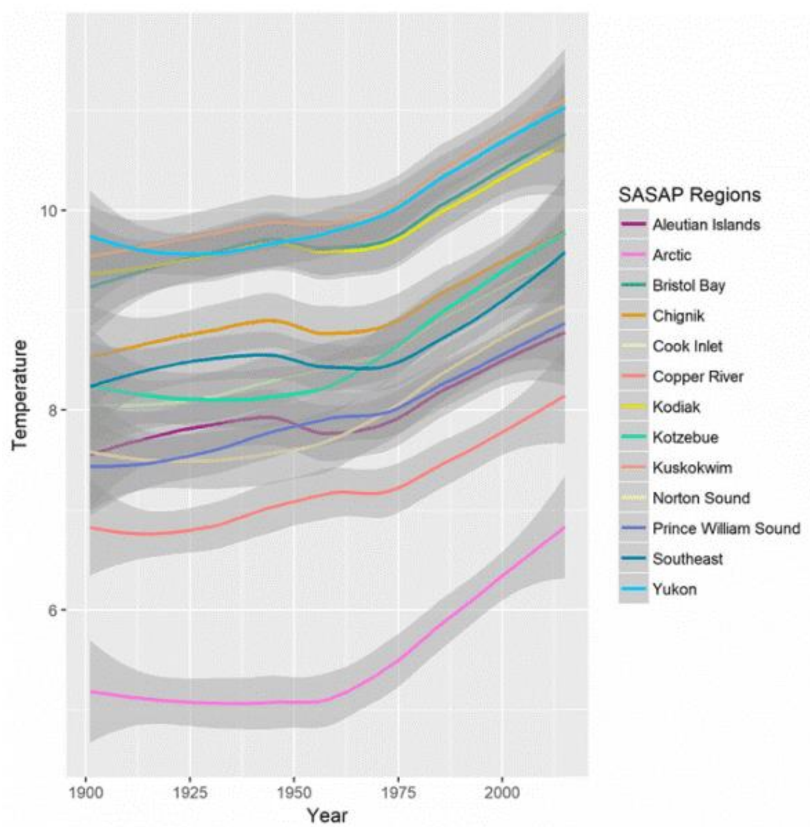
Have Pacific salmon always persisted in small numbers in the Arctic or is the apparent increase in their occurrence a new phenomenon? And if so, is it potentially linked to a warming climate system, or perhaps to more people to act as observers? Given the relatively low cultural value for salmon in this region, it seems unlikely that Pacific salmon have existed long-term in appreciable numbers. The Iñupiaq are familiar with salmon in this region; in Utqiagvik, for example, there are Iñupiaq words for pink salmon (amaqtuuq) and chum salmon (iqalugruaq), but for not for other Pacific salmon species. Multiple reviews of Pacific salmon in the North American (e.g. Craig and Haldorson 1986) and Canadian waters (e.g. Stephenson 2006) suggest that the frequency of encounters with Pacific salmon are increasing but that observations of salmon are documented back to at least the mid-19th century (Bockstoce 1988).

Whether historical or contemporary observations of salmon are evidence of established self-sustaining populations or interactions with strays from populations farther to the south is not known, but the Arctic region provides a vivid example of the biological importance of salmon straying for the colonization of newly suitable habitat as observed in southeast Alaska following the retreat of glaciers and human made barriers throughout the range of Pacific salmon (Pess et al. 2014). Speaking of glaciers, the Arctic region contains 908 glaciers that cover 1555 km², or approximately 1% of its total area.

Changes in Systems

The circumpolar Arctic region has experienced some of the most dramatic and rapid changes in climate and environmental variation in recent decades (Larsen et al. 2014). Climate change is impacting terrestrial and freshwater ecosystems in some areas of the Arctic according to results in the 2014 IPCC Assessment Report, and there is very high confidence that this is due to effects of reductions in extent and duration of snow cover and accelerated permafrost thawing (Larsen et al. 2014).

Compared to the rest of Alaska, the Arctic is a veritable desert, receiving only 100 mm of total precipitation on average from 1990-2015 (SNAP data). By comparison, the Prince William Sound region receives nearly 1400 mm on average. Trends of decreasing precipitation are making a relatively dry region even drier. On an annual basis, there was 36% less precipitation during the period of 1949 to 1998 and 106% less during the winter period (Stafford et al. 2000).



Average temperature in each SASAP region, 1900 – 2016. The Arctic region is the coldest, but most rapidly warming, region. Alaska Department of Fish and Game, Division of Subsistence. Subsistence and personal use harvest of salmon in Alaska, 1960-2012. Knowledge Network for Biocomplexity. doi:10.5063/F18P5XTN.

