Cloudberry in a Changing Climate:

Threats and Opportunities

Alaska Berry Futures
Alaska Climate Adaptation Science Center
UAF University of Alaska Fairbanks
International Arctic Research Center
Institute of Arctic Biology, University of Alaska Fairbanks
Bonanza Creek LTER Boreal Forest Ecology

Photo by Lindsey V. Parkinson. 9/2023

WELCOME!

In late summer, berry picking is on the to-do list of nearly every Alaskan. Alaska's wild berries provide delicious and highly nutritional food, and for remote communities they are the only source of wild fruit and hold cultural significance in recipes and stories. Berry picking is a recreational activity and tradition for rural and urban Alaskans alike. But all across the state people have observed changes in the timing and predictability of fruiting for many berry species, and wonder if a changing climate is having an influence. A shifting climate has led to many changes that could influence berry species, including rising temperatures, longer growing seasons, shorter snow covered seasons, and altered precipitation patterns. It can also lead to changes in the pollinators that our berry plants depend on, and in the populations of the animals and microbes that consume or protect the plants. The effects of those changes are complicated, and the overall impact can be positive or negative.

In the "Berries in Alaska's Changing Environment" series, we examine what we know about the impacts of climate change on our berry species based on scientific research and observations by community members across the state. We identify potential threats to the growth, health, and fruit production of each species. We also look at opportunities: ways that Alaskans may be able to preserve or even expand the availability of fruits. And third, we identify gaps in our knowledge that limit our current abilities to predict what will happen with our berry species. We hope this information will inspire berry lovers to find ways to take advantage of new opportunities, protect what we have, and adapt when that is not possible.

The reports will look at growth, flowers, pollination, fruits and seeds, mutualists (like fungi that help plants obtain nutrients) and plant enemies (like herbivores and pathogens), briefly discuss human use, and highlight threats and opportunities for each aspect of the plant life cycle under a changing climate.

TEXT: Christa P.H. Mulder, Kristin Schroder, Lindsey V. Parkinson, and Katie V. Spellman

GRAPHICS AND PHOTOS:
Hannah Foss, Molly Putman, Anne Ruggles, Kristin Schroder, Lindsey V. Parkinson, and Pamela K. Diggle

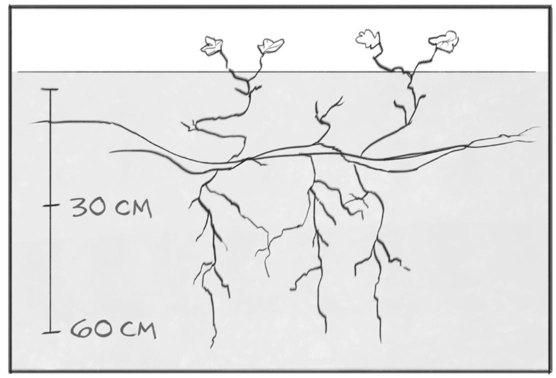
MORE INFORMATION:
For more information and to download copies of this booklet visit the Alaska Berry Futures website at *https://casc.alaska.edu/changingberries.*

ADVISORY AND REVIEW TEAM:
Matthew Balazs, Gwen Dilitz, Nancy Fresco, Faith Lussow, Elena Sparrow.

Suggested citation: Mulder, C.P.H., L.V. Parkinson, K. Schroder, H. Foss, M. Putman, K.V. Spellman, A. Ruggles, and P. K. Diggle. (2023). Cloudberry in a Changing Climate: Threats and Opportunities. Berries in Alaska's Changing Environment Series: *Rubus chamaemorus*. Institute of Arctic Biology and International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

CLOUDBERRY

This issue focuses on cloudberry (scientific name: *Rubus chamaemorus* L. in the Rosaceae family). It goes by many common names, including bakeapple, yellowberry, and salmonberry in English, and by many Indigenous names: *akpiq* (Iñupiaq)[1]; *appik* (Inuktut)[2], *aqavsik, aqevyik, atsalugpiaq* (Yup'ik[1])[3]; *alagnaq, agagwik* (Alutiiq/Sugpiak)[4]; *aqamda-x* (Unangam Tunuu)[5]; *naskal* (Gwich'in)[6]; *dondhi'on* (Deg Xinag Athabaskan)[7]; *kkotł* (Koyukon Athabaskan)[8]; *nqutl'* (Dena'ina Athabaskan)[9]; *néx̲'w* (Tlingít)[10]; *k̲'aax̲u ts' alaangg̲a* (Haida)[11]; and *g̲olk'* (Tsimshian).[12] It is one of the most popular berries across North America and northern Europe.



