Projecting Impacts of Resource Extraction on Wildlife Habitat in the Greater Chilkat Watershed, Alaska

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Signature Page

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The Group Project is required of all students in the Master of Environmental Science & Management (MESM) program. The project is a year-long activity in which small groups of students conduct interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Abstract

The Greater Chilkat Watershed (GCW) of Southeast Alaska is a unique, transitional ecosystem with a diversity of wildlife. Post-settlement management of the region emphasized resource extraction, with mining and logging being the principal drivers of land cover change and loss of habitat. This study takes a two-fold approach: First, it explores the location and impacts of extractive activities on the habitat of three charismatic species: Pacific salmon, mountain goats, and brown bears. These species' populations are valuable to the people and environment of the GCW. Second, we examine economic alternatives to timber harvest for two local institutional landowners, the University of Alaska and the Haines State Forest. In this project, we identify important areas for Pacific salmon, mountain goats, and brown bears under threat from logging and/or mining. We also analyze the amount of carbon stored in the GCW's forests and explore potential revenue streams from alternative management practices. Our results highlight several geographic areas of environmental importance in the GCW that face impending extractive threats. Our recommendations include exploring conservation strategies like easements and carbon sequestration values as alternatives to extraction. These results will help Lynn Canal Conservation and other regional environmental groups set and prioritize conservation objectives.

Keywords

conservation planning; Southeast Alaska; resource extraction; biodiversity hotspot; habitat connectivity; carbon sequestration; mountain goats; pacific salmon; brown bears

Objectives

The Greater Chilkat Watershed is a biodiverse and ecologically unique region of southeast Alaska that is currently threatened by mining and timber extraction. Unfortunately, the region also has limited resources available for research and conservation efforts. Therefore, the primary goal of this project is to empirically evaluate the impacts of resource extraction on both wildlife habitat and carbon sequestration within the GCW. Our results will help the nonprofit organization Lynn Canal Conservation (LCC) define regional conservation priorities.

We conducted three analyses involving ecologically and culturally significant species: *x̱áat* (Pacific salmon; *Oncorhynchus spp.*), *jánwu* (mountain goats; *Oreamnos americanus*), and *xóots* (brown bears; *Ursus arctos*). We also completed an economic analysis to determine the potential value of carbon sequestration as an alternative to timber harvest in the area. The impending development of the Palmer Project mine and extensive clear-cut logging of the Haines State Forest make the need for a conservation plan ever more pressing.

The project delineates conservation actions that LCC and its partners can employ to preserve and improve wildlife habitat connectivity. Additionally, we make management recommendations to two of the principal landowners in the region – the Haines State Forest and the University of Alaska. We also identify data gaps and guide LCC and other regional organizations on future research directions to achieve conservation goals.

Specific objectives include:

1. Identify parcels for *x̱áat* (salmon) habitat conservation prioritization based on biological value and vulnerability to extractive threats.
2. Map dispersal corridors between core areas of mountain goat subpopulations and determine where logging threatens these corridors or their winter habitat.
3. Identify highly suitable riparian forest habitat patches for *xóots* (brown bears), and determine where logging threatens these areas or movement corridors between them, with implications for habitat connectivity.
4. Evaluate the economic value of carbon sequestration as an alternative to timber harvest for the University of Alaska and Haines State Forest lands.
5. Educate and engage the local community in conservation efforts through an ArcGIS StoryMap, providing a valuable communication and advocacy tool for LCC.

Significance

Lynn Canal Conservation is a nonprofit organization that advocates for protecting public lands and waters throughout the Greater Chilkat Watershed (GCW), a biodiverse region of ecological and cultural importance. The Chilkat Valley's transitional climate contributes to its diverse forest types, including old-growth forests, unlike other forests throughout *Lingít Aaní* (Southeast Alaska). These forests offer a unique structure and function critical for both resident and migratory species.[1]

The Greater Chilkat Watershed is located at the end of the Inside Passage, a naturally sheltered sea route extending over 1,000 miles. The region has long been one of the only migratory corridors linking the Alaska coast to the state's interior. The GCW supports *Lingít Aaní* (Southeast Alaska)'s largest variety of mammals, making the conservation of this region imperative.[2] As one of the highest-value watersheds for salmon habitat in *Lingít Aaní* (Southeast Alaska), the Chilkat Valley also attracts the world's largest gathering of bald eagles each fall.[3] However, these critical habitats are being fragmented by industrial timber harvesting, which additionally increases soil erosion, reduces natural forest regeneration, and shifts vegetative species composition and structure.[4] Moreover, mining practices have historically affected these habitats, the impacts of which may be amplified by the proposed Palmer Project mine.

Permanently protected land in the GCW is scarce, despite its significance. Home to the village of *Tlákw.aan* (Klukwan), the Chilkat Valley is a critical resource for Alaska Natives who use the ecosystem for subsistence.[5] An estimated 90% of residents hunt, fish, and gather subsistence resources from the region, including salmon, moose, and wood.[6] A functional and intact ecosystem is necessary to sustain the livelihood and health of local people and support the valley's irreplaceable biodiversity.

This project utilizes spatial analyses to generate insight into priority areas for conservation in the GCW, with *x̲áat* (Pacific salmon), *jánwu* (mountain goats), and *xóots* (brown bears) as focal species. Additionally, we evaluate the economic potential of carbon sequestration as an alternative to commercial logging in the area. These analyses will inform LCC's future data collection, research, and development of conservation plans. The final deliverables include an ArcGIS StoryMap that will communicate the region's history, unique ecological features, and management recommendations for conservation prioritization based on habitat connectivity and, in the case of salmon, the results of hotspot analysis. We hope our work will inform actionable science to benefit LCC and the local and native communities within the GCW.

Land Acknowledgement

We acknowledge that the land on which our project takes place in Haines, Alaska, is the traditional territory of the Tlingit peoples: the Chilkats and Chilkoots. Settlement of this area dates back at least 10,000 years, and the Tlingits traveled North along the Northwest Coast or through the mountain valleys of Interior Alaska thousands of years ago as the glaciers retreated.[7] The Chilkats lived by the *Jilkaat Heeni* (Chilkat River), including *Tlákw.aan* (Klukwan), an ancient village 22 miles north of Haines, which translates from Tlingit to “Eternal Village.” [8] This area is still home to these peoples, now known as the Chilkat Indian Village.[7] However, the majority of *Tlákw.aan* (Klukwan)’s traditional 2.6 million acres were colonized by various entities and now consists of only 2,000 acres.[9] Trade routes of the Chilkats went down the west side of Lynn Canal, and their trail over the Chilkat Pass is now followed by the Haines Highway.[8] The Chilkoots had many permanent settlements in the region, including at Chilkoot Lake, just 11 miles north of Haines. Prospectors later used their trade trails during Alaska’s Gold Rush in the 1890s.[8]

We acknowledge these tribes as the original stewards of the land and hope to incorporate their priorities regarding habitat connectivity, both culturally and ecologically, if they desire. To integrate Indigenous knowledge and perspectives into our project, we will use traditional Tlingit Place Names for species, locations, and river names whenever possible, followed by English translations.

We also acknowledge that the land on which we complete our studies here at the University of California, Santa Barbara, is the traditional territory of the Chumash people.

Part 1: Background

Lingít Aaní (Southeast Alaska)

Lingít Aaní (Southeast Alaska) is a coastal ecosystem composed of rainforests, glacial fjords, rivers, estuaries, and mountains. With a marine shoreline spanning over 18,000 miles and more than 250,000 acres of intertidal habitats, this region of Alaska holds enormous biological diversity and richness.[10] *Lingít Aaní* (Southeast Alaska) is a geographically isolated region with rugged glacial terrain, dissected mountains, and steep-gradient streams.[3] The area is characterized by high topographic relief due to mountain building 60 million years ago and is one of the most seismically active zones in Alaska.[3,11] The region is dominated by glacial features such as glacial till, alluvial fans, ground moraine covering bedrock, and glacial uplift.[3,11] Many of the region's fjords, including Lynn Canal-Chatham Strait, the longest and straightest fjord in the region at 250 miles long, originated from glacial erosion.[12] These geological conditions have resulted in naturally fragmented ecosystems separated by islands and glacial landforms, largely isolating them from the North American continent. Forested land in the Southeast region is dominated by western hemlock *(Tsuga heterophylla)* and *Shéiyi* (Sitka spruce) *(Picea sitchensis)* and supports biodiversity in the area.

Regional impacts from decades of commercial logging of old-growth forests have considerably influenced the landscape.[13] The Tongass National Forest, the United States' largest national forest, has approximately 500,000 acres of extracted forestland.[10] Throughout *Lingít Aaní* (Southeast Alaska), at least 300,000 acres have been logged on both state and private lands.[10] These calculations do not include the historic extraction of natural resources in *Lingít Aaní* (Southeast Alaska), where the gold rush, salmon fishing, and development were largely unregulated, heavily impacting ecosystems and riparian buffers.[10] It is believed that over 20% of the 500,000 acres of Southeast floodplain forests that are vital to anadromous fish have been logged since the mid-1950s.[10] Our study region, the Greater Chilkat Watershed, contains many of these heavily logged alluvial forest wetlands.[14]

Region of Interest: The Greater Chilkat Watershed

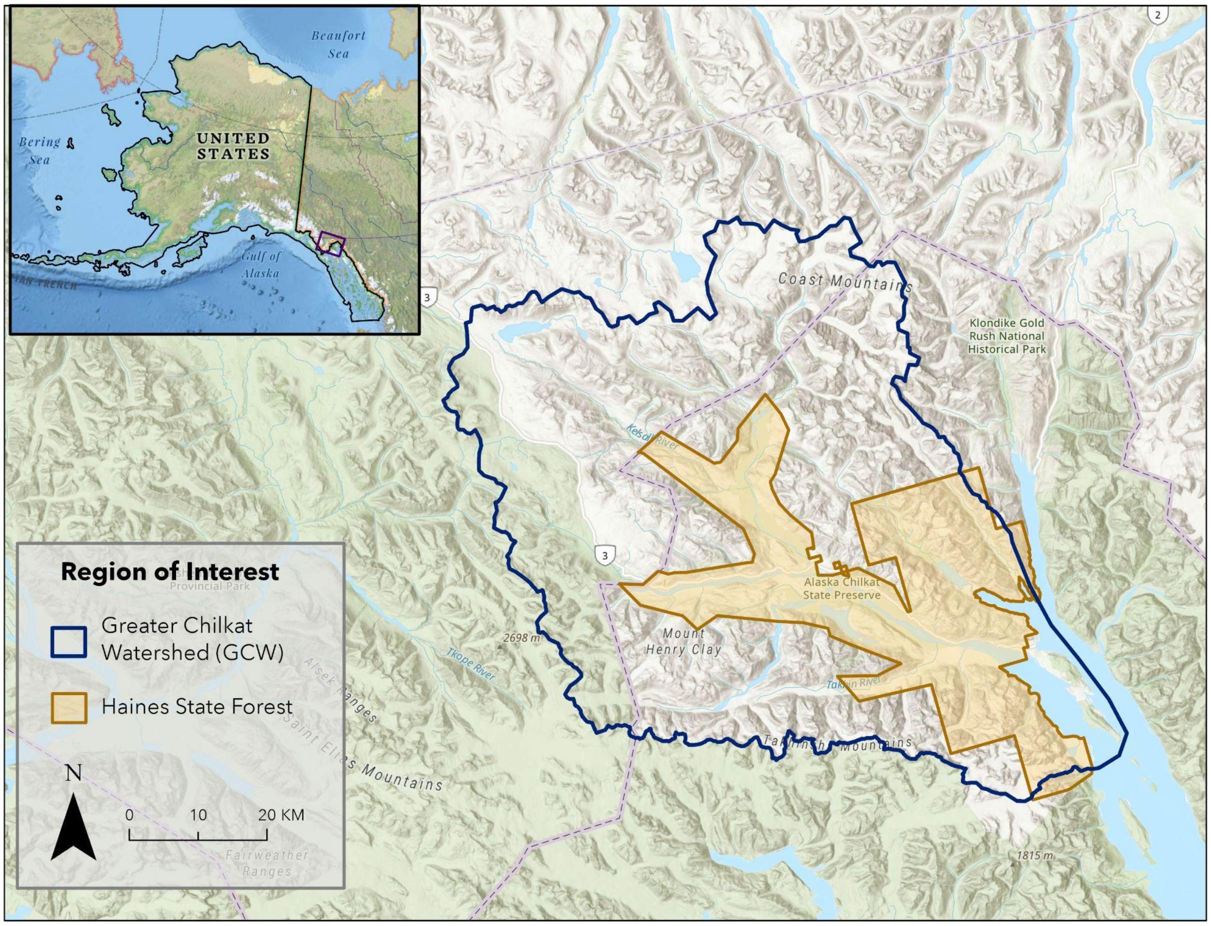

Figure 1. The study's region of interest. The Greater Chilkat watershed is a transboundary watershed between Alaska and Canada, encompassing numerous rivers and a transitional ecosystem spanning the coast to the interior. The Haines State Forest boundary is also shown in orange, as many of our analyses occur within this area.

The Greater Chilkat Watershed (GCW) (Figure 1) lies at the head of the Lynn Canal and the northern terminus of the Inside Passage. With watersheds drained by several large glacial rivers, the Chilkat Valley's riparian forests include cottonwood (*Populus balsamifera*), spruce (*Picea spp.)*, willow (*Salix spp.*), red-osier dogwood (*Cornus stolonifera*), and highbush cranberry (*Viburnum edule*).[2] Similar to all of *Lingít Aaní* (Southeast Alaska), the GCW is dominated by western hemlock *(Tsuga heterophylla)* and *Shéiyi* (Sitka spruce) *(Picea sitchensis)*. The GCW has the highest plant and mammal diversity in *Lingít Aaní* (Southeast Alaska), as it encompasses a transitional zone between the wet coast and dry interior.[2] The GCW is one of the most important watersheds for *x̱áat* (Pacific salmon) in the region, a species of cultural and social importance.[2] Despite the biological and economic value of the region, this area has the least amount of conserved land of any province in *Lingít Aaní* (Southeast Alaska).[2]

Geology, Topography, and Biodiversity of the Greater Chilkat Watershed

The Greater Chilkat Watershed's topography is characterized by dissected mountains with steep-gradient streams, numerous glaciers, and braided rivers.[11] Fjords, cirques, moraines, U-shaped valleys, and elevated deltas are present throughout the watershed, illustrating glaciation's effects on the region through its present landforms. Glaciation in the watershed is the primary land-shaping process.[11] The area of Haines, located at the outlet of the basin, experienced several glaciations during the Pleistocene epoch.[15] Glaciers are important drivers of biodiversity; repeated glaciations have forced populations to contract and expand as ice sheets have formed and retreated, contributing to environmental heterogeneity that supports a wide range of species.[16,17]

Alluvial and colluvial fans to the east of the *Jilkaat Heeni* (Chilkat River) consist primarily of detritus eroded from the Takshanuk Mountains. Ground moraine is also present throughout many of the alluvial fans in the region, covering much of the bedrock at lower elevations, including the large *Gathéeni* (Tsirku) River alluvial fan near the village of *Tlákw.aan* (Klukwan).[11] The *Gathéeni* (Tsirku) River alluvial fan maintains open reaches in the *Jilkaat Heeni* (Chilkat River) throughout low-flow periods, primarily from groundwater, and was of particular interest to USGS hydrologists in the 1980s.[18] This alluvial fan maintains streams where late fall-early winter runs of chum salmon spawn.[18] These spawned-out salmon are known to attract an immense concentration of bald eagles, as the area provides a food source.[18] This alluvial fan lies downstream of the proposed Palmer Mine, which could potentially pose a risk to this ecologically significant area. Perennial seeps and groundwater-fed springs that flow into alluvial fans across the GCW sustain flows in small channels and are often favored by salmon for spawning.[18]

Biodiversity in the GCW is unique, yet little research has been conducted in the region. Glaciation, old-growth forests, coastal and interior mammal species, a large variety of lichen, and all five species of *x̱áat* (Pacific salmon) contribute to its high level of biodiversity. The watershed's plant and mammal communities are *Lingít Aaní's* (Southeast Alaska's) most diverse.[10] Additionally, lichen is a key component of high-latitude ecosystems like the GCW.[19] Lichen creates oxygen, serves as a food source and habitat for many species, and provides and protects bird nesting material and protects trees and rocks from extreme weather. In addition to the abundance of lichen in the region, old-growth forests with multi-aged stands provide complex forest structures, dense canopy layers, understory vegetation, and large woody debris that support more biodiversity than clear-cut or second growth forests.[20] Therefore, conserving old-growth forests in the region plays a key role in sustaining biodiversity locally, regionally, and beyond.[21]

Indigenous History and Land Use

The Chilkat Valley is part of the traditional territory of the Chilkat and Chilkoot Tlingit tribes, who were able to travel along the northwest coast of North America as glaciers receded.[9] The Tlingit tribes' location and their network of trade routes between the coast and the interior, combined with the valuable resources of the landscape, helped establish them as one of the wealthiest, most powerful, and most complex hunting-gathering societies in the region.[22]

The subsistence economy of the Chilkat and Chilkoot Tlingit differed greatly from those on *Lingít Aaní* (Southeast Alaska) islands due to resource-abundant rivers, primarily the Chilkat River and Chilkoot River. *X̲áat* (Pacific salmon) was their staple food and most valuable natural resource due to large runs of all five species of salmon in the watershed – increasing the availability of this resource throughout the year.[23] Since their arrival to the landscape, the Tlingit's management approach to sustaining *x̲áa*t (Pacific salmon) runs was focused on managing individual streams by clan trustees, known in Tlingit as *heen sati*.[24] Traditional fishing grounds are considered one of the most valuable pieces of property and are passed down through generations.[23] *X̲áat* (Pacific salmon) were harvested with traps, spears, or hook and line, depending on the species. The Tlingit's fish-rich diet was supplemented by berries, roots, plant stems, and mammals, including bears, *g̲uwakaan* (deer), *jánwu* (mountain goats), and *s'igeidí* (beavers).