Temperatures have warmed markedly in the Arctic region. In 1901 the average ("summer") temperature during May, June, July, and August was 4.6℃ and in 2015 was 7.3℃ (SNAP Data). During this 115-year record, the average summer temperature was 6.5℃. In association with warming temperatures, a host of physical and biological processes have been changing on land, in freshwater, and in the surrounding marine ecosystem (Chapin et al. 2014).

The maximum extent of sea ice coverage, which usually occurs in March of each year, has declined rapidly since recording keeping began in 1979. Sea ice in March of 2017 was the lowest on record, covering 14.175 million km^2 compared to the highest extent in 1982 at 16.585 million km^2. This represents a loss of sea ice nearly 3.5 times the area of the state of Texas (695,662 km^2).

Warming temperatures, changes in precipitation, and other aspects of climate change may reflect apparent increasing numbers or increasing encounters of salmon in the Arctic (Nielsen et al. 2013, Mikow et al. 2016). Indeed, Dunmall et al. (2013) provocatively suggest that salmon in the Arctic are harbingers of a changing landscape. There is disagreement among residents as to whether the abundance of salmon in the region has actually increased (Cotton 2012). That being said, more subsistence users in Arctic communities are harvesting salmon than in past decades (Carothers et al. 2013; Brown et al. 2016). Potential ecological interactions between Pacific salmon and established fish communities is discussed in the Case Study below. Historical data for subsistence salmon harvest in the Arctic Slope region is limited as there were no annual harvest monitoring programs conducted by ADF&G prior to 2011, with the only systematic subsistence fisheries monitoring program being conducted by the North Slope Borough Department of Wildlife Management reporting from 1994-2003 (Bacon et al. rev 2011). Similarly, there are no escapement monitoring projects in the Arctic region and no commercial catches, given there are no commercial fisheries, from which to assess biological information. When asked, most respondents from Nuiqsut and Utqiaġvik expressed concern about the prospect of a commercial salmon fishery developing in the region (Cotton 2012).

Recreational use of salmon remains limited in the Arctic Slope region (Burr 2006). Similarly, due to the dispersed nature of the salmon runs and geographic isolation of communities, salmon harvest for commercial use remains very limited in the region and is usually incidental when targeting more commonly encountered species. Much of the region's navigable waterways fall under federal jurisdiction and are therefore managed with rural preference for subsistence activities (Burr 2006).

Regional Snapshot Today

Salmon and habitat

Compared to regions such as Cook Inlet or Yukon, the Arctic region is relatively less impacted by direct human modifications or alterations of salmon habitat. For example, there are currently no active mines operating in the Arctic and fish passage is not a major conservation concern given only 32 culverts exist in the region. That being said, 50% of these culverts known are likely to impact passage, which may have resulted in important localized effects, and could influence the probability of successful colonization by salmon. Thus, depending on whether salmon are viewed as friend or foe by the local peoples, culverts may be favorable or a concern. Overall, the Arctic region ranks 8 out of 13 regions based on an index of 0.47 representing the human footprint (standardized to region area to make comparisons possible among regions). The human footprint index in the Arctic mostly reflects built environments in communities such as Utqiaġvik and developments at the Prudhoe Bay oilfield, measures of population densities, and roadways (including seasonal ice roads).

Salmon and people

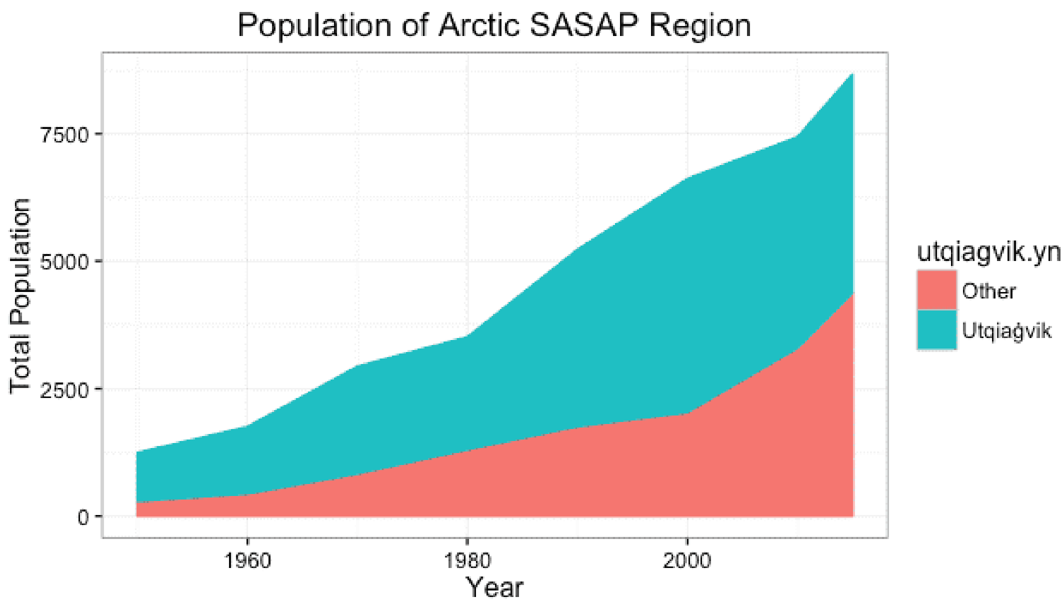
Emerging subsistence salmon fisheries in the high Arctic are just one of a suite of environmental and social changes occurring in this region. Arctic Slope communities are heavily engaged in subsistence livelihoods.