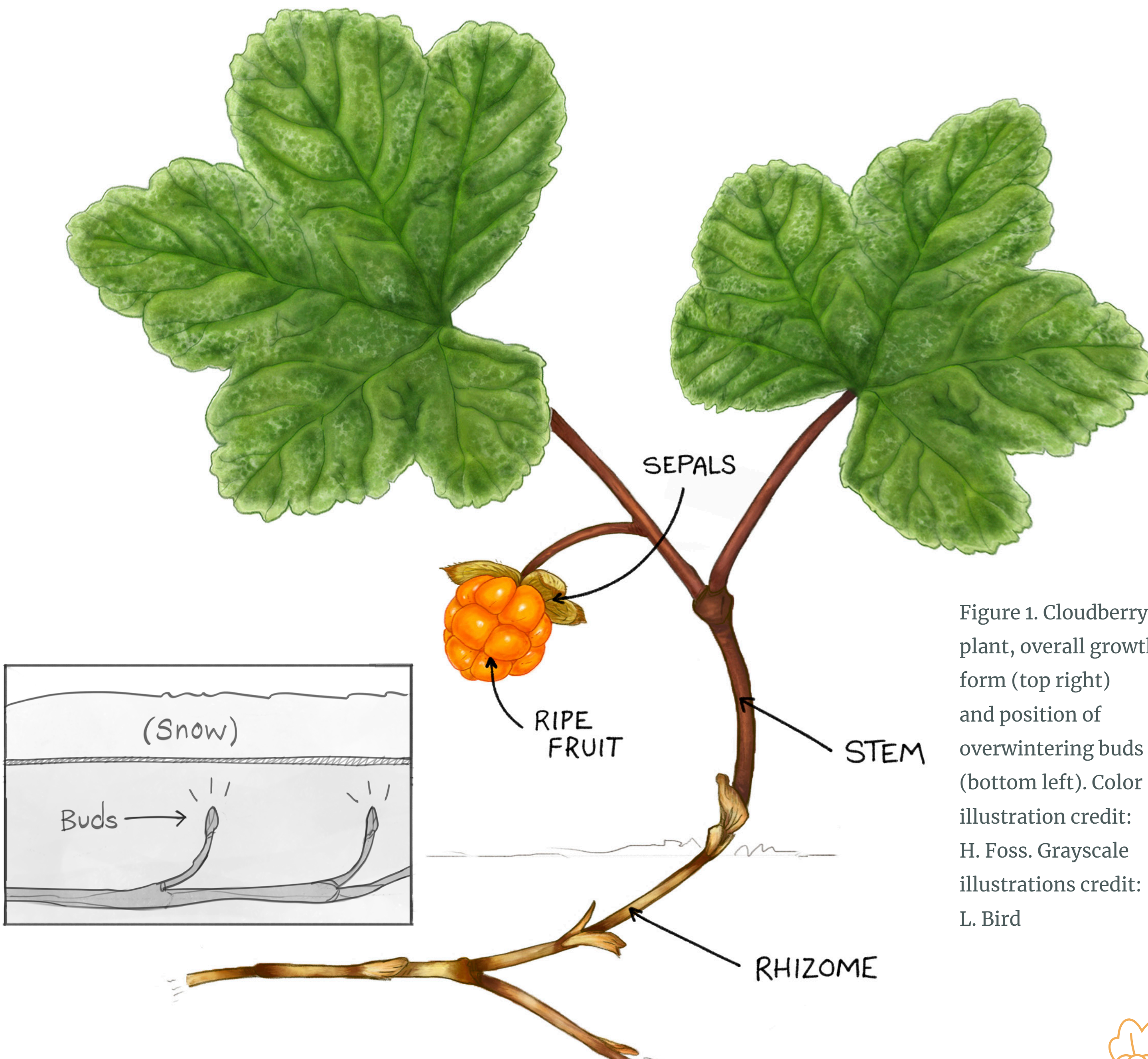


Figure 1. Cloudberry plant, overall growth form (top right) and position of overwintering buds (bottom left). Color illustration credit: H. Foss. Grayscale illustrations credit: L. Bird

GROWTH

Figure 2. Four cloudberry ramets (plantlets) likely connected by a rhizome (underground stem). Photo credit: A. Ruggles.

Cloudberry plants produce rhizomes (underground stems) that can run for several yards (meters); at multiple points along this stem they produce a set of leaves and a set of roots (Figure 1, Figure 2). Each of these plantlets, called ramets, has a single short shoot, about 2 – 4 inches (5 – 10 cm) tall, with 1 to 4 leaves and a single flower. The visible part of the plant is only a fraction of the whole plant; over 95% of the plant is belowground.[13]

The life of a leaf starts when a bud is produced belowground, just below the soil surface (Figure 1, about a year before they emerge. The leaf bud (which also includes the flowers) is kept below ground throughout the winter, where it is sheltered from extreme cold, and emerges once the ground thaws. Leaves usually expand in June, but this can vary by up to 3 weeks.[14,15] The leaves are large and thin compared to the leaves of other plant species in this habitat, with high nitrogen content and low tannin levels (bitter chemical compounds that deter animals from eating the leaves).[16,17] The leaves last for 88 – 104 days, turning brown and drying around the time that ripe fruits are produced. The roots of cloudberry go down into the soil to about 15 – 25" (40 – 60 cm), which brings them close to the boundary between seasonally thawing soil and permafrost.[18,19] This is deeper than most of the neighboring plant species.

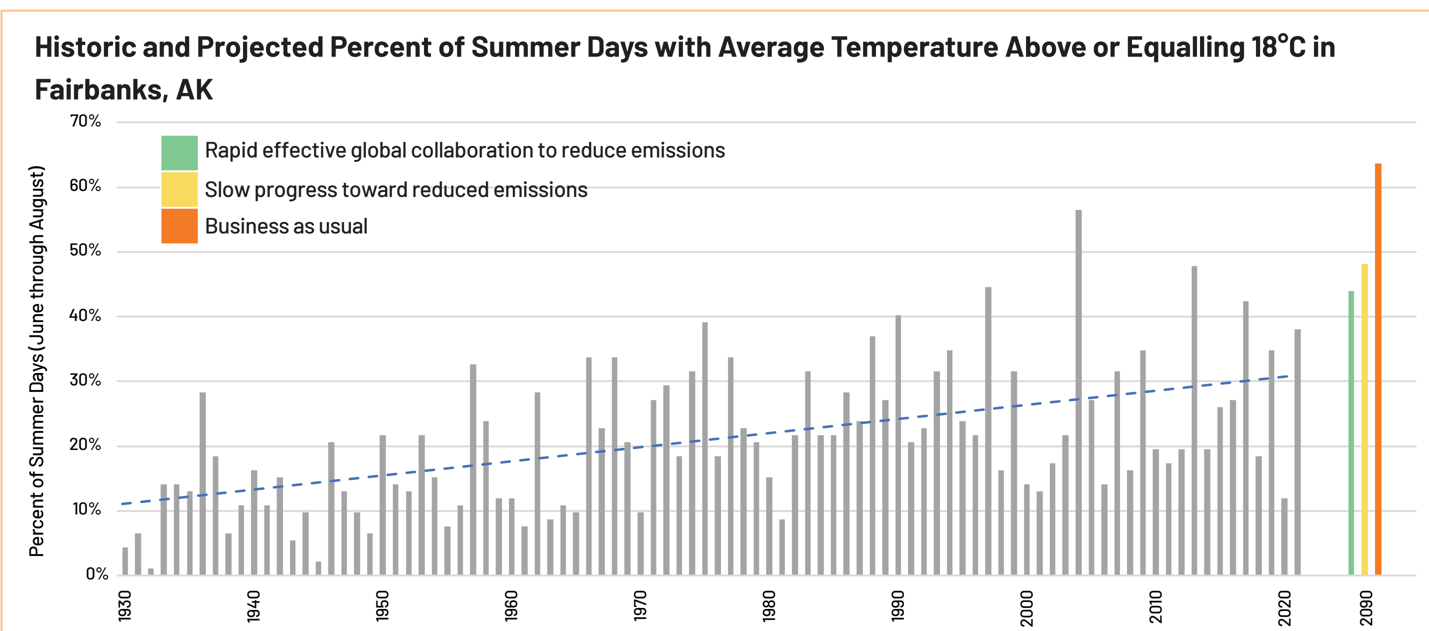


Figure 3. Historic and projected percent of summer days with average temperature ≥ 18 °C in Fairbanks, Alaska. Projections are based on the three Intergovernmental Panel on Climate Change (IPCC) Representative Carbon Pathway scenarios (RCP 2.6= green, RCP 6.0=yellow, RCP 8.5 = red), for a time period in the future (2090-99). The graph shows there has been an increase in days above 18 deg over the past century and that under the "business as usual" scenario about two-thirds of the days will be over this threshold by the end of this century.[20]