Despite the resilience and adaptability of the Chilkat and Chilkoot Tlingit, colonization of the land by non-native settlers in the late 1800s driven by the Alaska Gold Rush wiped out entire villages on the *Jilkaat Heeni* (Chilkat River) and heavily reduced the Tlingit population in the GCW primarily due to the introduction of disease and exploitation of their subsistence resources.[22] Tribal lands were further reduced as a result of legislation supporting mining claims and homestead laws.[25] This was exacerbated by Alaska's establishment as an official U.S. territory in 1912 when all land went into the public domain, and congressional action was required to transfer lands to tribes.

History of Resource Extraction Post-Settlement

Before the United States acquired Alaska, the dominant European presence was by the Russians (from the mid-18th century to the 19th century), who did not settle in Chilkat territory. The prominent activity between the Russians and the Tlingit was trade.[25] The discovery of gold in the Klondike spurred a massive migration of people into the region, bringing a different approach to resource management. This was exacerbated by the development of the mining town of *Deishú* (Haines), which began in 1879.

Mining

Gold was first discovered in the region in 1898. Soon after, commercial mining began in the Porcupine district, ranked one of the most important placer fields in *Lingít Aaní* (Southeast Alaska).[26] Outside interests from eastern states contributed to increased industrial extraction, consolidating district mining claims under "Porcupine Mining Company" in 1909. Due to an abundant water supply, hydraulic mining was the primary extraction method. This process involved the construction and maintenance of flumes to divert water from placer fields, requiring approximately one million board feet of local lumber every 1-2 years.[26]

A local prospector in the Porcupine Mining District, Merrill Palmer, discovered base-metal sulfide and barite deposits in the district in 1969 and 1971, which initiated exploration programs by various mining companies.[27] The massive volcanogenic sulfide mineralization discovered on Palmer's property is an extension of the Alexander terrane, which runs throughout *Lingít Aaní* (Southeast Alaska) and Northwest British Columbia, Canada.[28] Another significant deposit of these base-metal sulfides is found in the Windy Craggy deposit in British Columbia.

Like the Greater Chilkat Watershed, the Windy Craggy area has high biodiversity value. Yet an open-pit mine was proposed by Geddes Resources Ltd. in 1988. Located at the top of Windy Craggy, this project included constructing a 100-kilometer access road and bridges from the Haines Highway to Windy Craggy. Additional needs for the project included the transportation of ore concentrate to *Deishú* (Haines) for shipping. Alternative proposals detailed the creation of a slurry pipeline storing waste rock on glaciers and in tailing ponds that would require the construction of two dams.[29]

Defining the jurisdiction of the mine was complex, given the location of the deposit on the Canadian-American border. There was strong opposition to the project from Canadian and American environmental groups (including our client Lynn Canal Conservation) due to the high risk of acid mine drainage and the leaching of toxic metals into the surrounding waterways. This concern was compounded by the fact that Windy Craggy is located in an area of high seismic activity, increasing the risk of tailing dam breaches.[29] The proposed project did not proceed after the British Columbia government's 1993 environmental assessments because the proposed project did not meet environmental standards. The area was then designated as a UNESCO World Heritage Site in December of 1994 for its glacier and icefield landscapes and its importance as habitat for brown bears and caribou. Despite this history, mining projects in the region continue to be proposed, particularly along the base-metal sulfide and barite deposits in the GCW. Named after prospector Merrill Palmer, the proposed Palmer Project by Constantine Metal Resources Ltd. has been in development since 2006.

Salmon Fishing

The development of salmon canneries in the region preceded industrial mining in 1882. Under federal management, the canning industry in the Chilkat Inlet heavily exploited most streams within the watershed through the use of fish traps located at points along the east shore of the Upper Lynn Canal.[30] While early catches exceeded 250,000 salmon per year, overharvesting decreased catches significantly. This resulted in the permanent closure of the canneries from 1908 to 1917. [30]

Once Alaska became a state in 1959, fish traps were prohibited due to its facilitation in overharvesting, and gillnet fishing became a more sustainable harvest method in the GCW.[31] Statehood contributed to more sustainable management of salmon fisheries. Alaska's state constitution established the Alaska Department of Fish and Game (ADF&G) for improved wildlife management.[31] ADF&G conducted stock assessments and set escapement goals to produce the maximum sustainable yield of the state's fish resources and balance the needs of the local economy with conserving fisheries. This included issuing permits for commercial, sports, and subsistence fishers to control how much extraction could occur in the state. As of 2020, an average of 80 *Deishú*-based (Haines) fishers haul in over 5 million pounds of seafood annually, 90% of which are *x̱áat* (Pacific salmon). [32]

Logging

Timber extraction following the European settlement of the Chilkat Valley was primarily used to support the fishing and mining industries, with the area's first timber mill built in 1907.[33] Extraction rates in the region accelerated in the late 1930s with the establishment of the Schnabel sawmill at Jones Point, with a peak of 52 million board feet milled in 1968.[33] Land management changed with the passage of the Alaska Native Claims Settlement Act (ANCSA) in 1971, the largest land settlement in American history. ANCSA created 12 regional and 200 village corporations to receive 44 million acres of land and one billion dollars, extinguishing all other native land claims, including subsistence hunting, fishing, and gathering. [34] In the GCW, this resulted in the creation of the Chilkoot Lumber Company, which took over the Schnabel sawmill and milled up to 60 million board feet annually by 1990.[33]

Modern Policy and Management

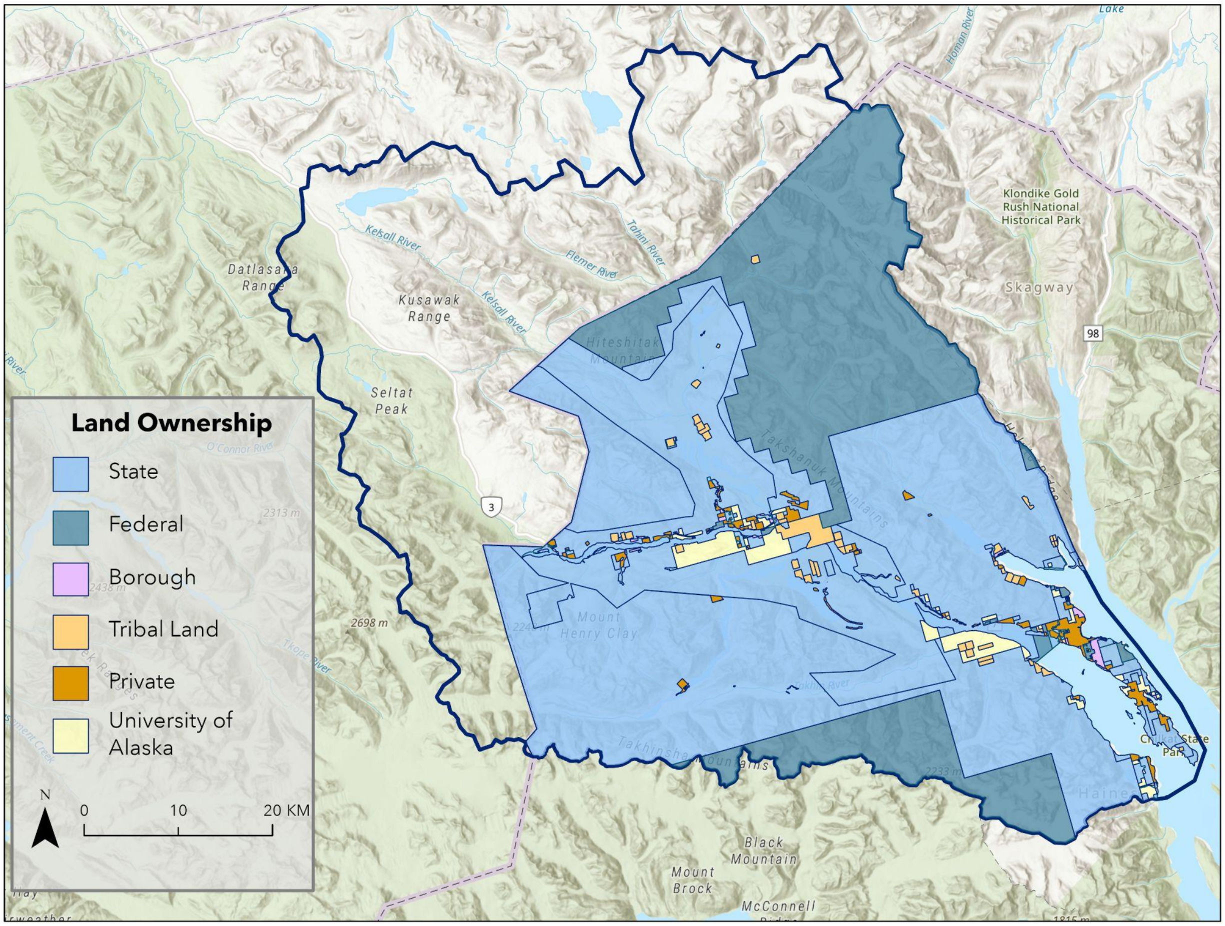

Figure 2. Land ownership status in the Greater Chilkat Watershed. Land ownership in the watershed is predominantly managed by the state and federal governments. State government land is represented in blue and includes the Alaska Department of Natural Resources and Alaska Mental Health Trust. The U.S. Bureau of Land Management (BLM) is the only federal landowner in the watershed and is represented in teal. Lands owned and managed by Haines borough, indigenous tribes, private landowners, and the University of Alaska are shown in purple, light orange, orange, and yellow, respectively.

The two largest landowners in the Greater Chilkat Watershed are the State of Alaska and the federal government as the Bureau of Land Management (BLM) (Figure 2).[35] The Haines State Forest represents much of the State of Alaska's ownership. Other notable landowners include the University of Alaska and Alaska Mental Health Trust, whose relatively flexible land management strategies make them promising targets for future conservation actions.[35] Despite large areas of public ownership in the GCW, only 2% of the valley is legislatively protected for conservation purposes.[10]

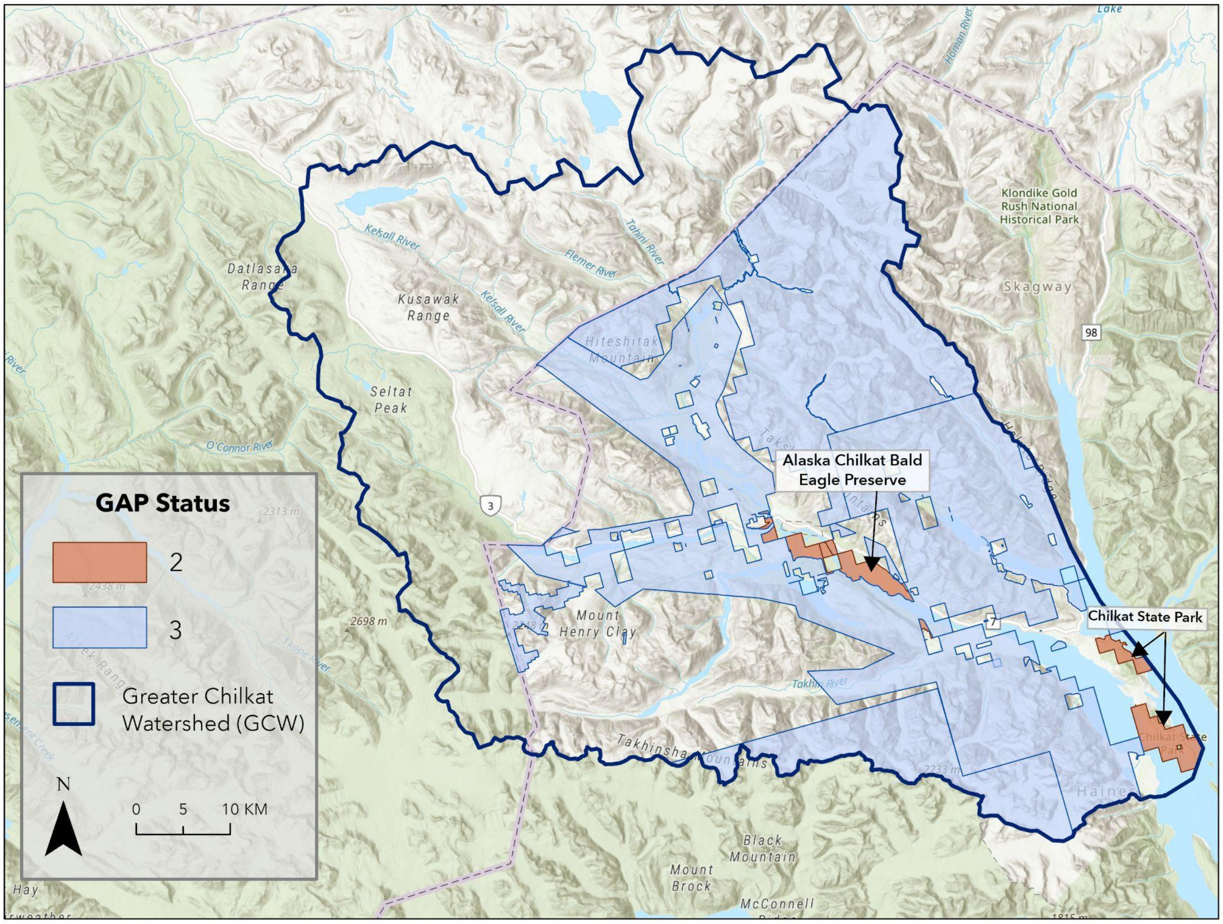

Figure 3. GAP status in the Greater Chilkat Watershed. The Gap Analysis Project (GAP) set forth by the U.S. Geological Survey (USGS) identifies and ranks terrestrial and marine protected areas across the United States. In the GCW, only areas under GAP Status 2 (managed for biodiversity where disturbance events are suppressed) and GAP Status 3 (managed for multiple uses and subject to extractive use) exist.