Fishing has always been a stable component of the seasonal round of subsistence production, but salmon has not been a key resource in this region.

Pink salmon and chum salmon have been documented in this region at least since the 1800s, but only recently have salmon harvests been increasing in communities such as Utqiaġvik and Wainwright.

Some view salmon as a pest species, while others are participating in emerging salmon fisheries and learning new knowledge about processing these fish.

Approximately 8500 people live in the Arctic region, with about 50% of those living in Utqiaġvik (Fig. 1). Data in Fig. 2 represent all people identifying as Alaska Native, either alone or in combination. Unlike in 2000 and 2010, census questionnaires in 1980 and 1990 did not allow for reporting as Alaska Native in combination with other races.



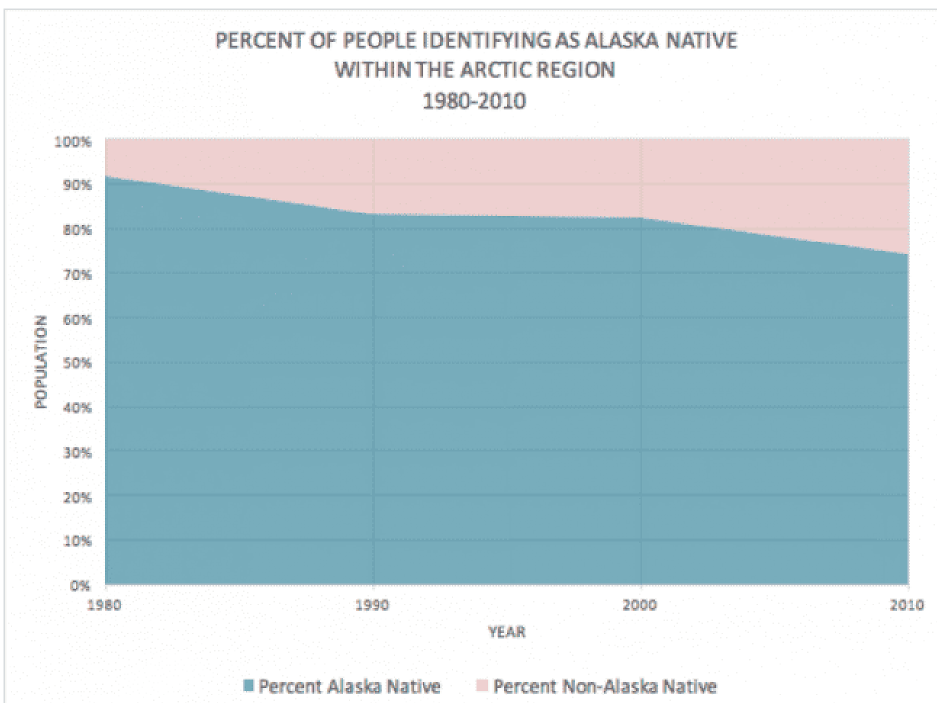
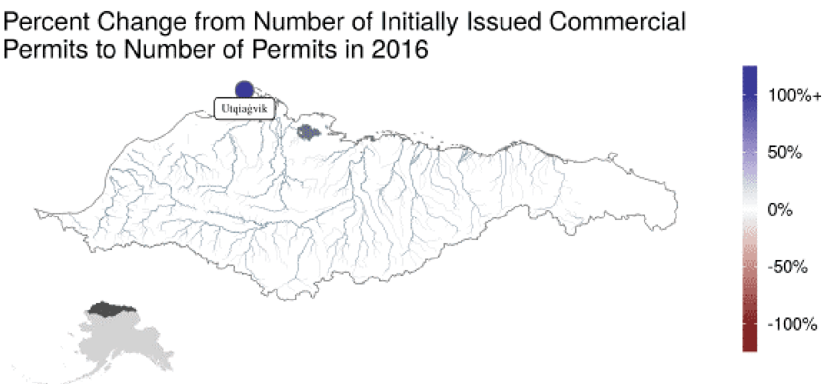
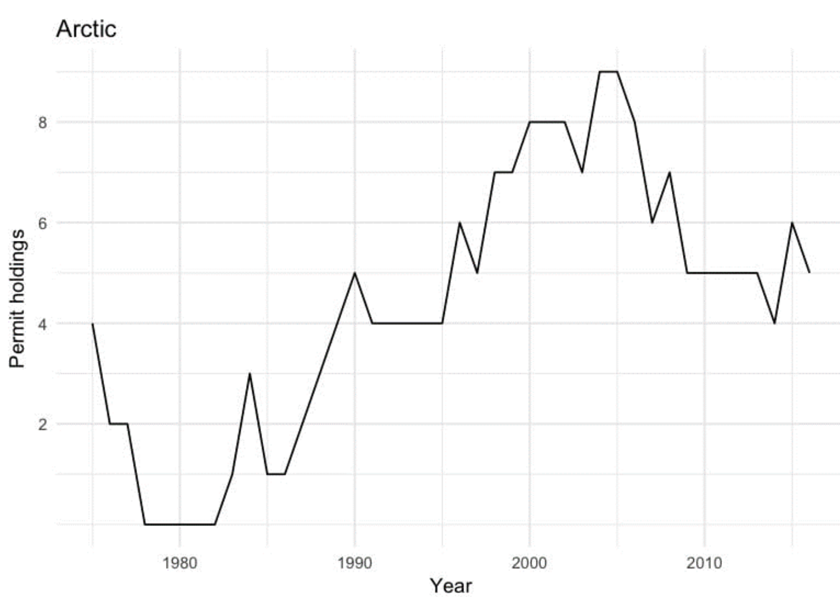