Warm air temperatures in summer: The leaves photosynthesize best at about 50 – 60 °F (10 –15 °C), and show a decline in photosynthesis once temperatures get above about 64 °F (18 °C).[21] Berry pickers on the Yukon-Kuskokwim Delta identified hot weather as a concern.[22] Temperatures in Alaska and the far north have been rising; in interior Alaska the percent of summer days with average temperatures above this threshold has been rising, and is projected to reach > 40% of days in the near future (Figure 3). This could translate into reduced growth, increased stress on the plant, and reduced sugars and supporting structures produced for fruits. Other regions of the state are also projected to reach this threshold for many days per summer (Figure 4).

Lack of snow cover in spring: In the middle of winter, belowground buds (which contain the pre-formed leaves) can tolerate quite cold temperatures: down to about 11 °F (-11.5 °C) for buds and 3 °F (-16 °C)[23] for rhizomes, which is colder than most snow-covered

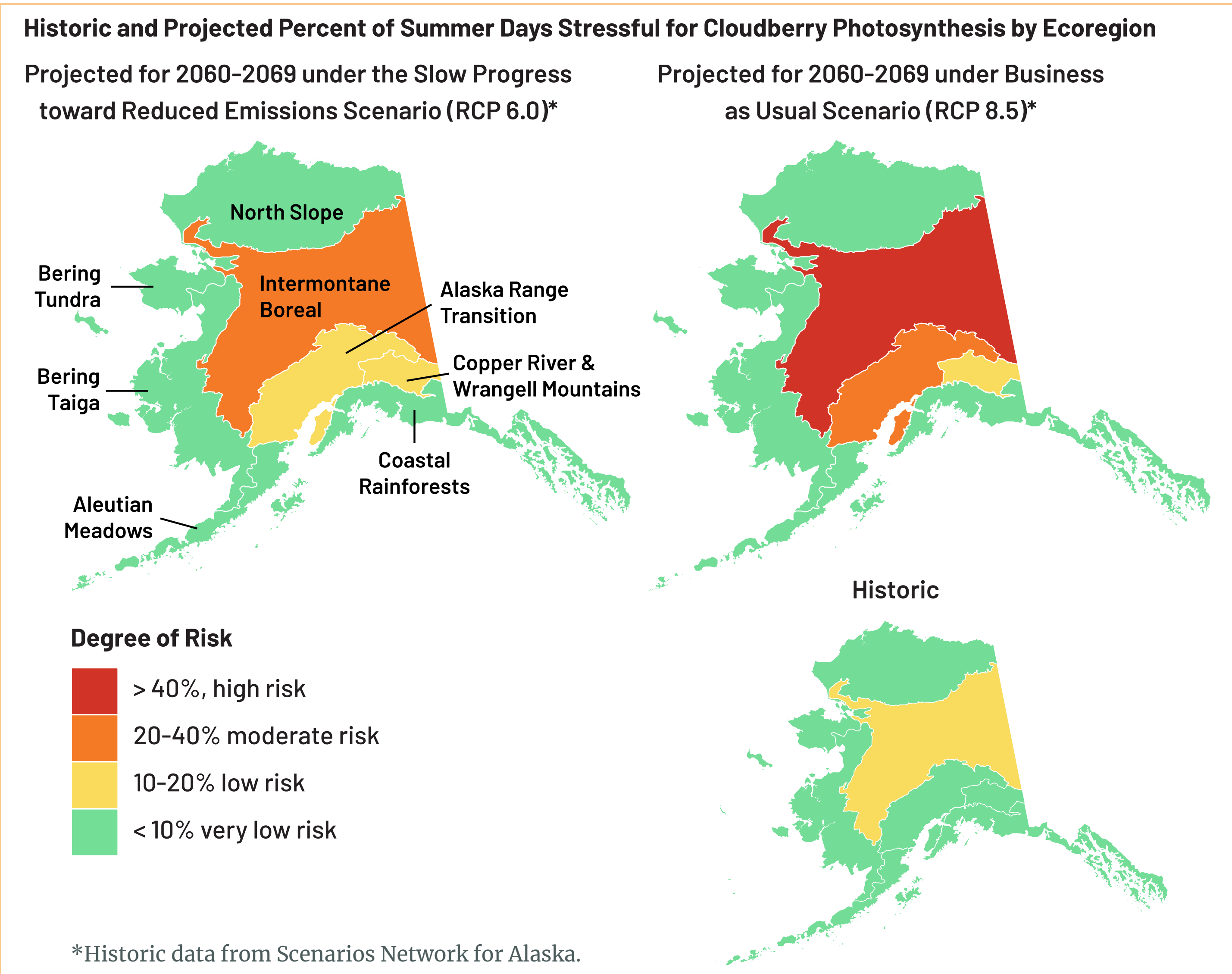


Figure 4. Historic and projected percent of summer days stressful for cloudberry photosynthesis by ecoregion. Projections are based on two Intergovernmental Panel on Climate Change (IPCC) Representative Carbon Pathways for 2060-2069. The figure shows that the Intermontane Boreal ecoregion is at highest risk of having many days that are stressful for cloudberries in the near future, while the Alaska Range Transition region has a moderate risk.[20]

soils will reach. However, the buds become more sensitive to cold in the spring, even before the snow melts, and during the growing season they can be damaged at temperatures as high as about 27 °F (-3 °C).[23] Berry pickers on the Yukon-Kuskokwim Delta identified low winter snowpack, and to a lesser extent cold winter temperatures, as a concern[22], and in some parts of Alaska (Yukon-Kuskokwim Delta, Interior) much of the winter precipitation will switch from snow to rain.[24] If snow cover is reduced in the springtime (because of low snowfall, increased wind, or because of above-freezing temperatures followed by below-freezing temperatures), then young buds may be damaged. However, because most of the plant is belowground, this is unlikely to kill the plant unless it happens many years in a row.