Land managed by BLM and the Haines State Forest falls under GAP Status 3, which describes areas that are protected from land cover conversion but can be used for logging and mining.[31] GAP Status 2 Areas, including the Chilkat Bald Eagle Preserve and Chilkat State Park, are areas actively managed for biodiversity where natural disturbances are suppressed.[32] Everything else in the watershed falls under GAP Status 4, having no form of protection, and there is no GAP Status 1 lands in the watershed (the highest level of biodiversity protection) (Figure 3).[32]

Because of this lack of formal protection, Audubon Alaska and The Nature Conservancy have identified the GCW as having the highest cumulative ecological risk.[10] Only 0.9% of its large-tree old-growth forests are preserved in watershed-scale reserves, which are crucial for the conservation of species such as salmon, bears, and wolves.[10]

Alaska’s unique political geography has resulted in a long-standing tension between development and environmental interests.[36] A lack of agriculture in the state has made resource extraction a significant economic activity and driver of political choices.[36] In the past, most Alaska residents have been firmly against federal government oversight and generally favor using public lands for economic development. However, as urbanization and population growth have increased, and the environmental movement has grown, attitudes toward such actions are slowly changing.[36]

Locally, the Haines Borough Assembly represents a divided constituency, some in favor of extractive economic development projects while others support policies that encourage non-consumptive use of the region’s natural resources. Until one view becomes the majority, the mayor's support for mining and development interests makes it challenging to implement conservation efforts.

Current Extractive Threats

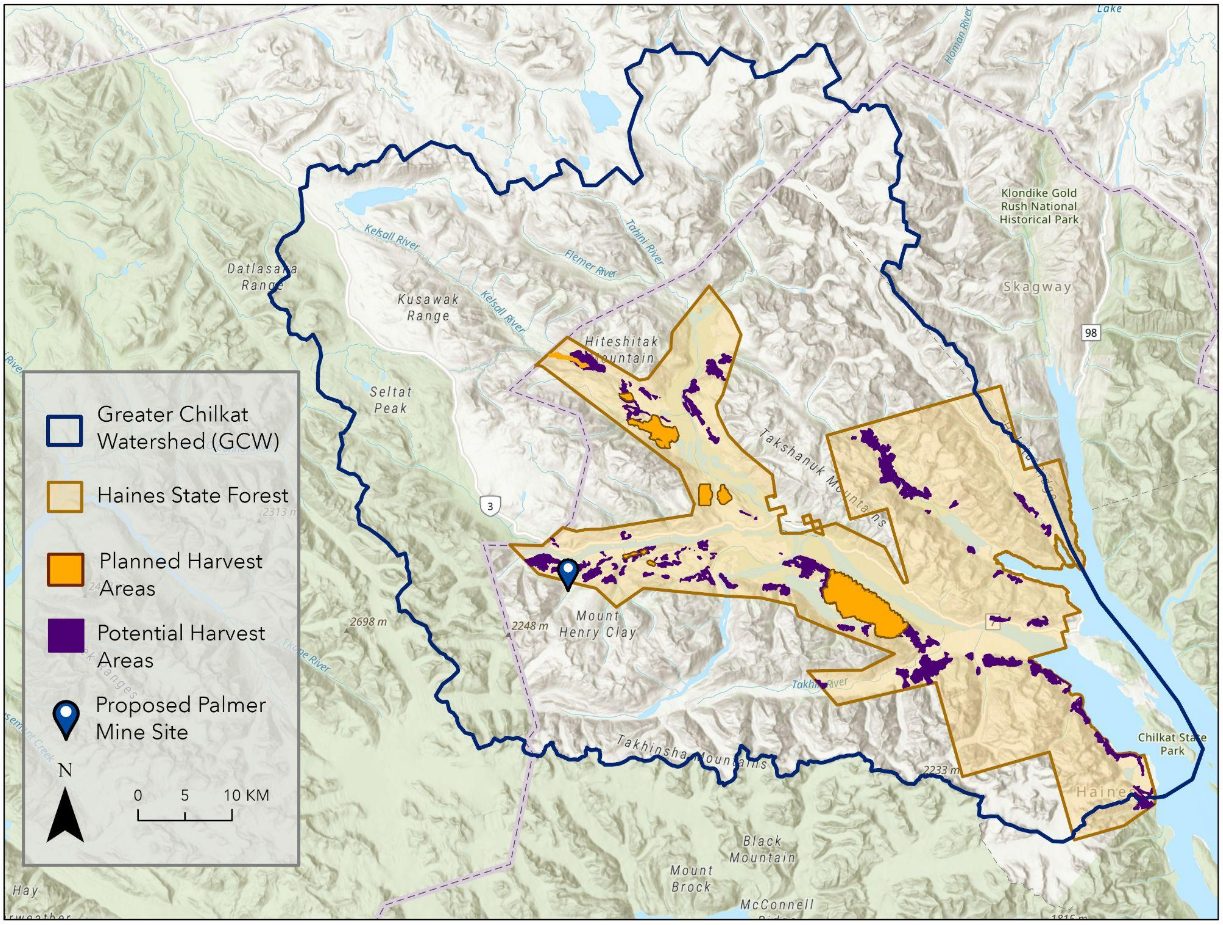

Figure 4. Extractive threats in the Greater Chilkat Watershed. Forest stands planned for clear-cutting by HSF management before the end of 2026 are highlighted in orange. Highly-stocked stands, “potential harvest areas,” are in purple. The blue icon in the northwest portion of the watershed indicates the location of the proposed Palmer Project mine.

Logging

The Haines State Forest spans 286,000 acres and represents a significant portion of the GCW, with its main forest type consisting of a western hemlock/Sitka spruce species mix.[37] 42,000 acres of this forest are dedicated to timber harvest, with over 5 million board feet allowed for extraction each year.[38] These logging practices disturb intact habitats, exacerbating negative effects on the regional ecosystem.[39]

The Haines State Forest management policy states that it will appropriately protect and value wildlife, even in units classified as commercial forest land. A key objective of this goal is to “maintain and enhance the existing diversity of fish and wildlife habitat.” However, the state forest classifies clear-cutting as the best method for forest regeneration and only acknowledges that it will “keep from harvesting some” of the remaining old-growth timber on its lands.[40] This policy is contrary to research demonstrating the myriad environmental benefits of alternative forms of harvest to clear-cuts.[41]

The Haines State Forest periodically releases a five-year management schedule with future logging activities. The most recent management schedule for 2022-2026 does not provide detailed harvest acreages and metrics for its planned extraction activities. Conservatively estimated, clear-cuts will occur on at least 2,500 acres of forestland in the next five years. The activities require over 10 miles of road construction, in addition to nine roads that will be either brushed, graded, or resurfaced.[42,43]

clear-cutting operations in *Lingít Aaní* (Southeast Alaska) have distinctive impacts on highly-valued species in the Chilkat Valley, including *ch’áak* (bald eagles), *x̲áat* (Pacific salmon), *xóots* (brown bears),[44] and *jánwu* (mountain goats).[45–47] Eliminating or minimizing the impacts of these harvest activities will improve the health and function of the GCW ecosystem.[43] Additionally, recent studies have estimated that the carbon sequestration values of southeastern Alaska forests may be greater than the forests’ timber values. This dynamic will only be exacerbated as regional mill closures make monetization of timber products a more difficult endeavor.[48]

Mining

Mining continues to be a significant part of the Alaskan economy. The state mining industry employed approximately 10,800 people in 2021, with a total export value of $2.1 billion.[49] In *Lingít Aaní* (Southeast Alaska), mines produce coal, gold, silver, zinc, sand, gravel, and rock.[49] The mining industry is responsible for much of the regional infrastructure, especially docks and roadways.[49] Many cities, such as *Deishú* (Haines) and Dzantik’i Héeni (Juneau), were founded as mining towns.

While the economic value of mining is evident, it is also well documented that these industries damage nearby ecosystems and cause a cascading effect on large areas of wilderness.[50] These effects include habitat destruction and alteration, changes in streamflow due to retention and discharge of water, ore processing, transport, and other activities that cause significant land-use changes affecting terrestrial and marine ecosystems.[50] The threat of leakage during routine operations is always present, and the failure of a tailings dam would represent a worst-case scenario that would have immense negative impacts on the local ecosystem.[51]

Within the Greater Chilkat Watershed, the mining project known as the Palmer Project is focused on preparations for underground exploration in 2023, which includes an engineering review of the access road, lease and site preparation for a camp, drilling program, and environmental and permitting work.[52] The program includes engineering studies such as metallurgical sampling and evaluation of the production site. The mine, proposed by Constantine Metal Resources Ltd., is a copper, zinc, gold, and silver mine along Glacier Creek, a glacially fed stream in the northwest corner of the greater Chilkat watershed. According to Constantine Metal Resources Ltd., the predicted lifespan of the mine is expected to be between 10 to 15 years.[53] Several different mining companies have tried and failed to obtain permits to mine this area since the 1960s; however, Constantine Metal Resources Ltd. insists it is capable of mining this region with limited environmental impacts and has made an active effort to integrate itself into the community with student scholarships and a presence at local fairs.[54]

Part 2: Analyses

Conceptual explanation of modeling methods and significance

This project models habitat connectivity and movement corridors for *jánwu* (mountain goats) and *xóots* (brown bears) using Circuitscape and the Linkage Mapper Toolkit.[55] Because habitat connectivity for *x̱áat* (Pacific salmon) involves marine and freshwater environments, we instead conducted a hotspot analysis to identify areas of high biological value and elevated threat level. Finally, we utilized the Natural Capital Project's InVEST software to model carbon storage and sequestration in the GCW.[56] A conceptual description of each approach and its conservation significance follows.

Hotspot Analysis

Hotspots have been widely used as a conservation tool for prioritizing efforts and resources within a given region of interest.[57] Norman Myers first introduced the concept of biodiversity hotspots in 1988, and since then, many conservation organizations have adopted this approach to identify regions critical for biodiversity conservation.[58] These hotspots are defined as areas with high levels of biodiversity facing significant habitat loss or elevated threat.[58] They are considered important because they often contain many endemic species, meaning they occur nowhere else in the world. Moreover, many of these species face extinction risk due to habitat loss, climate change, invasive species, and other threats.[58] By focusing conservation efforts on these hotspots, conservationists can maximize the impact of their resources and time.[57]

However, it is essential to note that the designation of hotspots is not the only criterion for prioritizing conservation efforts. Other areas outside hotspots may also be important for biodiversity conservation and deserve attention. For example, some areas may support key ecosystem services, such as water regulation, carbon sequestration, and soil conservation.[58] Others may provide critical habitats for migratory species or act as corridors for wildlife movement. In such cases, it is crucial to consider the broader ecological context and prioritize conservation efforts accordingly.[58]

Thus, the designation of hotspots is a valuable tool for conservation planning and has helped to allocate resources and prioritize actions in areas critical for biodiversity conservation. However, using this tool in conjunction with other criteria is important to ensure that conservation efforts are directed to the most essential areas for biodiversity conservation.

Habitat Connectivity Modeling

Habitat connectivity enables the functioning of ecosystems and the maintenance of biodiversity by allowing for the flow of organisms, materials, and energy across landscapes.[36] Broad-scale conservation projects have the value of enhancing connectivity, which benefits larger species and/or apex predators that are more likely to be integral to regional biodiversity and ecosystem health.[59] Beyond primary conservation values, habitat connectivity initiatives and research also generate an understanding of wildlife distributions, activity patterns, and interactions at an ecosystem level.

Due to its myriad ecosystems and biodiversity, understanding and enabling habitat connectivity is a significant conservation goal for the region. Connectivity initiatives have become more important as land use change and economic development increase regional fragmentation. This urgency is exacerbated by the accelerated loss of regional biodiversity as a result of climate change.[2] Mapping and modeling connectivity pathways for essential species in the GCW will be of considerable utility to LCC, given that sustaining functional connectivity is a crucial strategy for countering the negative impacts of anthropogenic threats in an ecosystem.[59] Additionally, these analyses will help inform improved management practices for the Haines State Forest and other regional landowners.

The Linkage Mapper Toolkit utilizes the Circuitscape algorithm to model organism movement across a landscape. For purposes of this software, landscapes are treated as conductive surfaces between nodes within electrical circuit theory.[60] A landscape-level resistance raster layer is utilized, with resistance to conductance approximating the difficulty with which an organism travels between core areas (or nodes) across a particular surface. The random walk principle is then utilized to map species movement, with influences from underlying factors that resist a species' passage (e.g., different land cover types, topography, etc.). The Linkage Mapper Toolkit uses Circuitscape to identify movement pathways and pinch points where connectivity is tenuous and to calculate metrics that reflect the quality and centrality of corridors. Algorithm results from Circuitscape and the Linkage Mapper Toolkit can be visualized in ArcGIS Pro to compare outputs spatially.

Integrating Valuation of Ecosystem Services and Tradeoffs (InVEST) Modeling

Determining annual rates of carbon sequestration is increasingly important to climate mitigation and conservation prioritization.[61] In forest systems, carbon is stored as aboveground biomass, belowground biomass, within the soil, and as dead organic material.[62] For the Natural Capital Project's InVEST model, InVEST utilizes land cover data and carbon values for aboveground, belowground, soil organic matter, and dead organic matter storage categories.[63] The model then aggregates the results to determine the total amount of carbon stored per cell in the given raster, according to land cover type.

For modeling carbon sequestration over a defined time frame, InVEST takes an additional land cover raster and calculates the difference between the two aggregated carbon storage values. The result is interpreted as carbon sequestration.[64] To do this, InVEST uses the cost of carbon per megagram, a discount rate, and the annual change in carbon price to calculate the net present value of carbon sequestration during the defined time frame. Mapping the total amount of carbon stored and sequestered within forested parcels of the GCW will provide additional guidance for Lynn Canal Conservation and area land managers when assessing economic alternatives to timber harvest.

Species of Interest

X̱áat (Pacific salmon; Oncorhynchus spp.)

X̱áat (Pacific salmon; *Oncorhynchus spp.*) is a genus of anadromous fish distributed across North America and Asia. Of the seven species of salmon, five are found in North America, with their range expanding from Northern California to the Gulf of Alaska. Though once abundant, salmon have experienced a significant population decline across most of its range, with 18 evolutionary significant units (ESUs) currently listed as threatened or endangered under the Endangered Species Act.[65] In contrast, all five species of North American salmon are found in Alaska, with no populations listed as endangered or threatened.[68] Lower development rates and the transition from federal to state management after statehood in 1959 have contributed to the health of these populations.[30] For this reason, 80% of wild-caught salmon in the United States come from Alaskan waters.[69]

Southeast Alaska's habitat features provide an ideal environment for *x̱áa*t (Pacific salmon), with cascading impacts across the ecosystem. Consequently, they are considered keystone species of central importance to the functioning of this ecosystem.[66–68] *X̱áat* (Pacific salmon) bridge ocean, freshwater, and terrestrial ecosystems through their distribution of nutrients, significance to the winter survival of birds, mammals, and fish, and influence on vegetation productivity within a watershed.[2] The spatiotemporal distribution of salmon as a food resource is primarily important for consumers such as *xóots* (brown bears) *(Ursus arctos)* and *ch'áak'* (bald eagles) *(Haliaeetus leucocephalus)* given their large nutritional needs.[70] Salmon represent 60-80% of brown bear diets in coastal ecosystems, and the carcasses they leave behind are essential for nutrient cycling within the greater food web.[70]

Salmon fisheries in *Lingít Aaní* (Southeast Alaska) are the largest in volume for the state, generating $3.4 billion in revenue within the past 50 years.[71] Sportfishing is also a significant contributor to the salmon economy in the region, with over half of the revenue generated by permits coming from holders outside of Alaska.[72] Alongside their economic significance, stable salmon populations play a prominent cultural and subsistence role. The Indigenous Tlingit people of the region have depended on *x̱áat* (Pacific salmon) for subsistence and cultural practices since their settlement of the region thousands of years ago. Whereas current management takes a different form than before pre-colonial contact in Lingít Aaní (Southeast Alaska) through establishing hatcheries and fishing restrictions, salmon play an essential role in subsistence harvests for native and non-native communities in the region. Household harvest surveys found that salmon provide about 30% of the total noncommercial harvest of wild foods for rural communities in *Lingít Aaní* (Southeast Alaska).[73]

Because of its competing uses and the migratory nature of this natural resource, the governance of salmon in *Lingít Aaní* (Southeast Alaska) is an intricate network of state, federal, and international institutions involving regional leaders in multilateral decision-making.[74] This multi-system management of salmon populations hinders conservation efforts throughout the region. For this reason, the biggest challenge to sustaining healthy salmon runs in *Lingít Aaní* (Southeast Alaska) involves issues with international jurisdiction. This complexity of governance is often the case regarding mineral extraction. Mines proposed by Canadian companies positioned at the headwaters of Southeast Alaska rivers pose a significant risk to salmon survival, given the threats of acid mine drainage, heavy metals pollution, and dam failures.[74]

Jánwu (Mountain Goat; Oreamnos americanus)

Jánwu (mountain goats) are one of the least-studied North American ungulates due in part to their remote, northern distribution, often in the inaccessible alpine.[75] *Jánwu* (mountain goats) have adapted to this steep alpine habitat to avoid predators. The species' preference to be near escape terrain, cliffs, or outcrops with a steep slope results in populations that are naturally small and geographically isolated.[76] In the winter, populations often retreat to old-growth forests at lower elevations to avoid deep, heavy snow and maintain access to forage.[77] In our study region, consecutive severe winters have contributed to significant population declines.[78]

In addition to the geographic isolation of their populations, mountain goat life history and sensitivity to anthropogenic disturbance contribute to the species' vulnerability.