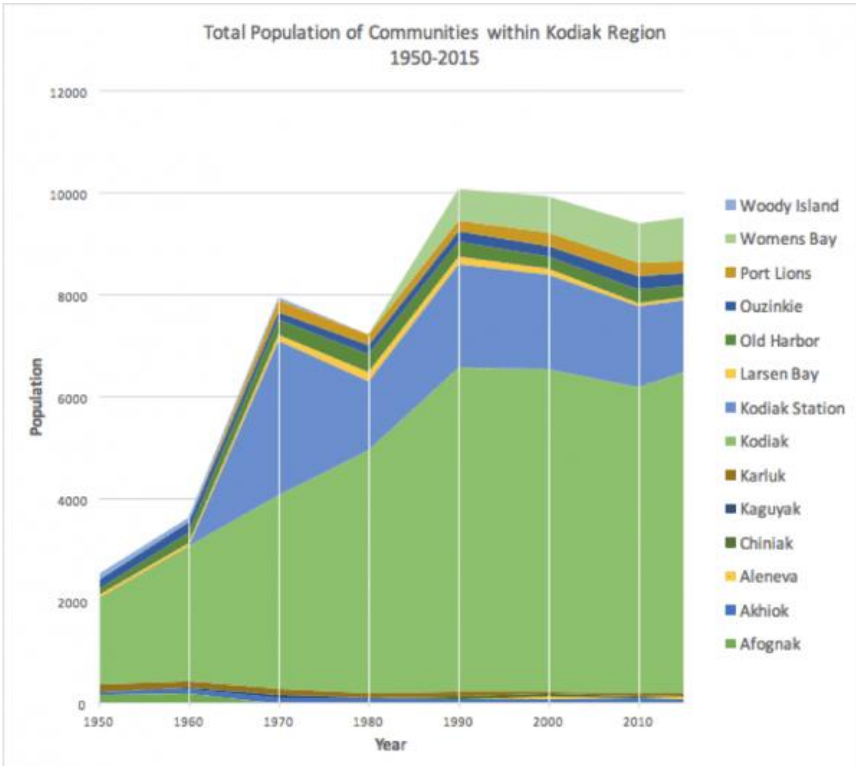
Fig 2. United States Census Bureau, Juliet Bachtel, John Randazzo, and Erika Gavenus. 2018. Alaskan Population Demographic Information from Decennial and American Community Survey Census Data, 1940-2016. Knowledge Network for Biocomplexity. doi:10.5063/F1XW4H3V.



Percent change from number of initially issued (ranging from 1975-1982) permanent commercial salmon permits held by Alaska residents to number of permits in 2016 by community. Alaska Department of Fish and Game, Commercial Fisheries Entry Commission. 2017. Commercial Fisheries Entry Commision CFEC Public Permit Holders by Community of Residence 1975-2016. Knowledge Network for Biocomplexity. [doi:10.5063/F189144V](doi:10.5063/F189144V).



Commercial fishery permit holdings among communities in the Arctic from 1975 to 2016. Alaska Department of Fish and Game, Commercial Fisheries Entry Commission. 2017. Commercial Fisheries Entry Commision CFEC Public Permit Holders by Community of Residence 1975-2016. Knowledge Network for Biocomplexity. [doi:10.5063/F189144V](doi:10.5063/F189144V).