Increased competition from shrubs: Cloudberries thrive in areas with permafrost, likely in part because deciduous shrubs are uncommon in that habitat. As the soil warms and permafrost thaws, alder, birch, and willow are expanding in tundra in large parts of the state.[25, 26] These shrubs may compete with cloudberries for light, water, and nutrients. While some shade may be beneficial to growth, leaf litter from deciduous shrubs is likely to decrease light availability for the short-statured cloudberry.

OPPORTUNITIES FOR INCREASED GROWTH

Warmer temperatures may benefit plants under some conditions. First, warmer late summer temperatures may delay leaf senescence (browning), which may allow plants to store more resources for the following year.[27] Second, because cloudberry roots grow close to the boundary between seasonally thawed ground and permafrost, they may be better at taking advantage of the nutrients that become available as permafrost thaws than other species.[28]

Snow accumulation has been increasing in coastal areas (but not in more interior regions)[29], and this may make coastal areas more suitable for cloudberries. However, wind is predicted to increase in the early parts of the year (approx. January – April) in large parts of the state[30], resulting in greater variation in snow cover (some patches with little snow, some with more snow), especially in open areas. This makes the overall effect of climate change on spring conditions for cloudberry difficult to predict.

Photo credit: K. Schroder.

Flower buds start to form about a year before flowers open (Figure 5), and are enclosed in the same bud as the leaves. Because the buds are held belowground, timing of flowering is driven primarily by the timing of ground thaw rather than by air temperature in spring, and so can vary by up to 3 weeks.[31,32] Flower buds are vulnerable to damage if springtime soil temperatures drop below about 27 °F (-3 °C) as a result of low snowfall or early snowmelt.[23] Once open, flowers are also damaged by frost.[33-35] Early snowmelt followed by freeze-thaw cycles has a high likelihood of destroying the flowers. Berry pickers in Labrador, Canada, have also reported damage from strong winds and downpours.[33,35]

Each cloudberry plant produces either male flowers or female flowers with 4-5 white petals (Figure 6). Male flowers have numerous stamens (where the pollen is produced) and female flowers have multiple pistils (where the pollen lands and pollen tubes grow) and about 10 ovules which after fertilization will become seeds.[36,37] However, flowering varies enormously between years, and in most locations and years the majority of ramets do not flower.[38] Because the plants are clonal, a patch of ramets may contain only male or only female flowers. A single clone can make up every ramet in an area of ~ 10 - 1000 square feet (1 to 10 m^2). The flowering period is short: individual flowers only last 2 – 3 days, and a whole population only flowers for about 5 – 7 days.[15,36]

THREATS TO FLOWER PRODUCTION:

Increased spring temperatures and **reduced snow depth** combined with increased winds in some parts of the state[30] might lead to greater damage to flowers.

OPPORTUNITIES FOR INCREASED FLOWER PRODUCTION:

Warmer spring temperatures may result in lower probability of frost damage to flowers.
Shrub expansion into tundra may protect flowers from frost or heavy rain and increase fruit production.[38]

Photo credit: A. Ruggles.

Female Flower **Male Flower**

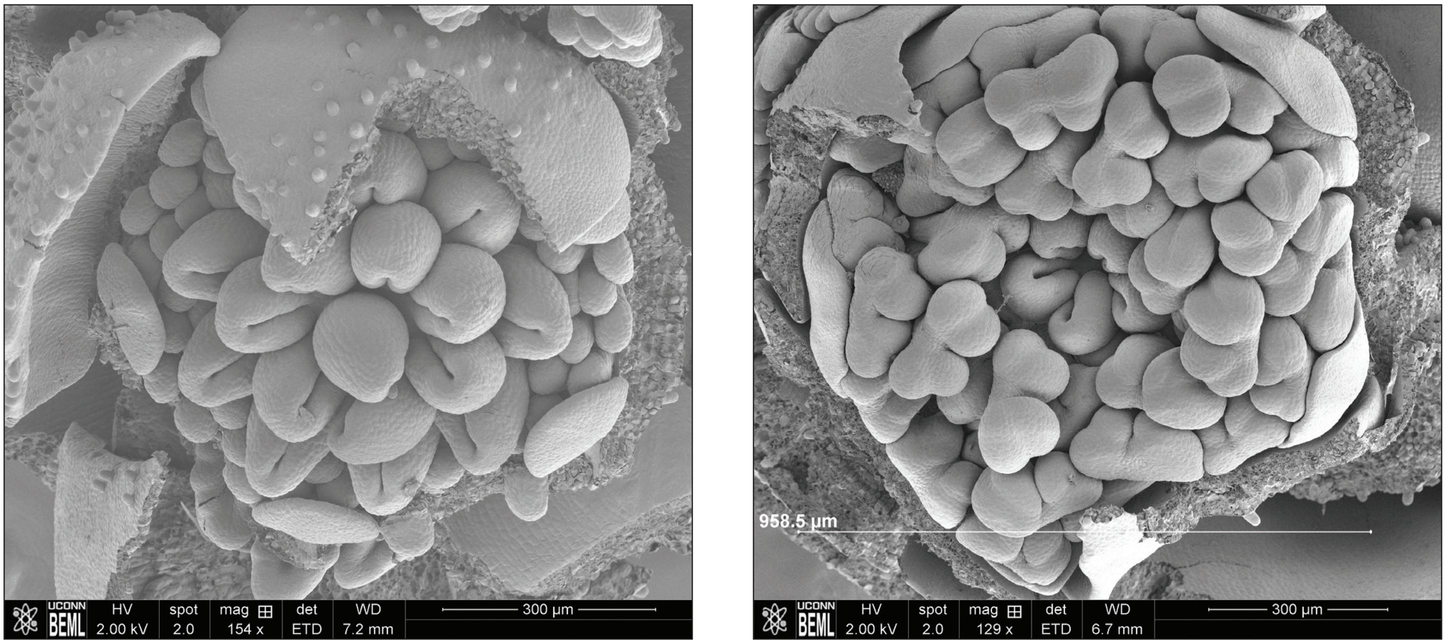


Figure 5. Preformed flowers buds the summer before flowers open. Left: female flower with immature carpels. Right: male flowers with immature stamens. The diameter of each bud is approx. 1 mm.
Image credit: P. Diggle.

Female Flower **Male Flower**

Figure 6: A female (left) and male (right) cloudberry flower. The structures in the center of the female flower contain carpels with (from top to bottom) the stigma (landing platform), style (tube) and ovary (green structure at the base). The male flower shows anthers (brown structures), which will release the pollen. Photo credits: A. Ruggles.