Mountain goat populations have slow growth rates; females reach sexual maturity after 3-4 years, gestate a single kid for six months, and care for them for at least a year.[75,76,79,80] Subsequently, harvest of females can pose serious threats, as they are disproportionately important for population growth and viability.[81]

Other forms of anthropogenic disturbance, such as mining, road construction, heli-skiing, and logging activities, also threaten mountain goat populations.[82] Among large North American mammals, goats are one of the species most sensitive to anthropogenic disturbance,[83] making consideration of these impacts important in management decisions.

Goats as a cultural resource

Jánwu (mountain goats) are a cultural resource in Alaska; they are loved by wildlife-viewing tourists, hunted as game meat for sport and subsistence, and represent an important source of wool for weaving by local Tlingit tribes.[81] An average of 1 million households visit or travel within Alaska to view or hunt wildlife every year,[84] and approximately 450-500 *jánwu* (mountain goats) are harvested statewide annually.[76] Since 2004, the Alaska Department of Fish and Game (ADF&G) has made permits available for Tlingit tribe members to harvest male *jánwu* (mountain goats) for use in weaving.[85] Alaska Native Rofkar (2014) explained the significance of goats to the Tlingits at the Northern Wild Sheep and Goat conference in 2014. Her tribe has been weaving Chilkat robes and blankets for thousands of years.[85] Maintaining stable mountain goat populations while promoting sustainable use is in the best interest of Alaska Natives, locals, and tourists.

Xóots (Brown Bears; Ursus arctos)

Xóots (brown bears) inhabit most of the state of Alaska, but there is significant variation in their physical appearance and lifestyle depending on their environment. The solitary and often aggressive grizzly bear (*Ursus arctos horribilis*) roams in the state's interior. On the coast, a much larger and more docile bear of the same species - colloquially called a coastal or Alaska Peninsula brown bear – feeds on ample fish supplies. Interior bears may grow to 600 pounds, while coastal bears can double that weight. The largest brown bear inhabits the Kodiak archipelago (*Ursus arctos middendorffi*) and reaches up to 1500 pounds.

In coastal ecosystems, *xóots* (brown bears) are invaluable ecological community members: as apex predators, salmon-fed bears facilitate many important ecosystem services, including resource provisioning and seed dispersal.[86] Brown bears rely on salmon more than any other terrestrial vertebrate, and through their consumption allow scavenger access to carcasses discarded in the surrounding forests.[87] In these salmon-rich areas, *xóots* (brown bears) can have minimal home ranges of only 3 - 10 square miles,[88,89] making habitat conservation important for the species. The most suitable habitat for *xóots* (brown bears) is old-growth riparian forest surrounding anadromous streams, which is often threatened by logging and mining activities.[90]

Brown bear populations do not have high growth rates. In the wild, *xóots* (brown bears) typically live between 20-30 years but have been found to reach 35 years or older. Although they reach sexual maturity around 5, brown bears do not usually successfully mate until later. Mothers often give birth to twins, and families stay together for 2-3 years, though less than half of all cubs live to maturity.[91] This, coupled with slow maturation rates and declining salmon stocks, has conservation implications for this species that heavily relies on intact habitat in Alaska.[90] The state is home to 98% of the United States' brown bear population as well as a majority of all North American brown bears,[91] making conservation here critical to the species' persistence.

1. *X̲áat* (Pacific salmon) Hotspot Analysis

Introduction

Due to its unique geology and hydrology, there are 649 miles (1,039 kilometers) of anadromous fish streams in the Chilkat Province, which includes the GCW and Skagway River Complex.[10] State management of salmon fisheries includes the selling of permits for commercial, sports, and subsistence fishers and the establishment of a maximum sustainable yield to dictate when the fishing season opens and closes. Because of these management practices, the *Jilkaat Heeni* (Chilkat River) produces the third to fourth largest runs of Chinook salmon, the second largest stock of Coho salmon, and the two largest runs of sockeye salmon in *Lingít Aaní* (Southeast Alaska).[92,93] Each salmonid species has its spawning habitat requirements, with factors such as stream morphology, temperature, and habitat type fostering salmon runs that persist throughout the year in locations across the watershed.[70] Therefore, bears and eagles eat salmon as their primary food source for most of the year.[94] These predators can disperse these marine-derived nutrients when discarding carcasses in the surrounding forests.

The GCW has the least habitat conservation protections of any region in *Lingít Aaní* (Southeast Alaska), with no riparian forests protected in watershed-scale reserves.[10] The primary protected area within the watershed is the Alaska Chilkat Bald Eagle Preserve, which covers 48,000 acres (Figure 2).[10] These two areas overlap, yet they are still not large enough to adequately protect salmon habitat across the watershed. Only one conservation plan exists in the watershed, which fails to address salmon habitat suitability and threats, leaving a gap for prioritization.[35]

Data

Table 1. Data types and sources. This table depicts the data used to create our threat and biological value rasters.

Data Type			
Threats		**Biological Value**	
ADF&G Anadromous Waters Catalog, 2022	Culvert locations	ADF&G Anadromous Waters Catalog, 2022	Species presence, Identification of anadromous streams
NI 43-101 Technical Report Palmer Project Alaska, USA, 2019	Mine location	Takshanuk Watershed Council Stream Temperature Data, 2023	Stream temperature

Haines State Forest Five-Year Management Schedule for 2022-2026	Planned timber harvest and	USGS National Land Cover Database, 2018	Identify preferred land cover types
University of Minnesota's Arctic Digital Elevation Models (DEM), 2021	Flow direction from potential mine failure	University of Minnesota's Arctic Digital Elevation Models (DEM), 2021	Stream gradient

The Greater Chilkat Watershed is a data-limited study region due to geographic and seasonal inaccessibility as well as a lack of research resources. Data collected from state entities such as the Alaska Division of Forestry and the Alaska Department of Fish and Game (ADF&G) are not readily distributed to the public. Therefore, the limited data that was available, this study heavily relies on. A key data source available to us was ADF&G's Anadromous Waters Catalog which identifies anadromous streams, species presence, and the locations of culverts. Additionally, stream temperature was provided by the Takshanuk Watershed Council.

There was more data available for the threats portion of this hotspot analysis. We matched other studies' methodologies in the threats portion of the research.[95] However, data corresponding to biological value was limited. Different studies have commonly used streamflow, substrate composition, and stream depth data to identify areas of highest habitat suitability for salmon; this was not available for the GCW, requiring land cover and stream temperature data as proxies.[95] Additionally, it is important to note that data was unavailable for the Canadian portion of the watershed; thus, our analysis for salmon conservation prioritization is limited to the Alaskan part of the watershed.

For more detailed information on our data sources, please see appendix table A-1.

Methods

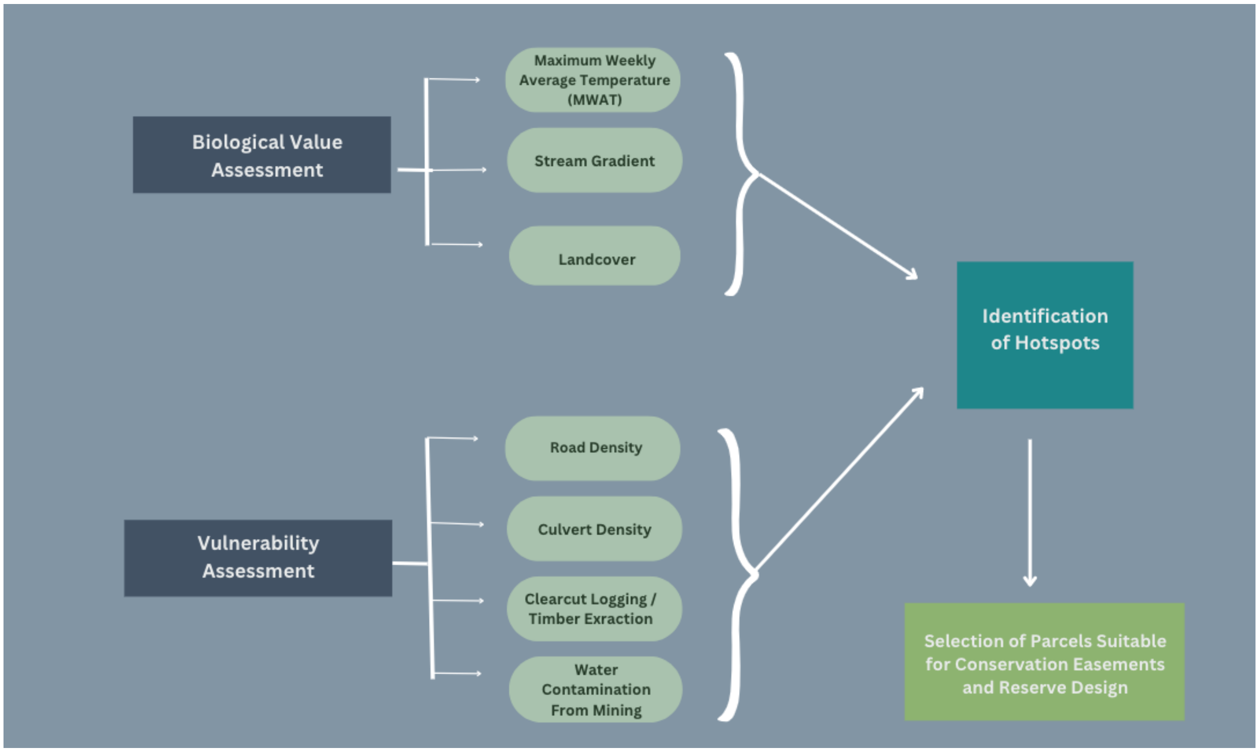

Figure 5. Methods for salmon hotspot analysis. Methods for biological value and threats assessment were combined to identify areas of priority for salmon conservation efforts in the watershed.

Scoring

Much of our methods rely on scoring raster cells based on data relating to biological value or threats. To account for binary and continuous data, we created a scoring system from 0 to 3. When the results are continuous, the scoring is between 0 and 3. In contrast, binary results will be given either a value of 0 or 3 based on the presence or absence of the necessary parameter. This is a version of the scoring updated from a previous study assessing salmon habitat suitability.[95]

Biological Value Assessment

River environments are heterogeneous habitats with varying suitability levels for anadromous fish like salmon. Our biological value assessment identified areas with the highest habitat suitability for salmon in their spawning life stage. We chose to focus on spawning specifically because it is the period when salmon provide the most resources to the surrounding ecosystem and local communities.[87] Access to pristine and intact spawning habitats has significant implications for the survival of salmon populations year to year.[94] To identify parcels with the highest biological value, we conducted an extensive literature review on the abiotic and biotic factors most relevant to the needs of *x̱áat* (Pacific salmon) throughout their distinct life stages. We decided to focus on the species' needs during their spawning stage.[96–101] These include variations in stream flow, discharge, dissolved oxygen, water temperature, stream gradient, glacial influence, and substrate composition. Data limitations led us to focus on the three metrics we could quantify with existing data: land cover, stream temperature, and stream gradient.

Land cover (substrate and riparian vegetation)

Our literature review revealed the importance of vegetation for creating suitable habitats for spawning salmon. The types of land cover ideal for salmon spawning include streams with forest cover and gravel beds. Specifically, forests provide cover which protects salmon from disturbance and egg predation and can provide shade, playing an important role in temperature regulation.[96] Riparian forests increase the food for spawning salmon due to the abundance of terrestrial invertebrates carried into streams by runoff. [96] Substrate composition also heavily influences the suitability of habitat. While specific substrate data does not exist in the GCW, the National Land Cover Database "barren land" class includes areas of "bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, dunes, strip mines, gravel pits and other accumulations of earthen material," enabling this class to be used as a proxy for identifying gravel beds surrounding anadromous streams.[102]

To identify the streams surrounded by suitable land cover types in the GCW, the AWC stream vector was first buffered with a value of 500m, which we selected because salmon nutrients within a forest ecosystem can be found up to 500m from a salmon-bearing stream.[103] We then joined this buffered vector with the NLCD Alaska Land Cover reclassified raster to identify stream areas composed of developed/urban land, broadleaf conifer forests, deciduous forests, and barren land. Once we identified land cover surrounding anadromous streams, this raster was reclassified with a score from 0-3, with 0 denoting areas with no data or developed/urban land and 3 indicating deciduous or conifer forests, the ideal land cover class for salmon habitat. Further reclassifications are displayed in Table A-2.

Stream temperature

Stream temperature is important for salmon migration and spawning habitat suitability. Water temperature can influence how far upstream salmon migrate, as the species cannot swim as efficiently in water that is too warm or too cold. Stream temperature is correlated to dissolved oxygen levels, which also impact the migration and spawning of salmon. For habitat suitability, the maximum weekly average temperature (MWAT) of streams must not exceed 15 °C, but ADF&G management guidelines use 20°C as their upper limit.[96,104]

One of our client's partners, Takshanuk Watershed Council (TWC), has implemented a monitoring network within the GCW focusing on stream temperature and water quality. Remotely operated monitors collect data daily at nineteen sites.[104] To determine if stream temperature is a viable parameter for our study, we first investigated the data provided by TWC to see if there is variation between temperatures across the watershed and if that variation is significant for salmon survival. The temperature variation across the watershed was determined to be significant enough to be a meaningful parameter for this analysis. This was supported through a literature review on the distinct temperature needs of each of the five species of salmon.[96] TWC provided MWAT data for each of the 19 sites in a tabular format along with the geographic coordinates.

The site coordinates were converted to point shapefiles. Temperature variation across the watershed was calculated using the Inverse Distance Weighted tool (IDW) to create a raster that maps stream temperatures based on the distance from each monitoring site.[105] The further away a cell was from a temperature monitoring site, the less influence it had on the temperature of that cell. A conditional if/else evaluation on each input cell for the land cover and stream temperature rasters was then performed using the 'Con' tool to exclude areas with no data and identify temperatures across all water in the watershed, not just anadromous streams. This water temperature raster was then reclassified to reflect the relative temperature value to salmon habitat suitability with a score of 0 to 3 – 0 depicting areas with uninhabitable temperatures and three depicting areas with ideal temperatures for salmon productivity (Table A-2).