Median household income, by region (data for 2010). United States Census Bureau, Juliet Bachtel, John Randazzo, and Erika Gavenus. 2018. Alaskan Population Demographic Information from Decennial and American Community Survey Census Data, 1940-2016. Knowledge Network for Biocomplexity. [doi:10.5063/F1XW4H3V](https://doi.org/10.5063/F1XW4H3V)

Salmon and subsistence

Under state regulations, the Arctic Management District is part of the Arctic-Kotzebue Management Area. There are no closed seasons or periods for subsistence salmon fishing, though based on the biology and the relatively low densities of salmon compared to other regions, the harvest of salmon is constrained to a few short ice-free months. State regulations allow fishing with gill nets or beach seines. There are no annual limits and no permit or harvest reporting requirements. Under federal regulations, this area is combined with the Yukon River drainage to form the Yukon-

Northern Area. Federal regulations also allow rod and reel subsistence fishing for salmon, in addition to gill nets and seines.

There has never been an annual harvest monitoring program for subsistence salmon harvests in the Arctic District. Salmon harvest estimates are only available through occasional comprehensive surveys conducted by the North Slope Borough (Bacon et al. 2009) or ADF&G. These estimates are summarized in Fall et al. 2018:51,53-54) and in the Community Subsistence Information System. Harvest estimates for five Arctic District communities (Anaktuvuk Pass, Utqiagvik [Barrow], Nuiqsut, Point Lay, and Wainwright) are available for 2014. Harvest estimates totaled 8,332 salmon, primarily chum (51%) and pink (31%). Some of these harvests (especially sockeye) likely took place outside the Arctic District (e.g. Brown et al. 2016:291). The dominant presence of pink salmon with their distinctive even versus odd year life cycle is reflected in subsistence catches where pink salmon are more commonly harvested every other year.

Encounters with sockeye salmon appear to be becoming a bit more common in the Arctic (see Fig. X image of sockeye salmon). Arctic District communities not included in this study (Atkasuk, Kaktovik) historically have harvested few salmon (Fall et al. 2018:53-54); therefore this study for 2014 likely provides a relatively complete single year snapshot of recent salmon harvests in the district. Taken as a whole, residents of Arctic District communities have reported observations of increasing runs of salmon along with increasing harvests and uses. Changing salmon abundance and distribution may be linked to climate change (Carothers, Cotton, and Moerlein 2013; Mikow et al. 2016).

There are some issues with identification of species of salmon in subsistence harvests in the Arctic. For example, local residents often refer to ocean bright salmon as “silvers” leading to misidentification of chums as coho in some cases, with a similar issue on parts of the Yukon River where relatively unsexually mature chum salmon are called ‘silvers’ and sexually advanced chum salmon are called ‘dog salmon’ (Gilbert and O’Malley 1921). Also, large chum might be mistaken for Chinook (Mikow et al. 2016:23; Carothers, Cotton, and Moerlein 2013:25-27; Cotton 2012); some guides list the same Inupiaq name, iqalugruaq, for chum and Chinook (e.g. George 2009).

Compared to other regions of Alaska, salmon are a relatively minor portion of subsistence harvests in Arctic Management District (North Slope Borough) communities. Based on the most recent comprehensive surveys, about 3% of the area’s subsistence harvest is salmon. Marine mammals (50% of total by weight) and land mammals (primarily caribou) (33%) as well as various species of non-salmon fish (12%) make up most of the harvest (see also Carothers et al. 2013:43).

Salmon and governance

The region encompasses a mix of jurisdictions, with many large federal conservation units. However, both state and federal salmon harvest regulations impose few restrictions, with no annual harvest limits and few restrictions on gear. Chum and pink salmon make up the majority of the salmon harvest. Residents report observing increasing salmon runs and growing harvests. Salmon governance in the Arctic Region faces few challenges as salmon returns provide for existing harvest levels with few regulatory restrictions. State and federal regulations allow year-round harvest of salmon with no annual harvest limit and no permits or reporting requirement. State regulations authorize use of gill nets and beach seines, with federal regulations also allow use of rod and reel. Harvest numbers recorded in 2014 are considered representative of contemporary harvest levels and show high reliance on chum and pink salmon. Compared to other regions, salmon make up a limited portion (about 3%) of overall subsistence harvest. Between 2000-2018, there were no disaster declarations for Arctic salmon fisheries.