Because the plants each have only male or female flowers, cloudberry plants need insect pollinators to produce fruit. They are accessible to many types of pollinators but they are not terribly attractive to many species because the flowers produce little or no nectar.[32,39] The most common pollinators are syrphid flies (family Syrphidae, Figure 7), muscid flies (family Muscidae), bumblebees (genus *Bombus*), and solitary bees, especially halictid bees (genus *Halictus*).[32,39] Overall, flies are probably the most important pollinators; although bumblebees can carry more pollen grains, they are less abundant and don't release pollen easily.[32,40] However, bees may be important in cold years.[32] In years with high wind speeds during the short flowering period, there is very little pollinator activity.[32]

Cloudberry plants flower early relative to most species in the community[41], and many of the plants flowering at the same time are not competing for pollinators because they attract long-tongued, large-bodied pollinators such as bumble bees.[32] The most likely competitors are other species that attract small flies, like Labrador tea (*Rhododendron* species).

The proportion of female flowers that sets fruit varies by location and between years, and ranges from about 60% to over 90%.[38,39,42] In some communities a lack of pollinators is responsible for the lack of fruit production, while in others plants may have sufficient pollen but lack other resources such as sunlight or soil nutrients.[39,42]

Figure 7: A syrphid fly visits a male cloudberry flower. Photo credit: A. Ruggles.

THREATS TO POLLINATION

Spring has been coming earlier in communities across Alaska, and snowmelt is expected to advance by 2 – 4 weeks across large parts of the state by the end of the century.[29] If the timing of ground thaw advances more than the timing of pollinator emergence, then there may not be enough pollinators for full seed set. Wind storms are also changing across Alaska[30] and the alignment of the windy season and the flowering period will have a strong impact on pollination of the flowers and the possibility of them making fruit.

OPPORTUNITIES FOR POLLINATION

Solitary bees (and likely syrphid flies, which are similar in size and shape) cannot fly at cool temperatures.[43] Warmer temperatures may lead to greater activity levels and greater pollination rates.

FRUITS & SEEDS

Figure 8. The relationship between the pistils (female flower parts) and the fruit. Note that each little ovary (green structure at the center of the flower) produces one orange drupelet. The old stigmas and styles can still be seen protruding from the drupelets. Photo credit A. Ruggles.

The fruits of cloudberry are known as "aggregate fruits", which means they are formed from many carpels (female structures) within a single flower. Each fruit is a collection of 5-25 "drupelets"[36], the small fruits that together make up what we think of as the berry (Figure 8). Each miniature orange globule is the result of fertilization of one ovule and corresponds to one carpel. The more carpels are pollinated, the bigger the fruit.

Fruits turn from green to orange or red as they ripen and, once ripe, are easily detached. Peak production of fruit occurs approx. 47 – 51 days after fertilization.[31] Ripe fruits remain on the plant for a short time only, typically less than a week. Although earlier flowering leads to earlier fruiting, fruiting time appears to vary less than flowering time.[31,41]

Mammals (including foxes and bears) and birds (including ravens, seabirds, ptarmigan and grouse) consume the fruits and disperse the seeds.[44-46] The seeds, which weigh about 8 mg, have thick seed coats that prevent them from germinating until the following summer.[44,47] Seeds germinate best from shallow depths and are viable for several years.[47,48] However, seedlings are uncommon and take about 7 years to reach a minimum flowering size.[45]

THREATS TO FRUIT PRODUCTION

Berry pickers in Labrador, Canada, have observed that fruits may be destroyed by temperature above 77 °F (25 °C).[33,35]

OPPORTUNITIES FOR GREATER FRUIT PRODUCTION

More shade can increase the probability of fruiting and result in larger fruits.[31]

PLANT ENEMIES

Unlike most closely related species (e.g., raspberries), cloudberry does not produce thorns, and the leaves are less tough than most co-occurring species.[50] They do have a compound, ellagic acid, that might reduce insect feeding.[51] Many invertebrates, including larvae of many moth species, aphids, and chrysomelid beetles, consume the leaves and fruits (Figure 9). Fungi can also do damage to leaves and fruits.[44,52-54] However, because so much of their biomass is belowground, plants can withstand high levels of defoliation without large negative effects on growth or flowering the following year.[52]

Figure 9: Senescing (browning) leaves of cloudberry in fall with evidence of insect herbivory. Photo credit: A. Ruggles.

PLANT FUNGAL ASSOCIATES

Unlike the majority of plant species, cloudberry does not have any associations with mycorrhizal fungi to help it gain water and nutrients from the soil.[19,49]

HUMAN USE

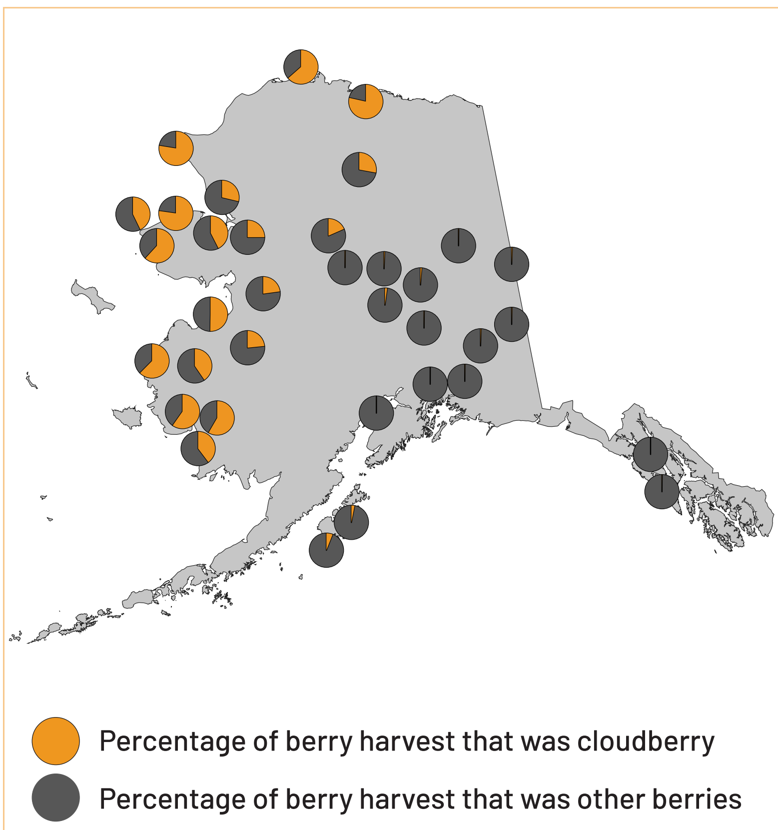
Cloudberries are important nutritionally and culturally for people living across the North, including Alaska, Canada, Scandinavia, and Russia.[33,35,55-58] In many places where it is found it is considered the most prized berry[56]; in Alaska, it is the most picked berry along the west coast (Bering Tundra and Bering Taiga ecoregions) and on the North Slope[22,57] [see also map]. In North America harvest is limited to wild fruits, but it is commercially harvested in cultivated bogs in Scandinavia.[32] Because the fruits are very soft they have to be harvested by hand.[36] Fruits are eaten fresh or frozen, and used in baked goods and jams, and in traditional dishes such as *aqutak* (Alaska) and *kissel* (Russia).[35,55] In Scandinavia they are also used for wines, liqueurs, and sweets. Leaves and sepals may be used in tea.[55] Because they are one of the first fruits to ripen[41], picking cloudberries does not interfere with picking of other fruits (other than, in some locations, the less prized crowberries (*Empetrum nigrum*)).