Stream gradient

Stream gradient is an essential factor to consider for salmon habitat suitability in data-limited regions because it positively influences stream velocity and increases the erosion rate and resulting sediment load.[106] The Arctic Digital Elevation Model (DEM) raster layer was used to calculate slope as a percentage across the entire watershed. To isolate areas of interest, the raster was extracted to isolate the slope of each anadromous stream in the watershed. Because streams with a high gradient (greater than 4%) have a high water velocity and provide minimal food for salmonids, the gradient raster was given a binary reclassification, where We gave streams with a gradient equal to or less than 4% a score of 3 for most suitable and all other stream gradients were assigned a score of 0 due to the literature lacking further detail than specific gradient range being suitable or not suitable (Table A-2).[106]

Cumulative biological value raster

We created a final raster to identify the stream portions within the watershed that have the most suitable habitat for the spawning life stage of salmon (Figure 6). Every raster was first resampled to 1400m x 1400m cells then each factor assessed for biological value was summed together, where cells with the highest value depict the areas with the highest biological value to salmon.

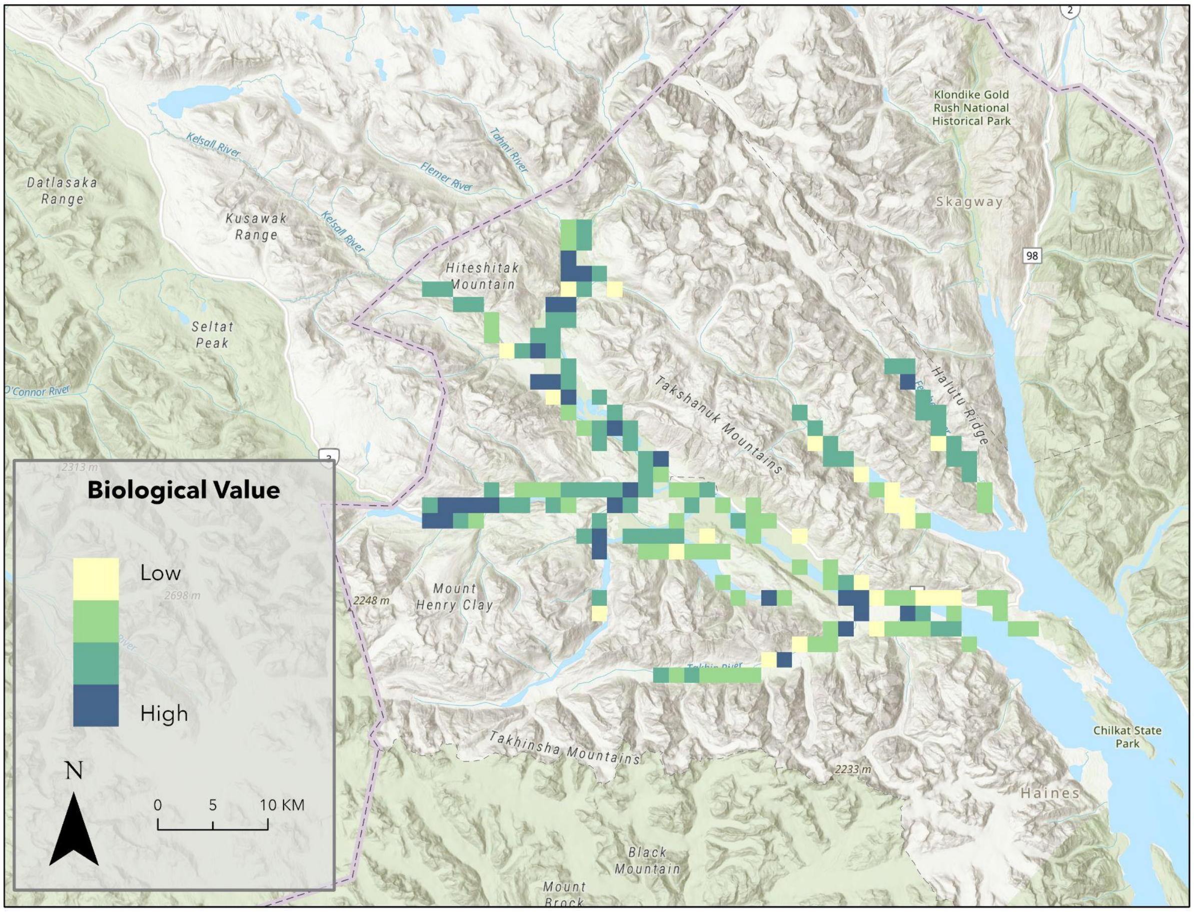

Figure 6. Cumulative salmon biological value layer. This raster represents the relative biological value of anadromous streams and considers riparian land cover and stream temperature. Values within this raster range from 0 (lowest biological value; depicted in yellow) to 9 (highest biological value; depicted in dark blue).

Threat Assessment

Data sources quantifying key human activities in the watershed were used to identify regions with elevated risks to salmon. These anthropogenic threats analyzed include timber harvesting, proposed mining, and the density of roads and culverts.

Proposed timber harvests

The Haines State Forest did not respond to our request to access spatial data identifying future harvest areas. By georeferencing maps from the Haines State Forest Five Year Management Schedule for 2022-2026,[40] we created a raster layer that outlines planned areas that will be clear-cut. The raster is binary; hence, cells are a value of 3 for tiles within planned clear-cutting areas and 0 for areas outside the region (Table A-2).

Proposed mining threats

Using the site of the proposed mine pulled from the Palmer Mine Proposal, we identified the location of the mine within the watershed by georeferencing.[107] Then, we created a decay raster from the mine site using both the trace downstream and flow length tools. The generated raster captures the distance of cells downstream relative to the mining site, where contamination would originate in the event of a breach. The final threat values were determined on a pixel-by-pixel basis by splitting the distances of the resulting cells into quantiles. Cells within the first quantile (closest to the mine) were assigned a value of three, cells in the second quantile were assigned a value of two, and the cells furthest away from the mine but still downstream (the third quantile) were assigned a value of one. Cells outside the downstream flow path from the mine site were given a value of zero (Table A-2).

Human infrastructure

We merged two shapefiles to create one layer with all the roads in the watershed. Using the Line Density tool, we created a raster with values representing the road density within each cell. Raster cells were assigned scores between 0 (for no roads present) and 3 (highest road density) depending on the quantile in which their road density value fell (Appendix Table A-2). Additionally, we created a raster reflecting culvert density in the watershed as culverts hinder salmon migration upstream for essential migrations.[99] Using the point-to-raster tool, we created a raster that reflects the culvert density within each raster cell within the watershed. Raster cells were assigned scores between 0 (for no culverts/no data present) up to 3 (particularly culvert dense) depending on the quantile in which their culvert density value fell (Appendix Table A-2.)

Cumulative threats

To determine the streams and associated riparian habitats facing the highest collective threat from anthropogenic activities, we generated a final raster that reflects the sum of all other threat layers (Figure 7). First, all rasters were resampled into 1400m x 1400m cells. According to available data, the values from the individual threat rasters were added so that each cell in the cumulative raster reflected the overall threat level. The higher the cell value in the cumulative threats raster, the higher the threat. For this study, all threats were weighted evenly. If more data were available to better evaluate the impact of each environmental and human indicator on salmon habitat, it could be possible to weigh some threats higher than others. Our priority in this data-poor region was to reflect all available data in the final output.

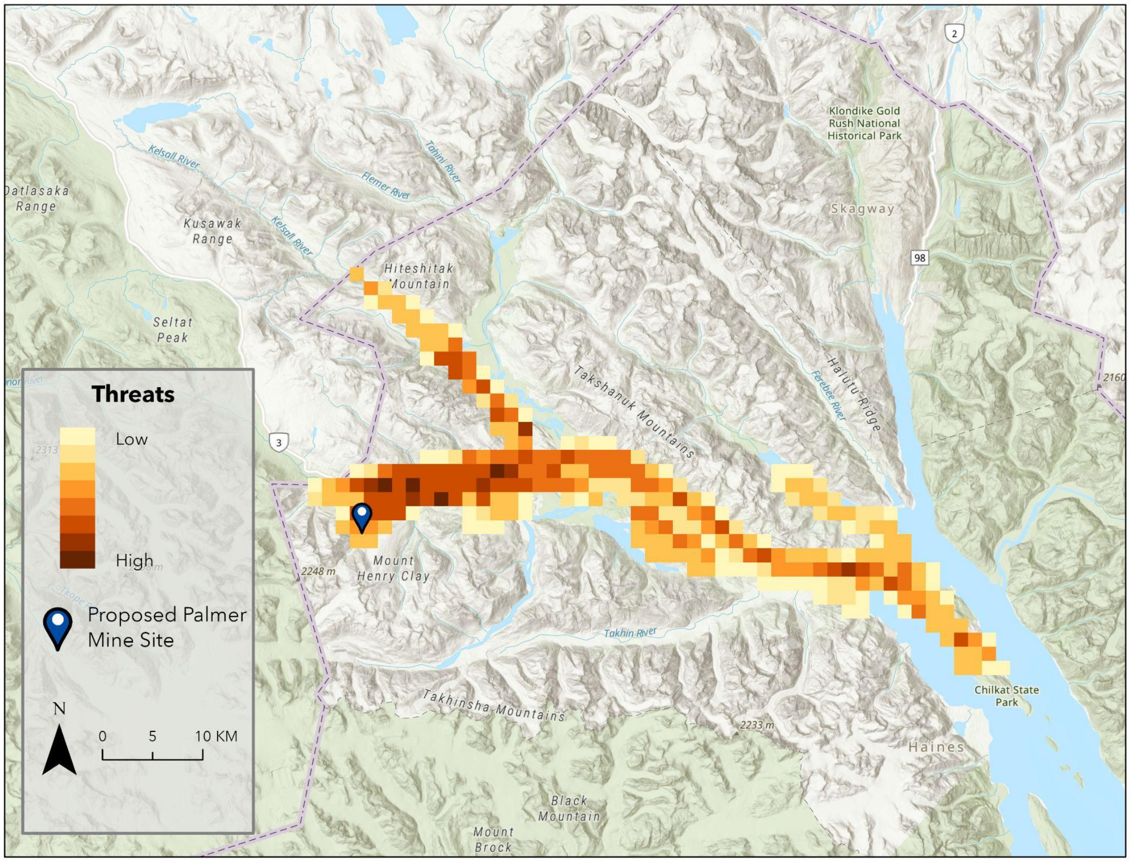

Figure 7. Cumulative salmon threats raster. This raster encompasses the threat values associated with planned logging, the Palmer Mine, and infrastructure density as a single value. Values within this raster range from 0 (no identified threat) to 9 (highest threat level).

Hotspot Analysis and Conservation Prioritization

Identifying hotspots & associated land parcels

We used spatial analyst tools to determine areas at the intersection of the highest level of biological value and threat. First, the data was divided into quartiles; this sorted an equal amount of surface area into four bins that classify the region from highest to lowest score. Then, in the biological value and threat rasters, the quartiles representing areas with the highest scores were isolated by removing all quartiles representing lower scores. Finally, we isolated all cells where the highest quartile of threats and biological value overlap. Parcels that overlap with our identified salmon conservation hotspots were isolated for use as a resource for potential conservation actions.

Results

Threats

Our cumulative threats analysis determined that areas near the proposed mine are particularly threatened due to the confluence of proposed logging, mining, and existing infrastructure. Our cumulative threat raster contains threat scores between 0 and 9, with most cells earning a score of 0 due to missing data in the region (1345 out of 1627; 82%). When considering only cells with data, 32% of these cells earned a score between 5 and 9 (89 out of 282). Cells with a value over 3 represent the top 25% of all threatened cells. Hence, a cell must contain at least two threats to score within the top quartile of cells related to threat.

Biological value

The inclusion of stream temperature and land cover classification along anadromous streams revealed a significant amount of suitable habitat for *x̱áat* (Pacific salmon) near the proposed mine site (Figure 9). The cumulative biological value raster contains scores between 0 and 9, with most cells earning a score of 6 (42 out of 174; 24.1%). While only 5% (9) of all cells score between 0 and 1, 31% (54) of the total cells obtain a score between 6 and 9, representing areas in the top quartile of biological value. These areas have less than 4% gradient, forest cover, and ideal stream temperatures in the watershed.

Hotspot analysis

Our hotspot analysis isolated 17 raster cells that reflect the areas of overlap between the top 25% of the biological value and threat layers (Figure 7). Although the biological value score was lower, both threats and biological value were given equal weight in the analysis. This means that the top 25% of areas with high biological value and high threats were considered equally important in creating the final raster. Once intersected with parcel data provided by Haines Borough, we identified 444 parcels suitable for prioritizing salmon habitat conservation (Figure 8). The ownership status of each of the parcels is described in Table A-3. Priorities for conservation easements should be focused on lands owned by the University of Alaska or other private owners (Figure 9).

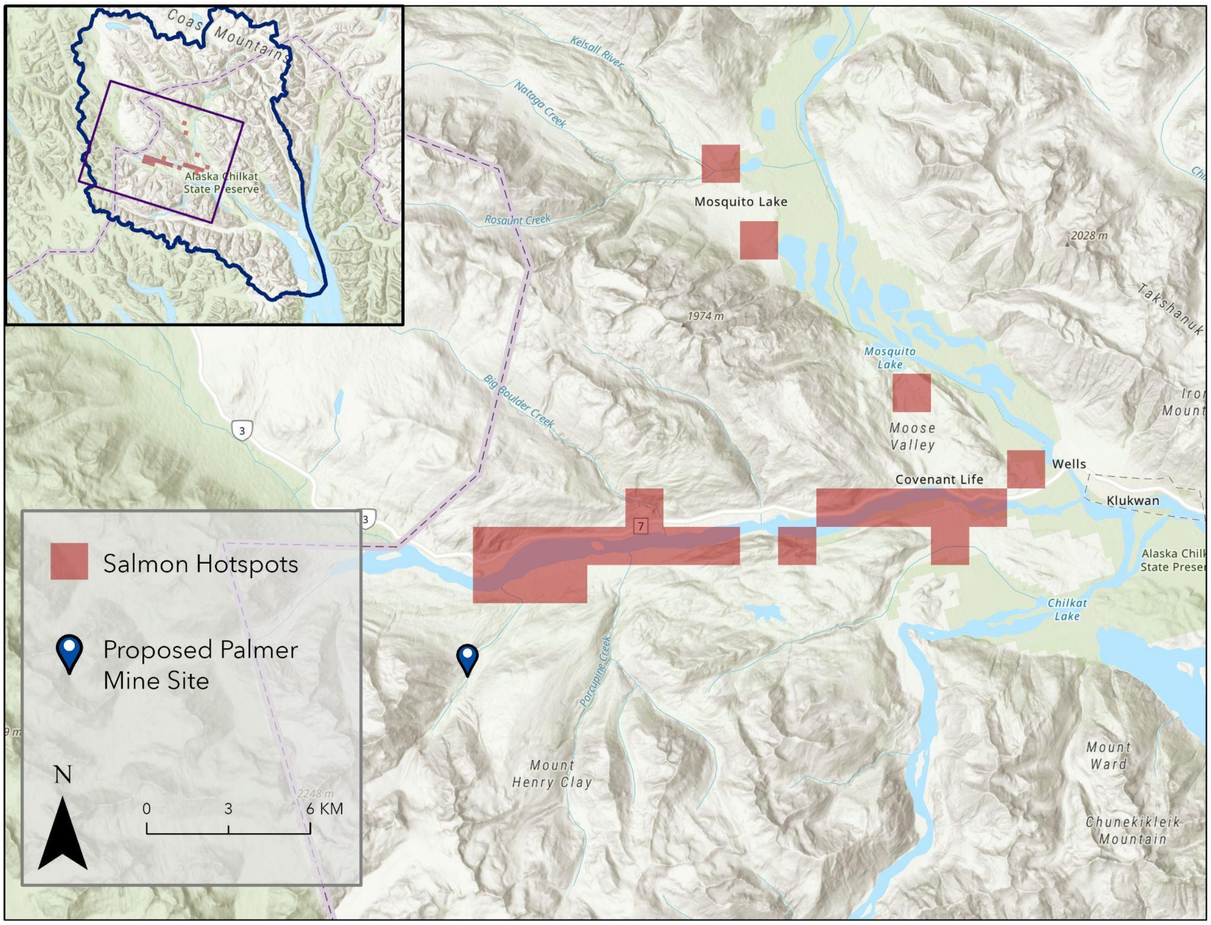

Figure 8. Salmon conservation hotspots, After overlaying our cumulative biological threat and cumulative raster layers, the hotspots above (red squares) represent cells with the highest quantile of threat and highest quartile of biological value overlap. This resulted in salmon conservation hotspots shown in red.