CASE STUDY

Salmon Colonization of a Rapidly Changing Arctic: The Intersection of Ecosystems and Sociocultural Systems

By Peter Westley and Courtney Carothers

One of the most coherent and pervasive signals of climate change is the poleward shifts in species distributions and altered timing of key life history events such as spawning or migration (reviewed by Parmesan et al. 2006). In freshwaters of the continental United States, cold water adapted salmonids have increasingly little suitable habitat owning to rapidly warming temperatures (Wenger et al. 2011). In stark contrast, ecosystems of the Arctic are only now approaching warm enough temperatures to potentially support viable self-sustaining populations of Pacific salmon (genera Oncorhynchus) or Atlantic salmon (Salmo salar). Salmon colonizing the Arctic represents a fascinating intersection of the biophysical and sociocultural aspects of the Alaska salmon system. While the biological and physical aspects related to successful salmon colonization are relatively known given our understanding of salmon ecology, the responses to salmon by the human system and the ecosystem impacts of a novel species are far from clear.

Photo: Rita Frantz Acker, accessed from North Slope Borough

Despite a lack of compelling evidence, it is widely thought that invading Pacific salmon are likely to have negative impacts on local species established in the Arctic (Reist et al. 2006). The potential for competitive exclusion of local species such as whitefishes, Dolly Varden, lamprey, or sticklebacks seems unlikely as these species coexist throughout much of the range of Pacific salmon. Experimental and field-based work to quantify the competition between Pacific salmon (coho salmon) and Dolly Varden indicate low risk for competition as species exploited resources uniquely from one another, thereby facilitating coexistence in small streams (Dolloff and Reeves 1990). Similarly, biological interactions between local and invading salmon are unlikely to markedly impede the probability of establishment. Though once the subject of a statewide sponsored bounty based on perceptions of being a prolific predator, Dolly Varden are not major consumers of juvenile salmonids in many systems, including the Chignik region (Roos 1959).

Arctic sockeye salmon. Photo by Craig George

In contrast, the weight of evidence suggests that colonizing Pacific salmon may provide beneficial subsidies to freshwater ecosystems and directly influence the growth of local fishes through the consumption of salmon eggs and flesh during the spawning season and after natural death of spawning salmon. Where examined, the annual energy intake by species such as Dolly Varden is dwarfed by the effect of spawning salmon during a relatively short window. Indeed, the importance of the salmon subsidy is reflected in the seasonally flexible digestive capacity of Dolly Varden who ramp up their internal hardware for processing salmon eggs during the time they are available and then shrink their stomach and other organs during the winter and thereby save on energy while they wait for the next cycle of salmon nutrients (Armstrong and Bond 2013). The role of salmon-derived subsidies on freshwater growth of juvenile fishes is well known and thus it seems likely that the colonization of spawning Pacific salmon may serve to benefit local species. That being said, whether increased growth will translate to increased survival or population robustness is far less clear. Beyond the potential direct effects of growth on survival, increased growth may have life history effects for some species who migrate to sea during the summer given the greater options for foraging compared to freshwater. If the amount of high quality food increased from salmon (e.g. salmon eggs) migrating species like Dolly Varden may alter their life history decisions to spend more of their life in freshwaters and may even forego going to the ocean all together (Bond et al. 2015).

A catch of pink salmon Elson Lagoon, Utqiaġvik, July 21, 2011. Photo: Shelley Cotton

A warming climate system and the increased suitability of freshwaters for colonizing salmon has spurred a curious biological race. Pacific salmon are expanding into the Arctic from their native North American range and from populations (particularly pink salmon) that were introduced to the Barents Sea area of Russia. At the same time, Atlantic salmon that are native to Eastern North America and Eurasia are also expanding north, leading to the potential for interactions between these species that have been geographically isolated for at least 15 million years. If one were to place a wager on the outcome of this biological race, who should be picked as a winner? To the extent that the past can predict the future, Atlantic salmon have a dismal track record of successfully colonizing habitats outside of their native range. Despite chronic releases of farmed raised Atlantic salmon in Patagonia and periodic escapes in British Columbia and the Pacific Northwest, no self-sustaining populations of Atlantic salmon are currently known (Bisson 2006). That is not to say that evidence of successful reproduction by Atlantic salmon is absent as periodically the juveniles of invading parents are observed in streams of the Pacific Northwest (e.g. Volpe et al 2000). However, repeated sampling of these rivers has failed to find evidence that the population is established and generally the occurrence of juveniles disappears after a few seasons. In contrast, Pacific salmon have successfully colonized and established populations throughout the Southern Hemisphere in locales such as New Zealand (Quinn et al. 2001) and the Patagonia region of Chile and Argentina (Correa and Gross 2008). Given this track record of colonization, coupled with increased observations of Pacific salmon into the Beaufort Sea it seems that the upper hand is tipped in favor towards Oncorhynchus.