Cloudberries are considered highly nutritious: they are rich in antioxidants (including anthocyanins and carotenoids, which give them their orange color), ellagic acid, and other nutrients.[51,59] These compounds can help prevent high blood pressure and reduce the risk of cancer.[51,59] Traditionally, fruits and leaves were used in Scandinavia to prevent scurvy and diarrhea.[59] The Mi'kmaq of eastern coastal Canada historically used the roots to treat fevers, coughs, and other respiratory ailments[60] while the Nihithawak of eastern Saskatchewan, Canada used a decoction of roots and stems to aid in birth or to treat infertility.[61]

CLIMATE IMPACTS ON HUMAN USE

Concerns about cloudberry plants are mentioned in at least 12 climate adaptation plans from communities across Alaska and are reported by additional communities in Alaska and Canada.[24,35,57,62,63] Most concerns center on one of three issues. First, increased variability in abundance of fruits from year to year leads to reduced food security. Second, increased variability in timing of fruiting makes it more difficult to plan harvesting and combine it with other activities, while increased variability in when plants ripen within a year may require more trips to harvest berries. Third, the distance people need to travel to harvest fruits has increased, resulting in greater costs and time required, especially in areas where traditional berry patches are lost to tree and shrub growth.

Cloudberry (*Rubus chamaemorus*) harvested in Alaska by community (ADFG 2013-2018)



SUMMARY

Cloudberry faces multiple threats from a warming world. However, these threats depend on the region of the state and in many cases it may be possible to take action to maintain good berry production.

BUILDING RESILIENCE TO CHANGES IN CLOUDBERRIES

Providing shade (either with other plants or with shade cloth) may reduce overheating and increase plant growth[9] and also increase fruit production.[19,21]

Cloudberry responds well to experimental fertilization[27,64,65], so **amending soils with fertilizers** may also increase growth.

For small and important community cloudberry patches, **snow addition** may help protect underground buds in spring. This could be implemented through snow fences, shrubby windbreaks to trap snow, or manual or mechanical movement of the snow (e.g., with a snow blower) to protect key cloudberry patches of concern.

In Scandinavia and Quebec, **the addition of honeybees** has been shown to increase pollination and fruit set.[24] This has not been tested for pollination of cloudberry in Alaska, where honeybees are not native, and found only where people have deliberately introduced them.

KEY KNOWLEDGE GAPS

We don't know enough about what triggers the emergence of syrphid and muscid flies in spring to determine how likely it is that cloudberry will suffer a loss of pollinators.

We don't know under what circumstances the advantages of shading by shrubs outweigh the disadvantages, or whether it depends on the shrub species (for example, alder vs. willow).

GLOSSARY

Mycorrhizae - a beneficial fungal partner that grows into and around many plant roots

Pistil - female part of a flower; contains stigma (pollen collector), ovary (fruit or seed to be), and style (piece connecting stigma and ovary)

Ramet - A single stem from a clonal plant

Senescence - growing old, decaying; in botany often refers to leaves or plants browning in autumn

Stamen - pollen producing, male part of a flower, which includes the anther (where the pollen is produced and released)