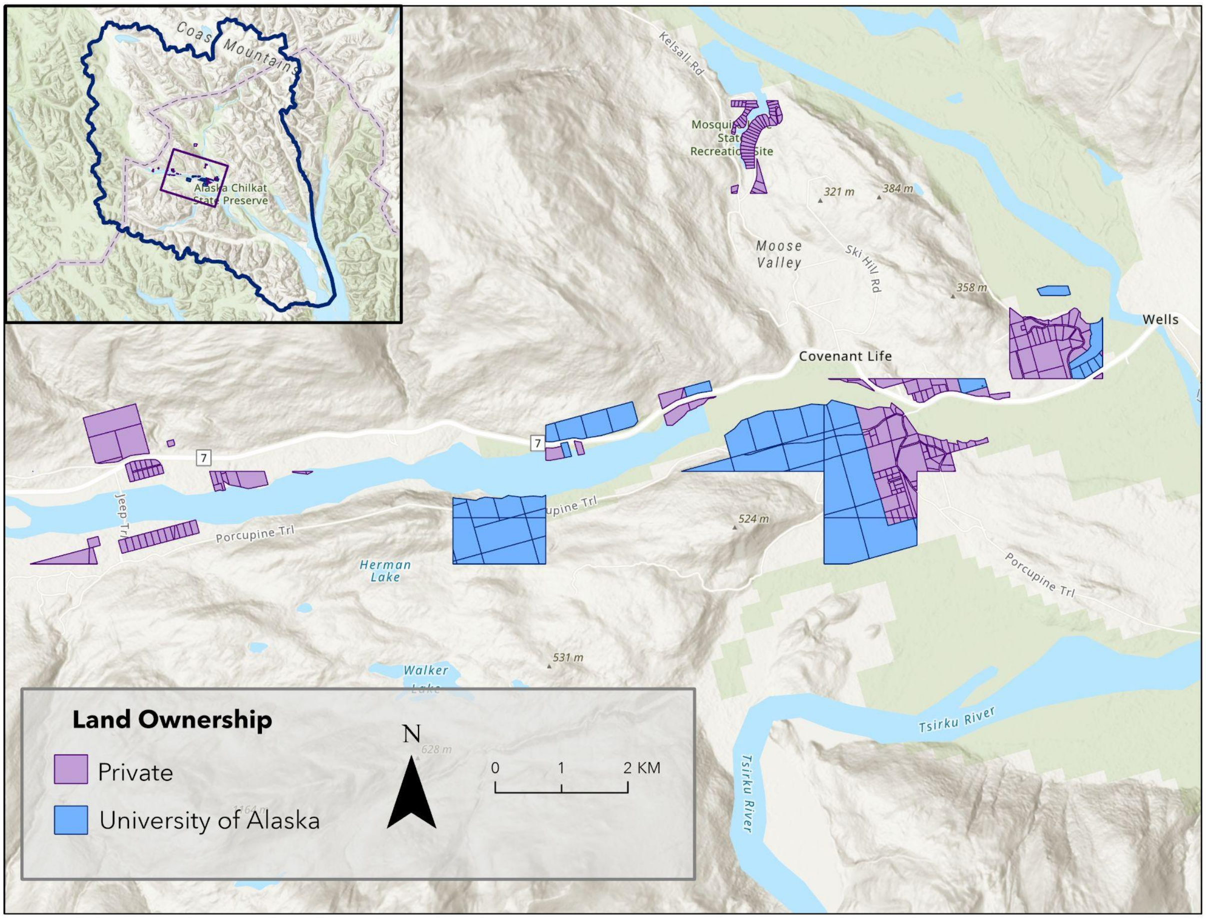

Figure 9. Parcels within salmon conservation hotspots: The area within the GCW salmon hotspots which overlapped with the most parcels. Ownership of the parcels is shown by color. In particular, parcels owned privately or by the University of Alaska present opportunities for conservation easements.

Discussion

Implications for conservation easements

Conservation easements are an effective tool for landscape conservation and have successfully protected valuable ecosystems over the past four decades.[108–110] This technique creates a partnership between land trusts and private landowners to protect threatened ecosystems on their property, prohibiting further development on privately-held land and providing tax benefits and income to landowners.[110] There is currently only one conservation easement established in the area held by the Southeast Alaska Land Trust, the Nelson Homestead Conservation Easement located in the Mud Bay area of Haines Borough.[35] This easement was created in 2013 and protects 128.51 acres of the estuary, mud flats, and forested land.[35] Unfortunately, this easement does not overlap with any of the hotspots identified in this analysis as critical to salmon.

This analysis identified 444 parcels within the Greater Chilkat Watershed that should be prioritized for salmon conservation. Of the parcels identified, 252 are owned by private landowners, the University of Alaska owns 59, the State of Alaska owns 25, and 19 are owned by the Mental Health Land Trust (Table A-3. Most hotspots (82%) identified within the watershed are along the *L'ehéeni* (Klehini) River. This suggests that conservation efforts should be prioritized along this stream, given its high vulnerability and suitability for salmon habitat. It is also important to note that many parcels located in the easternmost hotspots near the indigenous village of *Tlákw.aan* (Klukwan) are owned by the University of Alaska (Figure 9). Although land owned by the University of Alaska within the region has been predominantly used for timber extraction, there is a new incentive set forth by the University of Alaska to prioritize carbon sequestration and carbon banking throughout their properties.[111] This is especially important as proposed and potential areas planned for harvest within the Haines State Forest overlap with these hotspots (Figure 10). Given this pivot in approaches to management, there is a clear window of opportunity for land trusts in the region to designate conservation easements within these parcels as they are forested and have high value for salmon habitat. The economic benefits of monetizing carbon sequestration on these lands are explored in more detail in our "Economic Value of Carbon Sequestration" analysis section.

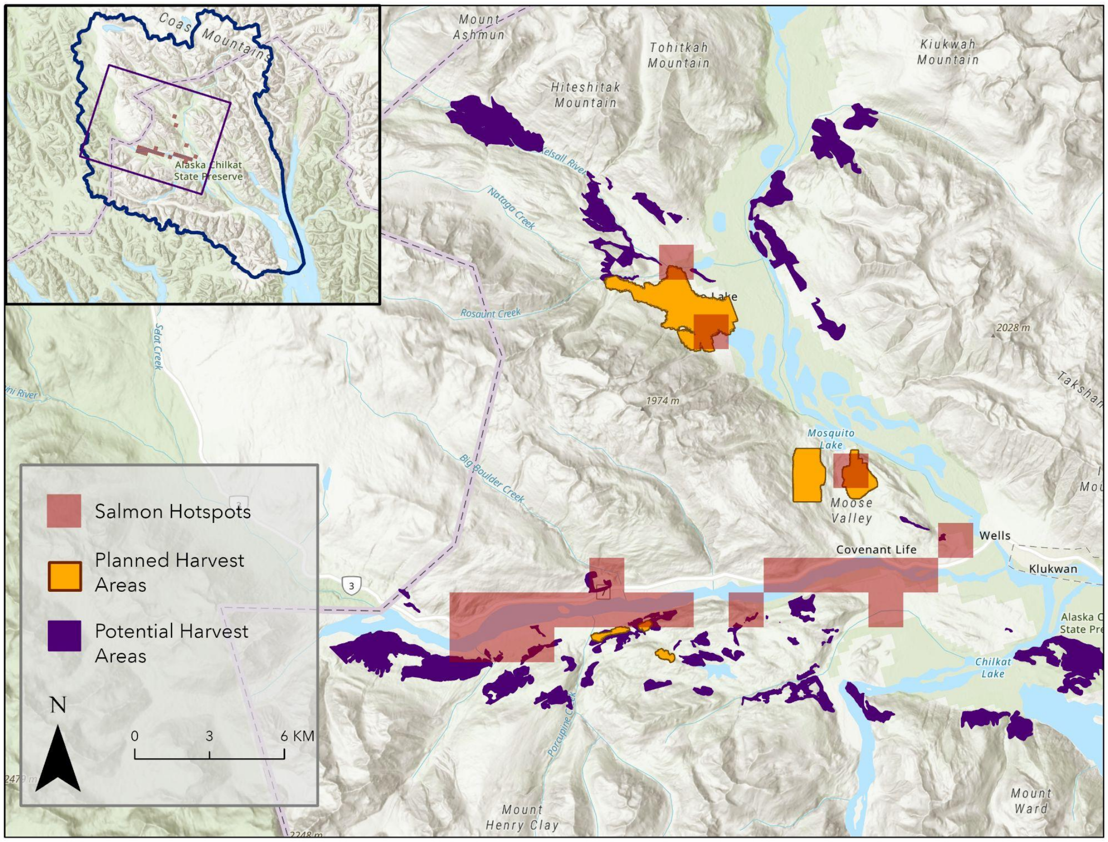

Figure 10. Haines State Forest planned harvests within salmon conservation hotspots. Areas in orange represent those designated for harvest in the next 5 years as identified in the Haines State

Forest Management Schedule for 2022-2026 by the AK DNR Division of Forestry. Areas in purple represent highly stocked stands within the Haines State Forest that are likely to be harvested. These were mapped alongside salmon hotspots to identify areas of overlap. If clear-cutting occurs in these harvest areas, there are strong implications for salmon habitat degradation.

Further data collection

Due to limited funding and employees, data collection in the GCW region remains limited, particularly concerning factors that contribute to and reflect the biological value of salmon. Local conservation groups can prioritize data collection zones based on identifying areas with high threat levels and potential for high biological value. Collecting more robust data in salmon hotspots would enable local stakeholders to make informed decisions regarding extractive industries in their watershed. To capture biological value in the region more effectively, conservation professionals can use various methods based on access to funding and labor. The installation of fish weirs would be ideal if sufficient funding were available. If not, collecting data on stream temperature, streambed substrate composition, and stream flow in hotspots would significantly contribute to identifying biologically valuable areas in the Chilkat watershed. Additionally, there is a notable lack of data concerning stream substrate composition in the GCW, which should be addressed as it is critical for understanding salmon habitats and the impacts of climate change on them. Furthermore, future iterations of this study could perform a risk analysis to understand particularly impactful threats and score the threats relative to the potential threat. Considering the next steps, if funding and labor remain limited, emphasis should be placed on data collection relating to streambed substrate composition, which is less labor and cost-intensive. Alternatively, if LCC can obtain funding for further data collection, continuous streamflow data should be prioritized. Establishing baseline data within the watershed is critical, especially as climate change impacts glaciers and precipitation, influencing stream flow.[112,113] Additionally, our threats analysis could be improved by incorporating edge effects of threats in the study area. This could be achieved by examining the interactions between threats and the surrounding landscape, which may significantly impact the persistence of species and ecosystems in the study area.

Conclusion

X̲áat (Pacific salmon) play a crucial role in the ecosystem and economy of the Greater Chilkat Watershed region, making these findings significant for conservation efforts in the region. Identifying concentrated hotspots along the *L'ehéeni* River provides valuable information to managers in the area who can conserve this land as critical salmon habitat. Participation in carbon sequestration markets and the purchase of conservation easements are two mechanisms to accomplish this. While only one easement exists in the GCW, there is potential for future partnerships between land trusts and private landowners to protect threatened ecosystems while supporting the region's economy. Overall, our findings highlight the salmon habitat most in need of protection and can be used to inform future conservation actions to preserve the watershed’s valuable salmon populations.

2. *Jánwu* (mountain goats) Habitat Connectivity

Introduction

Jánwu (mountain goats) in the GCW are a unique, genetically diverse, refugial metapopulation that survived the most recent glaciation period.[114] In our study region, there are currently 8 mountain ridges with distinct goat populations, essentially inhabiting "sky islands" created by the natural habitat fragmentation of mountainous alpine terrain.[46,114] These subpopulations show high levels of local adaptation, with only 6% genetic distance between them, compared to 12% between other southeastern Alaska management units.[115] Therefore, maintaining healthy, natural populations in this region is critical to preserving this population's genetic diversity.

The ability of male mountain goats to disperse between subpopulations is critical for gene flow and the continued persistence of the species. Especially in preparation for the rutting season (October - December), males may travel long distances in search of mates.[77] These dispersal corridors have not yet been mapped, but knowledge of their locations would be valuable to inform management plans. Additionally, although the impacts of mining and heli-skiing on goats in this area are well-documented, there has yet to be a comparison of planned logging areas to mountain goat winter habitat or movement corridors.[79,80,85] Therefore, our analysis contributes useful knowledge for forest managers and conservation organizations in a relatively data-poor area.

Impacts of forest management

Maintaining and improving habitat connectivity is a common strategy for ensuring long-term population viability. This strategy can be achieved by preserving or creating movement corridors between suitable habitats. Logging activities increase fragmentation and loss of habitat, which can reduce genetic diversity and put mountain goat populations at greater risk of extinction.[116,117] In addition to threatening connectivity, mature, intact forests' clear-cutting also jeopardizes important wintering habitat. In the winter, goats retreat from high-elevation ridges and peaks to lower elevations where closed-canopy coniferous forests prevent deep snowpacks from accumulating.[77] Reduced snow makes forage more available, and the quality and quantity of winter forage has a large impact on *jánwu* (mountain goats)' ability to survive the season.[77] Logging of old-growth forests can reduce forage for decades, making conservation of goat winter habitat critical to their survival.[82] A loss of winter habitat carrying capacity can have long-term negative impacts on goat populations.[118] Even outside of wintering sites, logging of corridors between habitat can increase the energy needed to travel due to deep snow, potentially further depleting males' already limited resources.[77] *Jánwu* (mountain goats) show strong fidelity for their seasonal ranges, with Shakeri et al. (2021) finding that 99% of individuals (n = 138) in the upper GCW region returned to their previous year's range.[119] This reinforces the need for the preservation of these areas.

Data

Table 2. Data types and sources. Data inputs to mountain goat analysis.

Core Area Determination (Summer)	Mountain goat *summer* resource selection function (binary) from White & Gregovich, 2018			
Resistance Raster Generation	NLCD 2016 Alaska Land Cover (USGS)	Canada Centre for Remote Sensing 2020 Land Cover	USGS 5 Meter Alaska Digital Elevation Model (2020)	Landscape Resistance Values from the Washington Statewide Habitat Connectivity Working Group (2010)
Logging Threats	State of Alaska Division of Forestry Haines State Forest Inventory (2021)			
Winter Habitat Comparison	Mountain goat *winter* resource selection function (binary) from White & Gregovich, 2018			

For more detailed information on our data sources, please see appendix table A-1.

Methods

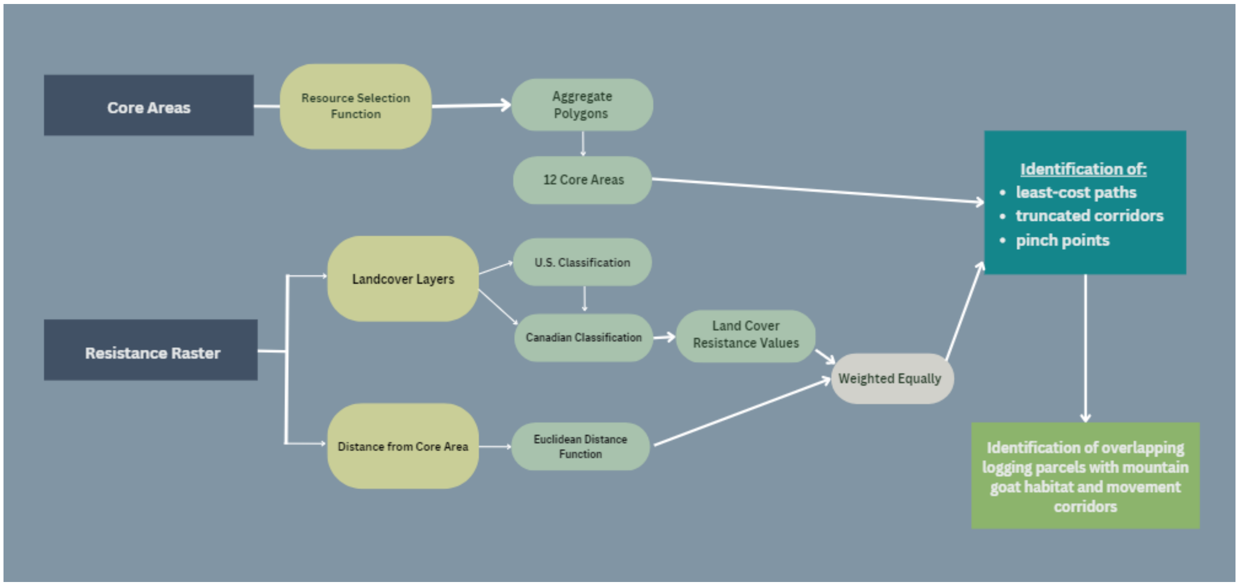

Figure 11. Methods for *jánwu* (mountain goats) habitat connectivity analysis. Methods for creating core areas and the resistance raster used in the Linkage Mapper Toolkit in ArcGIS Pro.