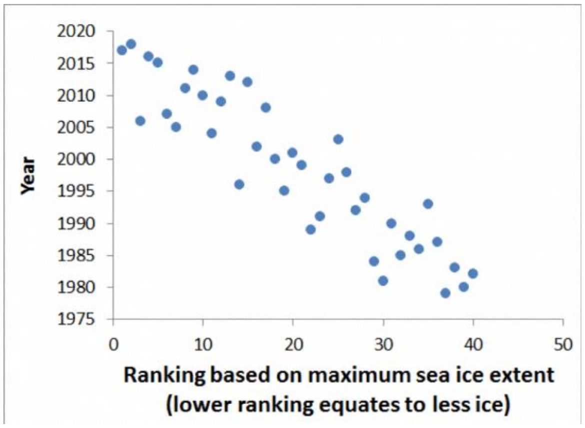
Utqiaġvik fisherman using a small skiff to pick his gill net, August 15, 2011. Photo: Courtney Carothers

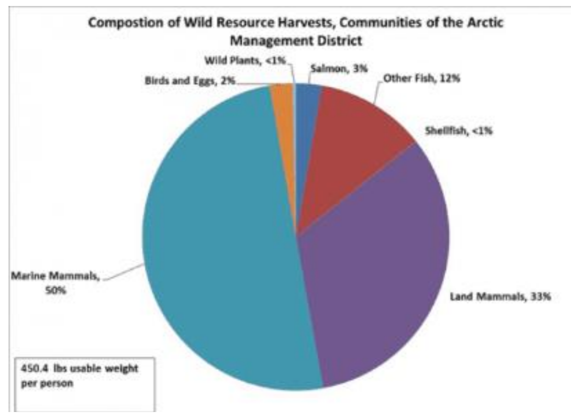
A catch of chum salmon from Elson Lagoon, Utqiaġvik, August 20, 2011. Photo: Courtney Carothers

Pacific salmon are being met with a mixed reception by the indigenous traditional harvesters in the region. Through discussions with resident elder and long-time fishermen, Carothers et al. (in preparation, synthesizing Cotton 2012) relay variable opinions about perceptions regarding changes in salmon abundance in the Arctic, but consistent belief that harvests are on the rise. The perception of the benefits of increased salmon harvests likewise varied among local experts. Several fishermen spoke detrimentally about the numbers of pink salmon being caught that have "gotten to the point where there's too many pinks to deal with" and another noted "we get more of the humpies (pink salmon), a lot of the humpies, and the last two years there's been mostly humpies". Given that pink salmon deteriorate in quality very quickly as they approach sexually maturity it is understandable that these increases in pink salmon harvests are not view favorably. In contrast, informants from both Utqiaġvik and Nuiqsut report to being considered lucky if they catch one or two Chinook salmon over the course of the season.

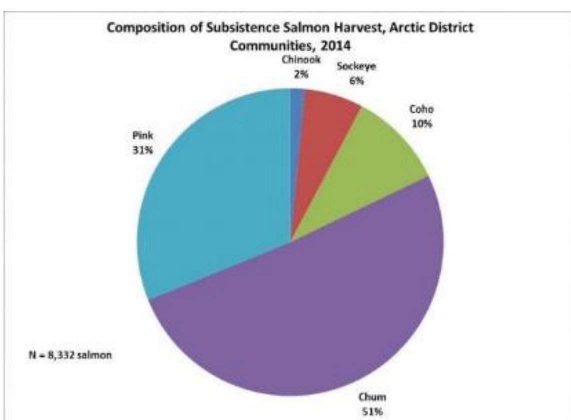
Table 1

Common Western Names	**Scientific Name**	**Iñupiaq Names**
Chum salmon	*Oncorhynchus keta*	*Iqalugruaq, Qalugruaq*
Dog salmon		
Chinook salmon	*Oncorhynchus tshawytscha*	*Iqalugruaq, Iqalukpak,*
King salmon		*Taġyaqpak*
Pink salmon	*Oncorhynchus gorbuscha*	*Amaqtuuq*
Humpback salmon		
Sockeye salmon	*Oncorhynchus nerka*	
Red salmon		
Silver salmon	*Oncorhynchus kisutch*	
Coho salmon		





Alaska Department of Fish and Game, Division of Subsistence. 2018. Subsistence harvest information by region, community, resource, and year, 1964-2015. Knowledge Network for



Alaska Department of Fish and Game, Division of Subsistence. Subsistence and personal use harvest of salmon in Alaska, 1960-2012. Knowledge Network for Biocomplexity. [doi:10.5063/F18P5XTN](doi:10.5063/F18P5XTN).

References

Armstrong, J. B. & Bond, M. H. Phenotype flexibility in wild fish: Dolly Varden regulate assimilative capacity to capital

Bacon, J.J., T. R. Hepa, H.K. Brower, M. Pederson, T.P. Olemaun, J.C. George, and B.G. Corrigan. (2009). Estimates of Subsistence Harvest for Villages on the North Slope of Alaska, 1994 – 2003. North Slope Borough, Department of Wildlife Management. Barrow.

Bond, M. H., Miller, J. A. Quinn, T. P. Beyond dichotomous life histories in partially migrating populations: cessation of anadromy in a long-lived fish. Ecology 96, 1899–1910 (2015).