ENDNOTES

1. *Iñupiatun Uqaluit Taniktun Sivuniŋit: North Slope Iñupiaq to English Dictionary*. https://inupiaqonline.com/ (accessed 2023-03-01).
2. *Uqausiit: The Inuktut Grammar Dictionary*. https://uqausiit.ca/ (accessed 2023-05-26).
3. Jacobson SA. 2012. *Yup'ik Eskimo Dictionary: Volume 1 (of 2)*, 2nd ed. Alaska Native Language Center.
4. Leer J, C Anahonak, A Moonin, D Tabios, S Moonin, D Anahonak, M Anahonak. 2007. *Nanwalegmiut Paluwigmiut-Llu Nupugnerit: Conversational Alutiiq Dictionary, Kenai Peninsula Alutiiq*, 8th ed. National Bilingual Materials Development Center and the Alaska Native Language Center.
5. Bergsland K. 1994. *Aleut Dictionary: An unabridged lexicon of the Aleutian, Pribilof, and Commander Islands Aleut language.* Alaska Native Language Center, https://uafanlc.alaska.edu/Online/AL950B1994a/bergsland-1994-aleut_dictionary-smaller.pdf, (accessed 2023-03-01).
6. Gwich 'in Social and Cultural Institute. 2009. *Gwich'in Topical Dictionary: Gwichyah Gwich'in & Teetl'it Gwich'in Dialects*, 6th ed. https://gwichin.ca/sites/default/files/gsci_gsci_2009_gwichin_topical_dictionary.pdf (accessed 2022-3-28).
7. Kari J. 1978. *Deg Xinag: Ingalik Noun Dictionary*. Alaska Native Language Center. https://uafanlc.alaska.edu/Online/IK974K1978a/kari-1978-deg_xinag_dictionary.pdf (accessed 2023-5-25).
8. Jones E. 1983. *Dinaakkanaaga Ts'inh Huyoza (Junior Dictionary for Central Koyukon Athabaskan)*. National Bilingual Materials Development Center. https://uafanlc.alaska.edu/Online/KO972J1978i/koyukon%20junior%20dictionary.pdf (accessed 2023-5-26).
9. Kari J. 1974. *Kenai Tanaina Noun Dictionary*. Alaska Native Language Center. https://uafanlc.alaska.edu/Online/TI972K1974i/kari-1974-kenai_tanaina_noun_dictionary.pdf (accessed 2023-2-23).
10. Edwards K. 2009. *Dictionary of Tlingit*. Sealaska Heritage Institute. https://www.sealaskaheritage.org/sites/default/files/Tlingit_dictionary_web.pdf (accessed 2023-2-24).
11. Lachler J. 2010. *Dictionary of Alaskan Haida*. Sealaska Heritage Institute. https://www.sealaskaheritage.org/sites/default/files/Haida_dictionary_web.pdf (accessed 2023-5-26).
12. Roberts DM. 2009. *Dictionary of Shm'algyack*; Sealaska Heritage Institute. https://www.sealaskaheritage.org/sites/default/files/TsimshianDictionaryOnline_sml.pdf (accessed 2023-5-26).
13. Dumas P, L Maillette 1987. Sex ratio and reproductive success of Rubus chamaemorus, a herbaceous dioecious species of subarctic distribution. *Canadian Journal of Botany* 65: 2628-2639.
14. Mulder CPH, KV Spellman. 2019. Do longer growing seasons give introduced plants an advantage over native plants in Interior Alaska? *Botany* 97: 347-362.
15. Ågren J. 1988. Sexual differences in biomass and nutrient allocation in the dioecious *Rubus chamaemorus*. *Ecology* 69: 962-973.
16. Kenzo T, A Tanaka-Oda, Y Mastuura, LD Hinzman. 2016. Morphological and physicochemical traits of leaves of different life-forms of various broadleaf woody plants in interior Alaska. *Canadian Journal of Forest Res*earch 46:1475-1482.
17. Olsrud M, A Michelsen. 2009. Effects of shading on photosynthesis, plant organic nitrogen uptake, and root fungal colonization in a subarctic mire ecosystem. *Botany*. 87:463-474.
18. Hewitt RE, DL Taylor, H Genet, AD McGuire, MC Mack. 2019. Below-ground plant traits influence tundra plant acquisition of newly thawed permafrost nitrogen. *Journal of Ecology* 107:950-962.
19. Kutschera, L, M Sobotik, L Lichtenegger. 1997. *Bewurzelung von Pflanzen in Verschiedenen Lebensräumen. Allgemeiner Teil*. Linz : Land Oberösterreich, Zur Zeit zu erhalten bei Pflanzensoziologisches Institut.
20. Projections are based on three Representative Concentration Pathways (RCPs) defined by the Intergovernmental Panel on Climate Change (IPCC). RCPs represent different levels of greenhouse gases in Earth's atmosphere over coming decades, out to 2100, resulting in different amounts of climate change. RCP2.6 (green), RCP6.0 (yellow), and RCP8.5 (red) are all possible pathways that may occur globally, based on what choices governments make. The numbers are Watts per square meter, representing the increase in solar energy likely to be absorbed compared to average levels before industrialization (1750). RPC2.6 would require very strict immediate cuts in emissions. RCP6.0 might occur if emissions peak around 2080 and then decline. RCP8.5 is the most pessimistic future, with emissions continuing to rise throughout this century. For each RCP, two future time periods are shown (the 2060s and the 2090s).

    IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
21. Marks TC, K Taylor. 1978. The carbon economy of *Rubus chamaemorus* L. I. Photosynthesis. *Annals of Botany* 42:165-179.
22. Herman-Mercer NM, RA Loehman, RC Toohey, C Paniyak. 2020. Yukon-Kuskokwim Delta berry outlook: results from local expert surveys. *Human Ecology* 48:85-89.
23. Kaurin A, O Junttila, J Hanson. 1981. Seasonal changes in frost hardiness in cloudberry (*Rubus chamaemorus*) in relation to carbohydrate content with special reference to sucrose. *Physiologia Plantarum* 52:310-314.
24. Mulder CPH, LV Parkinson, K Schroder. Data underlying graphs and climate statements in the Berries in Alaska's Changing Climate series. Published online 2023. TBA
25. Tape, K, M. Sturm, C Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology* 12: 686–702.
26. Pearson RG, SJ Phillips, MM Loranty, PSA Beck, T Damoulas, SJ Knight, SJ Goetz. 2013. Shifts in arctic Vegetation and associated feedbacks under climate change. *Nature Climate Change* 3: 673–677.
27. Bellemare M, L Rochefort, L Lapointe. 2009. Rhizome sectioning and fertilization increase the productivity of cloudberry in natural peatlands. *Canadian Journal of Plant Science* 89: 521-526.
28. Natali SM, EAG Schuur, RL Rubin. 2012. Increased plant productivity in Alaskan tundra as a result of experimental warming of soil and permafrost. *Journal of Ecology* 100: 488-498.
29. Lader R, JE Walsh, US Bhatt, PA Bieniek. 2020. Anticipated changes to the snow season in Alaska: Elevation dependency, timing and extremes. *International Journal of Climatology* 40: 169-187.
30. Redilla K, ST Pearl, PA Bieniek, JE Walsh. 2019. Wind climatology for Alaska: historical and future. *Atmospheric and Climate Sciences* 9: 683-702.