Resource selection functions and determination of core areas

Core areas of mountain goat habitat were identified using the results of a summer resource selection function model (RSF) provided by White and Gregovich (2018).[82] A RSF depicts individual pixels with respective probabilities of goat occurrence based on landscape variables. The variables included in this RSF were elevation, slope, distance to cliffs, solar radiation, vector ruggedness measure, and topographic position index.[82] Areas of suitable habitat identified by the RSF were vectorized by White and Gregovich to create a binary representation of summer goat habitat. We then combined these areas using the aggregate polygons tool with the following parameters: an 800m aggregation distance, minimum area of 0, and a minimum hole size of 1,000,000 square kilometers to prevent the retention of holes in core areas. U.S. and British Columbia rivers and streams datasets were used as barriers to prevent aggregation across valleys. These large polygons were used as core areas in our Linkage Mapper analysis, representing primary habitat for the geographically separated goat subpopulations of the GCW. To streamline our analysis, we used the 12 largest core areas created by this processing. See Figure A-1 to view the original summer and winter habitat layers and regional/subpopulation naming conventions.

A binary representation of a winter resource selection function model provided by White and Gregovich (2018)[82] was also used in the final steps of our analysis to determine where planned and potential harvest threatens these areas critical for goat survival.

Land cover standardization

Using data from the USGS National Land Cover Database and the Canada Centre for Remote Sensing, land cover classifications were paired based on metadata analysis of corresponding cover features (see Table A-2 for pairings). We reclassified the attributes of these rasters to have uniform land cover values across the boundary between the USA and Canada, which is in our study region. Because of more detailed classification categories that were relevant to the Chilkat Valley region (e.g., temperate forest areas), land cover codes were based upon the Canadian classification system. This also allowed for uniform symbology for visual representation.

Creation of resistance raster

We consulted relevant literature to determine appropriate resistance values for the land cover classifications surrounding the core areas. The Washington Statewide Habitat Connectivity Working Group provided landscape resistance values for jánwu (mountain goats).[120] We used provided values (ranging from 0-100) associated with the land cover types, elevation ranges, and road types found in our study region. Tiles from the USGS 5 Meter Alaska Digital Elevation Models were merged to represent the watershed's surface, which allowed for the calculations of slope angles in the area. Slope angles 20-40 degrees were assigned a resistance value of 1, while slopes greater than 40 degrees were assigned a resistance value of 3.

Identification of planned and potential harvest polygons

The Haines State Forest did not respond to requests to provide layers of their planned harvest activities. To represent their published harvest areas identified in the Five-Year Management Schedule for 2022-2026, we used .jpeg images from this document for georeferencing. See Figures A-2–A-6 for these original images and Table A-8 for the accompanying harvest activities table. By referencing boundaries of planned harvest areas with control points and transforming images to raster layers, we created polygons representing these parcels for use in our analysis. Small margins of error in referencing the exact extent of harvest sites were expected but not deemed significant for analysis. This is due to the impacts of harvest activities on wildlife that extend beyond but close to these sites. Literature has indicated impacts on wildlife behavior within 400 meters of some harvest activities.[77]

Although more than 2,500 acres of the HSF are planned for clear-cutting by 2027, thousands more may be considered for harvest beyond that time frame. We filtered forest stand data from the Haines State Forest, choosing the highest-stocked parcels to expand the analysis scope for future harvest areas that are not currently planned. These parcels have the greatest potential economic value for timber production, a key consideration for harvest activities. Per-acre data for commercial parcels are uniform across these highly-stocked stands; thus, a more specific analysis of timber stocking in each parcel was impossible. We filtered the data based on this attribute to cover all potential future harvest areas and made a new vector layer.

Linkage Mapper Toolkit analysis

After the creation of our core area and final resistance layer, we used the Linkage Mapper toolkit to run analyses.[60] Results of the Build Networks and Map Linkages tool (using a cost-weighted and euclidean network adjacency method and 30km truncated cost-weighted distance threshold) identified likely movement corridors and least-cost paths (LCPs) between core areas using the Circuitscape algorithm.

LCPs were ranked by quality according to two metrics – the cost-weighted to Euclidean distance ratio and the cost-weighted distance (CWD) to LCP length ratio.[120] The CWD to Euclidean distance ratio reflects how difficult it is for an organism to move between core areas relative to the distance between them.[120] A direct path will have a lower value, while a meandering route will have a high value. The CWD to LCP length ratio indicates the average resistance an organism encounters along the path.[120] A path through low resistance habitat will have a low value, regardless of length, while a path through high resistance habitat will have a high value. These two values were averaged to calculate a value representing overall quality. Like the individual parameters, having a low mean ratio value (close to 1) indicates high quality, while a high ratio indicates low quality. Locations of LCPs and corridors were compared to planned, and potential harvest areas, and areas of overlap were noted for further analysis.

We then identified pinch points, using the Pinchpoint Mapper tool to truncate the cost-weighted corridor width to 500 meters. Pinch points are narrow areas where movement is likely funneled within migration corridors. Finally, Centrality Mapper was used to determine core areas and LCP centrality within the network produced by the Linkage Mapper tool.

Winter habitat comparison with harvest areas

A binary representation of the winter habitat RSF by White & Gregovich (2018) was used for comparison with planned and potential harvest areas. The planned and potential harvest polygons clipped the RSF layer to find winter habitat areas that either will be harvested between 2022 and 2026 or are highly stocked and may be considered for harvest in the future.

Results

Linkage Mapper

Linkage Mapper results display likely corridors of mountain goat movement and the least cost paths (LCPs) between core summer habitats. Figure 12 illustrates numerous planned harvest areas and highly-stocked stands ("potential harvest areas") within or close to LCPs and movement corridors. Using the mean of two ratio metrics, we ranked the quality of LCPs from high (low mean ratio) to low (high mean ratio). Generally, higher-quality LCPs are found near the northern and western perimeters of the watershed.

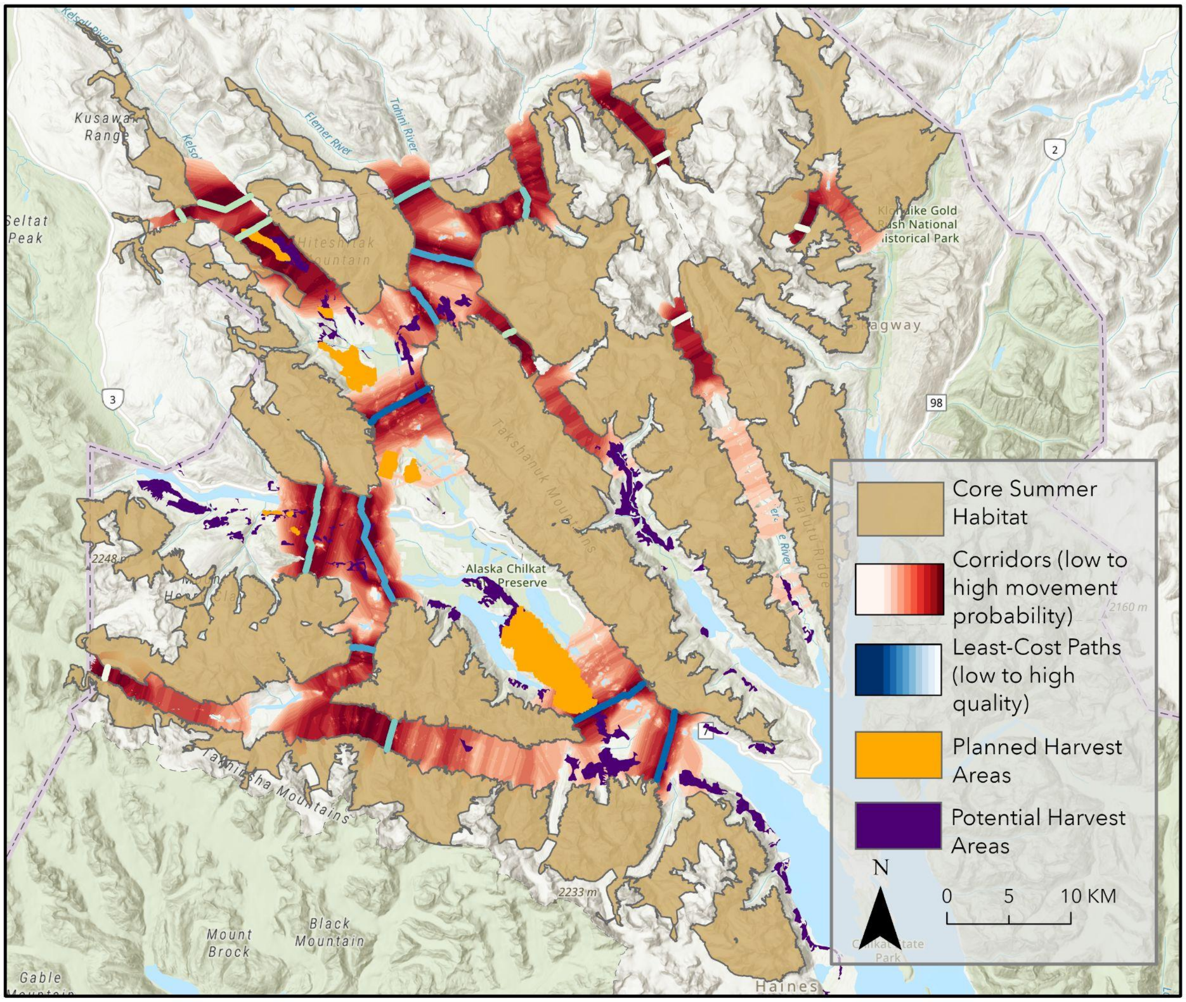

Figure 12. Greater Chilkat Watershed overview with Linkage Mapper toolkit results. An overview of the study's region of interest shows the core areas of summer mountain goat habitat, as well as corridors of modeled goat movement and least cost paths (LCPs). LCPs are symbolized from lowest to highest quality (dark blue to white), as indicated by the mean of the ratios between cost-weighted and Euclidean distances and cost-weighted distance and LCP length (low ratio = higher quality, high ratio = lower quality).

Further analysis reveals 3 areas where LCPs and corridors occur in or adjacent to the Haines State Forest's planned or potential harvest areas (Figure 13). Map A shows the Single 15 (2025) and Turn Around (2026) planned harvest areas overlapping with a least-cost path and likely movement corridors. Additionally, highly stocked stands 75, 81, 84, and 100 intersect these corridors and represent areas that may be scheduled for harvest in 2027 and beyond. Map B highlights the proximity of the Chilkat Ridge parcels (planned for harvest in 2024 and 2026) and highly-stocked stands 813, 1482, 1534, 1543, 1562, 1586, 1697, 1705, 1760 to LCPs and corridors in this region. Specifically, the Chilkat Ridge 2 harvest area is close to the LCP and accompanying corridor between the Takhin and Takshanuk subpopulations. Additionally, parcel 1705 directly intersects an LCP between the Takhinsha and Takshanuk subpopulations. Finally, Map C highlights numerous planned and potential harvest areas that intersect

LCPs and movement corridors at the confluence of the Jilkaat (Chilkat river), *Yéil Héeni* (Kelsall river), and *Gathéeni* (Tsirku) Rivers. Planned harvest areas on this map include Porcupine Junction 1 (2024), Porcupine Junction 2 (2026), West Herman V (2023), 4 Winds Opener (2024), Ski Hill Opener (2023), Ski Hill Ridge (2025), and Kelsall 100CW (2024). Logging in these areas may impact connectivity between the Four Winds, Summit, and Takhin subpopulations. Appendix Table A-15 lists all the potential harvest areas intersecting LCPs and/or corridors identified in our analysis.

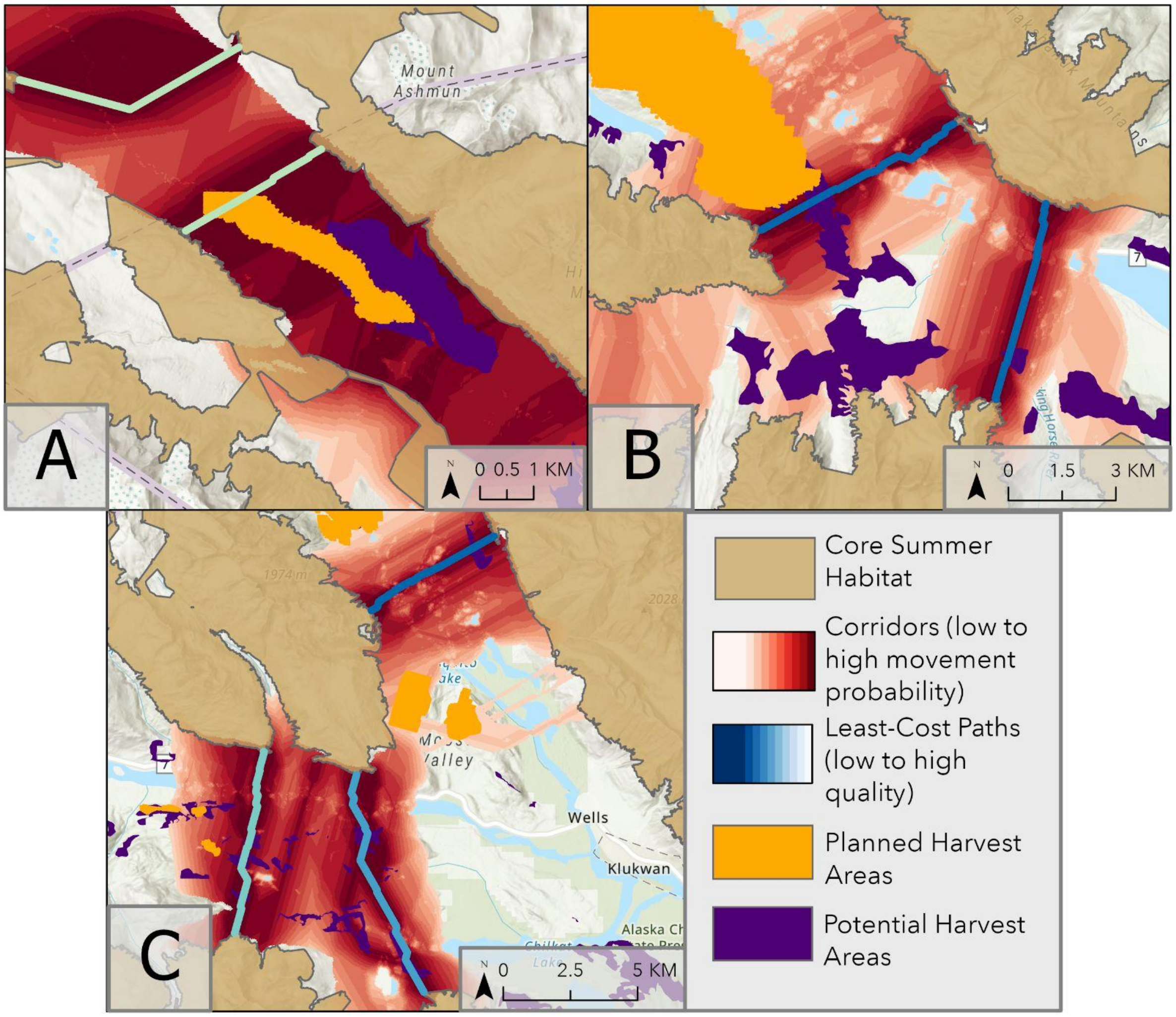

Figure 13A-C. Movement corridors and LCPs that intersect planned and potential harvest areas. A. Movement corridor and LCP overlap with the Turn Around (2026) and Single 15 (2025) planned harvest areas and highly-stocked stands. **B.** Movement corridor and LCP overlap with the Chilkat Ridge 2 (2026) planned harvest area and highly-stocked stands. **C.** Highly stocked stands and planned harvest areas intersecting LCPs and corridors near the confluence of the *Jilkaat* (Chilkat), *Yéil Héeni* (Kelsall river), and *Gathéeni* (Tsirku) Rivers.