Bisson, P. A. Assessment of the risk of invasion of national forest streams in the Pacific Northwest by farmed Atlantic salmon. Gen. Tech. Rep. PNW-GTR-697. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p 697, (2006).

Brown, C. L., Braem, N. M., Kostick, M. L., Trainor, A., Slayton, L. J., Runfola, D. M., Simon, J. J. (2016). Harvests and Uses of Wild Resources in 4 Interior Alaska Communities and 3 Arctic Communities, 2014 (Technical Report). Alaska Department of Fish and Game.

Brown, R. S., Hubert, W. A. & Daly, S. F. A primer on winter, ice, and fish: what fisheries biologists should know about winter ice processes and stream-dwelling fish. Fisheries 36, 8–26 (2011).

Burr, J. (2006). Fishery Management Report for Sport Fisheries in the Arctic-Yukon Management Area, 2003-2005 (Fisheries Management Report No. 06-66) (p. 97). Anchorage, Alaska.

BurnSilver, S., Magdanz, J., Stotts, R., Berman, M., & Kofinas, G. (2016). Are Mixed Economies Persistent or Transitional? Evidence Using Social Networks from Arctic Alaska: Are Mixed Economies Persistent or Transitional? American Anthropologist, 118(1), 121–129. https://doi.org/10.1111/aman.12447

Carothers, C. S. Cotton, and K.J. Moerlein. 2013. Subsistence use and knowledge of salmon in Barrow and Nuiqsut, Alaska. University of Alaska Fairbanks Coastal Marine Institute: Fairbanks.

Craig, P. and L. Haldorson 1986. Pacific salmon in the North American Arctic. Arctic 39 (1): 2-7.

Cotton, S. 2012. Subsistence salmon fishing in Beaufort Sea communities. Master's Thesis. University of Alaska Fairbanks.

Correa, C. & Gross, M. R. Chinook salmon invade southern South America. Biological Invasions 10, 615–639 (2008).

Dolloff, C. A. Reeves, C. H. Microhabitat partitioning among stream-dwelling juvenile coho salmon, Oncorhynchus kisutch, and Dolly Varden, Salvelinus malma. Canadian Journal of Fisheries and Aquatic Sciences 47, 2297–2306 (1990).

Dunmall, K. M. et al. Pacific salmon in the Arctic: harbingers of change. Responses of Arctic marine ecosystems to climate change. Edited by FJ Mueter, DMS Dickson, HP Huntington, JR Irvine, EA Logerwell, SA MacLean, LT Quakenbush, and C. Rosa. doi 10, (2013).

Fall, James A. et al. 2018. Alaska Subsistence and Personal use Salmon Fisheries 2015 Annual Report. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 440. Anchorage.

George, C., L. Moulton, and M. Johnson. 2009. A field guide to the common fishes of the North Slope of Alaska. Version 1.5. Barrow, Alaska: Department of Wildlife Management, North Slope Borough.

Langdon, S. (2002). The Native people of Alaska: Traditional living in a northern land. Anchorage, AK: Greatland Graphics.

Mikow, E., Retherford, B., Godduhn, A., & Kostick, M.L. 2016. Exploring Subsistence Fisheries of Point Lay and Wainwright, Alaska. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 419. Fairbanks.

Nielsen, J. L., Ruggerone, G. T. & Zimmerman, C. E. Adaptive strategies and life history characteristics in a warming climate: Salmon in the Arctic? Environmental Biology of Fishes 96, 1187–1226 (2013).

Parmesan, C. Ecological and evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37, 637–669 (2006).

Pess, G. R., Quinn, T. P., Gephard, S. R. & Saunders, R. Re-colonization of Atlantic and Pacific rivers by anadromous fishes: linkages between life history and the benefits of barrier removal. Reviews in Fish Biology and Fisheries 24, 881–900 (2014).

Quinn, T. P., Kinnison, M. T. & Unwin, M. J. Evolution of chinook salmon (Oncorhynchus tshawytscha) populations in New Zealand: Pattern, rate, and process. in Microevolution Rate, Pattern, Process (eds. Hendry, A. P. & Kinnison, M. T.) 8, 493–513 (Springer Netherlands, 2001).

Reist, J. D. et al. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. AMBIO: A Journal of the Human Environment 35, 381–387 (2006).

Roos, J. F. Feeding Habits of the Dolly Varden, Salvelinus malma (Walbaum), at Chignik, Alaska. Transactions of the American Fisheries Society 88, 253–260 (1959).

Stephenson, S. A. A review of the occurrence of Pacific salmon (Oncorhynchus spp.) in the Canadian Western Arctic. Arctic 37–46 (2006).

Wenger, S. J. et al. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. Proceedings of the National Academy of Sciences 108, 14175–14180 (2011).