31. Yudina VF. 1993. Phenological development and yields of cloudberry (*Rubus chamaemorus*) in Karelia, Russia. *Acta Botanica Fennica* 149: 7-10.
32. Brown AO, JN McNeil. 2009. Pollination ecology of the high latitude, dioecious cloudberry (*Rubus chamaemorus*; Rosaceae). *American Journal of Botany* 96:1096-1107.
33. Karst AL, NJ Turner. 2011. View of local ecological knowledge and importance of bakeapple (*Rubus chamaemorus* L.) in a Southeast Labrador Métis Community. Ethnobiology Letters 2: 6-18.
34. Kortesharju J. 1995. Effects of frost on the female flowers, unripe fruits and vegetative growth of the cloudberry (*Rubus chamaemorus*) in Finnish Lapland. *Aquilo, Series Botanica* 35: 31-35.
35. Anderson D, JD Ford, RG Way. 2018. The impacts of climate and social changes on cloudberry (Bakeapple) picking: a case study from southeastern Labrador. *Human Eco*logy 46:849-863.
36. Li J, D Percival, J Hoyle, J White, K Head, K Pruski. 2016. Phenology and yield of native fruits cloudberry/bakeapple (*Rubus chamaemorus* L.) and lingonberry/partridgeberry (*Vaccinium vitis-idaea* L.) grown in Southern Labrador, Canada. *Canadian Journal of Plant Science* 96: 329-338.
37. Kortesharju J. 1988. Cloudberry yields and factors affecting the yield in northern Finland. *Acta Botanica Fennica* 136: 77-80.
38. Karst AL, JA Antos, GA Allen. 2008. Sex ratio, flowering and fruit set in dioecious *Rubus chamaemorus* (Rosaceae) in Labrador. *Botany* 86: 204-212.
39. Pelletier L, A Brown, B Otrysko, JN McNeil. 2001. Entomophily of the cloudberry (*Rubus chamaemorus*). *Entomologia Experimentalis et Applicata* 101: 219-224.
40. Naess SK, M Chagnon. 2011. Honeybees are useful as pollinators of the dioecious cloudberry, a high-value northern berry. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science* 61(sup1): 1-7.
41. Mulder C, Spellman KV. Flower and leaf phenology of Interior Alaska forbs and shrubs as observed near Fairbanks Alaska from 2013-2015. Published online 2021. doi:10.6073/PASTA/AE8B2F7626FD96A24BF347AD5E8BA733
42. Ågren J. 1989. Seed size and number in *Rubus chamaemorus*: between-habitat variation, and effects of defoliation and supplemental pollination. *The Journal of Ecology* 77:1080.
43. Bishop JA, WS Armbruster. 1999. Thermoregulatory abilities of Alaskan bees: effects of size, phylogeny and ecology. *Functional Ecology* 13: 711-724.
44. Taylor K. *Biological Flora of the British Isles*. Rubus chamaemorus *L.* 1971. *Journal of Ecology* 59: 293-306.
45. Resvoll TR. *Rubus chamaemorus* L. 1925. Die geographische Verbreitung der Planze und ihre Verbreitungsmittel. Veröffentlichungen des Geobotanischen Institutes der ETH, Stiftung Rübel, Zürich 5: 223-241.
46. Persson IL, J Swenson, I Mysterud. 2001. The diet of the brown bear *Ursus arctos* in the Pasvik Valley, northeastern Norway. *Wildlife Biology* 7: 27-37.
47. Rantala EM. 1976. Sexual reproduction in the cloudberry. *Annales Agriculturae Fenniae*. 15: 295-303.
48. Jauhiainen S. 1998. Seed and spore banks of two boreal mires. *Annales Botanici Fennici* 35:197-201.
49. Harley JL, Harley EL. 1987. A check-list of mycorrhiza in the British Flora. *New Phytologist* 105(s1):1-102.
50. Fetcher N, S. Iglesia, SJ Turner, TC Parker. 2022. Interspecific and intraspecific variation in leaf toughness of Arctic plants in relation to habitat and nutrient supply1. *Arctic Science* 8: 952-966.
51. Maas JL, GJ Gelletta, GD Stoner. 1991. Ellagic acid, an anticarcinogen in fruits, especially strawberries: a review. *HortScience* 26: 10-14.
52. Ågren J. 1987. Intersexual differences in phenology and damage by herbivores and pathogens in dioecious *Rubus chamaemorus* L. *Oecologia* 72:161-169.
53. Koponen H, S. Hellqvist, H. Lindqvist-Kreuze, U. Bång, JPT Valkonen. Occurrence of *Peronospora sparsa (P. rubi)* on cultivated and wild *Rubus* species in Finland and Sweden. *Annals of Applied Biology* 137:107-112.
54. Molenko W. 1994. Notes on some rare and unusual species of parasitic fungi collected from natural plant communities in Poland. *Mycologist* 8:71-77.
55. Kolosova V, O Belichenko, A Rodionova, D Melnikov, R Sõukand. 2020. Foraging in boreal forest: wild food plants of the Republic of Karelia, NW Russia. *Foods* 9:1015.
56. Boulanger-Lapointe N, J Gérin-Lajoie, L. Siegwart Collier, S Desrosiers, C Spiech, GHR Henry, L Hermanutz, E Lévesque, A. Cuerrier. 2019. Berry plants and berry picking in Inuit Nunangat: Traditions in a changing socio-ecological landscape. *Human Ecology* 47:81-93.
57. Hupp J, M Brubaker, K Wilkinson, J Williamson. 2015. How are your berries? Perspectives of Alaska's environmental managers on trends in wild berry abundance. *International Journal of Circumpolar Health* 74:28704.
58. Bellew C, A Ross, R Wells, V Hiratsuka. 2004. *Final Report on the Alaska Traditional Diet Survey*. Alaska Native Epidemiology Center, Alaska Native Health Board.
59. Thiem B. 2003. *Rubus chamaemorus* L. - a boreal plant rich in biologically active metabolites: a review. *Biology Letters* 40: 3-13.
60. Chandler RF, L Freeman, SN Hooper. 1979. Herbal remedies of the Maritime Indians. *Journal of Ehtnopharmacology* 1:49-68.
61. Leighton AL. 1985. *Wild Plant Use by the Woods Cree (Nihithawak) of East-Central Saskatchewan*, University of Ottawa Press, Ottawa, Canada.
62. Kellogg J, J Wang, C Flint, D. Ribnicky, P Kuhn, E González de Mejia, I Raskin, MA Lila. 2010. Alaskan wild berry resources and human health under the cloud of climate change. *Journal of Agricultural and Food Chemistry* 58: 3884-3900.
63. Cuerrier, A, ND Brunet, J Gérin-Lajoie, A Downing, E Lévesque. 2015. The study of Inuit knowledge of climate change in Nunavik, Quebec. *Human Ecology* 43: 379-394.
64. Gough L, JC Moore, GR Shaver, RT Simpson, DR Johnson. 2012. Above- and belowground responses of arctic tundra ecosystems to altered soil nutrients and mammalian herbivory. *Ecology* 93:1683-1694.
65. Bret-Harte MS, EA García, VM Sacré , JR Whorley, JL Wagner, SC Lippert, FS Chapin III. 2004. Plant and soil responses to neighbour removal and fertilization in Alaskan tussock tundra. *Journal of Ecology* 92: 635-647.

Photo credit: C. Mulder

Funding Acknowledgement: This report is part of the Alaska Berry Futures project of the Institute of Arctic Biology and International Arctic Research Center at the University of Alaska Fairbanks. Major funding is provided by the US Geologic Survey through the Alaska Climate Adaptation Science Center (G17AC00213) and additional support is provided by Arctic Harvest- Public Participation in Scientific Research project (NSF Award AISL-1713156) and the Bonanza Creek Long Term Ecological Research program (NSF Award DEB-163476 and USDA USFS award RJVA-PNW-01-JV-1161952-231)