Pinchpoint Mapper

A pinch point analysis revealed significant constriction of current flow within numerous goat movement corridors in the GCW. Pinch points represent areas where goat movement is likely funneled and connectivity is tenuous. As illustrated in Figure 14, four out of five corridors connecting the Takshanuk subpopulation to other core areas are especially constricted. The Four Winds subpopulation appears to be similarly affected. While no planned harvest areas directly encompass pinch points, there are numerous potential harvest areas containing pinch points; the full list can be found in Appendix Table A-9.

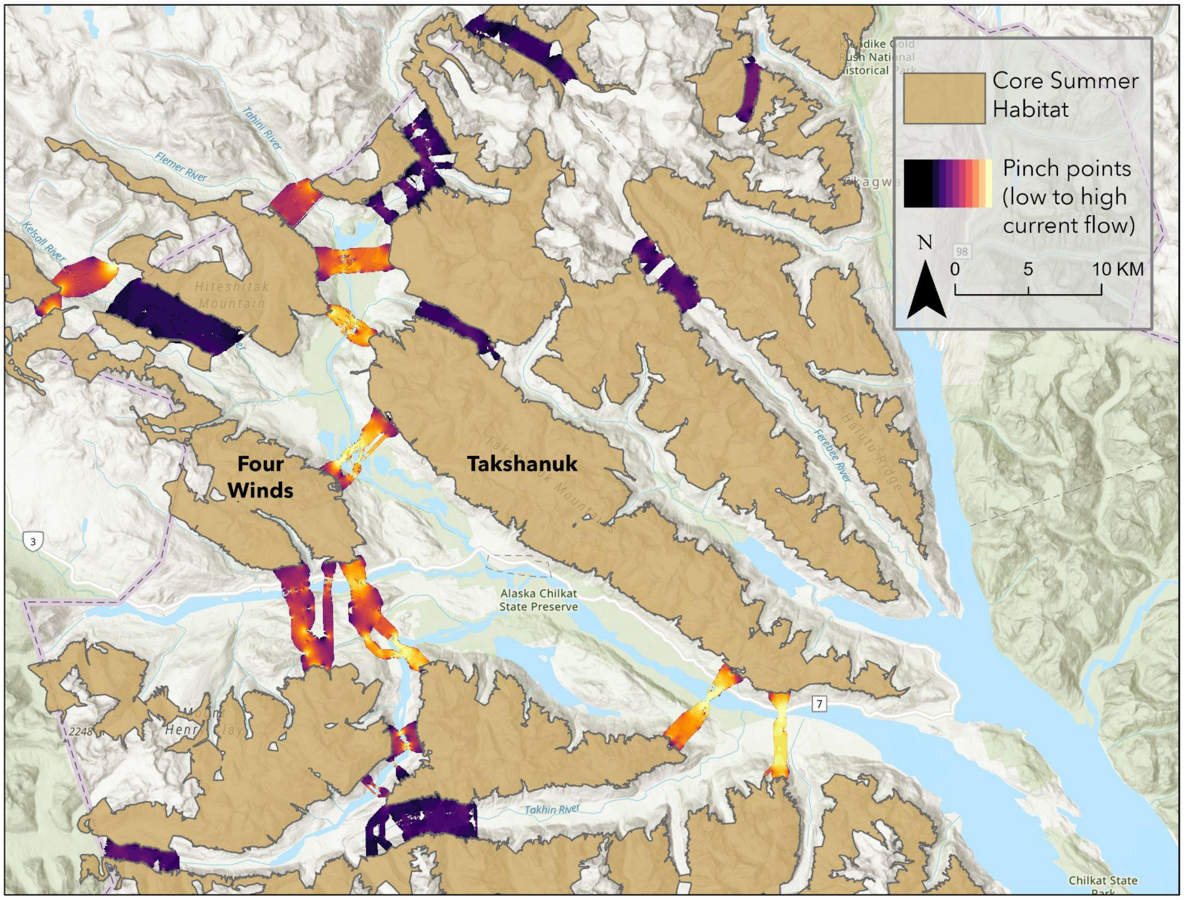

Figure 14. Pinch points to goat movement within corridors. Based on the results of our analysis, connectivity between the Takshanuk and Four Winds subpopulations and surrounding core habitat is especially tenuous.

Centrality Mapper

Results of the Centrality Mapper tool (Figure 15) demonstrate the core areas and least-cost paths that are most “central,” meaning they are most important for keeping the entire network connected.[55] Among core habitats, the Takshanuk and Chilkoot-Ferebee ranges are the most critical for ensuring connectivity across the metapopulation. The most central LCPs connect these areas to the Nourse region. LCPs of very high centrality also exist close to the U.S.-Canada border, one of which intersects the Single 15-Turnaround planned harvest area.

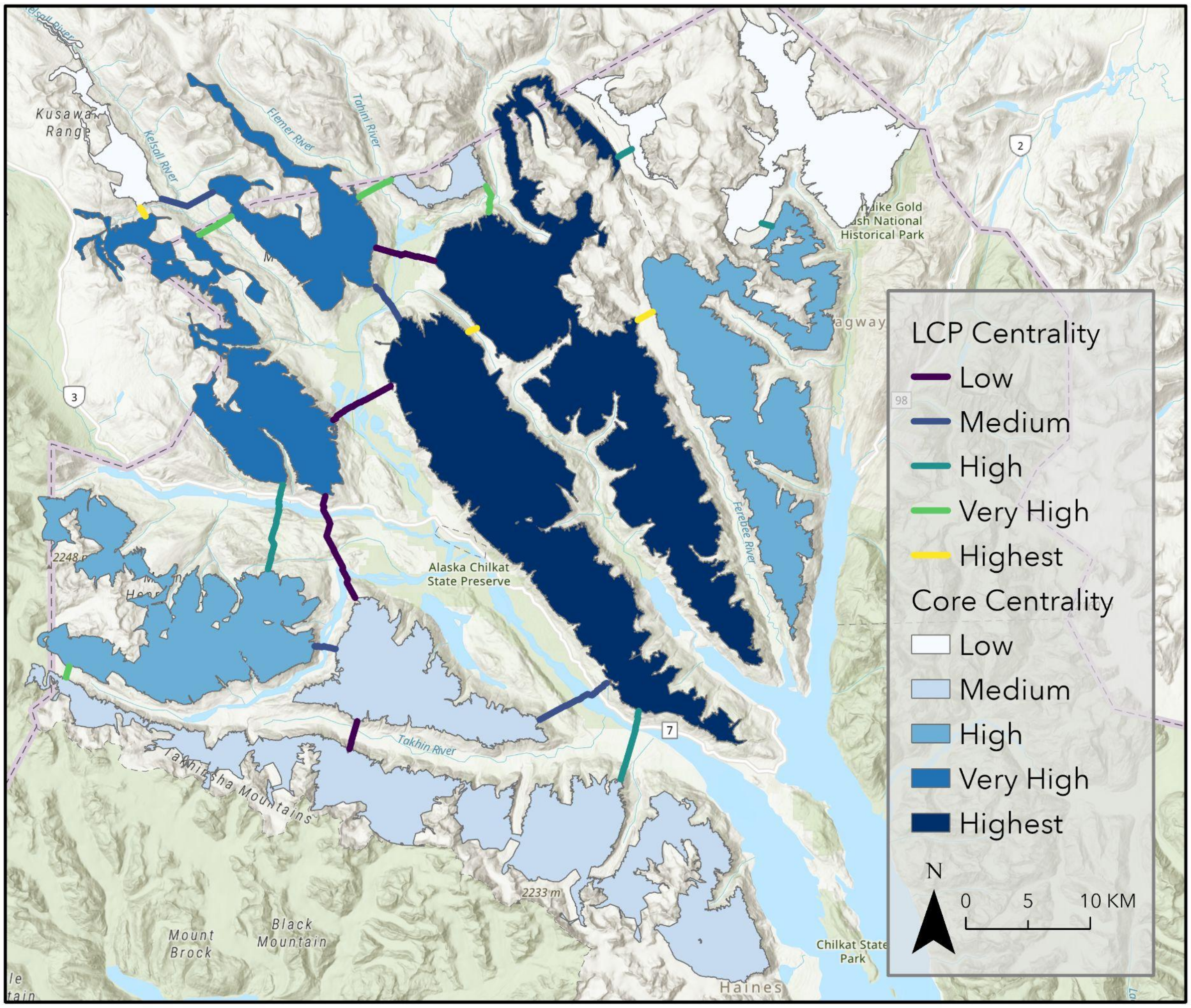

Figure 15. Core and LCP centrality. Core areas are visualized to reflect the results of the centrality analysis, with dark blue signifying the highest centrality and white indicating low centrality within the network produced from Linkage Mapper. Similarly, LCPs are symbolized to represent centrality, with yellow representing the highest centrality and dark purple as low centrality.

Winter habitat overlap

Results of our binary winter habitat versus planned and potential harvest area analysis (Figure 16) reveal significant overlaps with highly-stocked forest stands, particularly for winter habitat of the Takhinsha, Takhin, and Takshanuk subpopulations. Planned harvests of Kelsall Pocket and 100CW (2023 & 2024), 4 Winds Opener (2024), and Chilkat Ridge 2 (2026), will remove suitable winter habitat, with the latter being the largest, clearing approximately 277 acres. Many highlighted stands in the southern part of the figure represent winter habitat for the southern Takhinsha subpopulation, for which the 2022 harvest was canceled due to a sudden steep population decline.

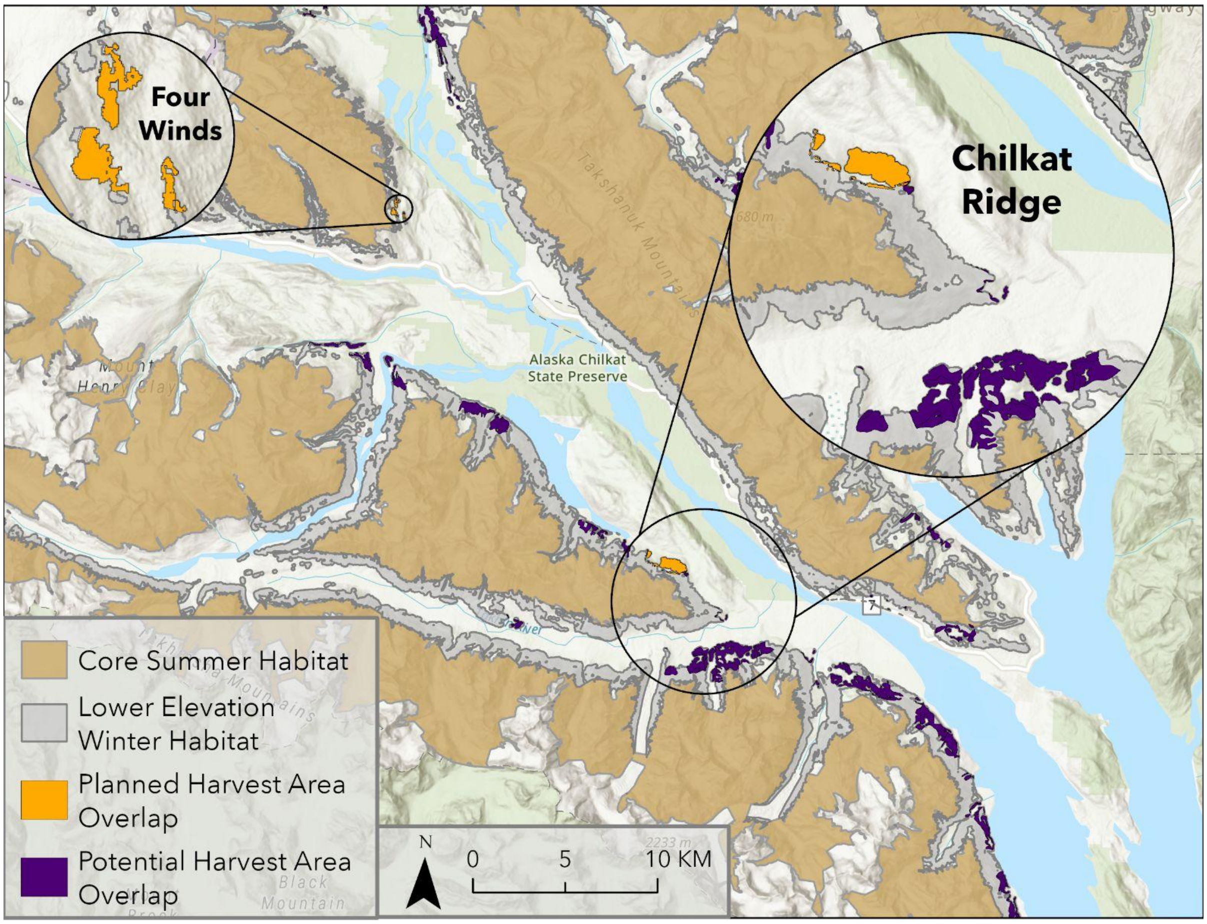

Figure 16. Overview of planned and potential harvest areas that overlap with mountain goat winter habitat. Purple areas represent portions of winter mountain goat habitat that overlap with stands identified as highly-stocked by the AK DNR Division of Forestry. Orange areas represent parcels from the HSF Five-Year Management Schedule for 2022-2026 that encompass winter habitat. The insets show close-ups of portions of the planned harvests of 4 Winds Opener and Chilkat Ridge 2, which will remove around 46 and 227 acres, respectively.

Discussion

Habitat connectivity

The results from our Linkage Mapper analyses demonstrate that proposed harvest areas are within or near mountain goat movement corridors. While the effect of clear-cut logging on goat movement has not been well-documented in the literature, helicopter use associated with logging activities has been shown to alter mountain goat behavior in British Columbia.[121] These impacts include habitat displacement, which could reasonably be expected to affect the ability of goats to move through their favored corridors. Chadwick (1974) found that road construction and logging disturbances deterred *jánwu* (mountain goats), promoting their use of familiar terrain while discouraging exploratory movements.[122] Given the 19.4 miles of new road construction and 2,500 acres planned for logging in the near future, HSF management actions could have negative consequences for goat dispersal.

The presence of roads can also increase direct mortality, causes of which include car collisions, death in avalanche control activities, and increased hunting access to previously inaccessible regions.[123] Overall, the literature shows that industrial disturbances, which include mining, helicopters, road construction and use, and logging, have negatively impacted foraging behavior, movement patterns, and population dynamics of *jánwu* (mountain goats).[118]

In our study region, special consideration should be given to proposed disturbances that fall within corridors between core areas, so as not to disrupt gene flow between already-fragmented and isolated subpopulations. We encourage land managers to look into alternative locations that pose fewer threats to important corridors for this species. Specifically, we urge Haines State Forest management to reconsider the upcoming logging of the Chilkat Ridge 2, Single 15, Turn Around, Porcupine Junction 1 & 2, and West Herman V sales. These areas either overlap or are very near LCPs and corridors between core areas. For potential harvest areas, we discourage future harvest scheduling of any highly-stocked stands that fall within LCPs or highly suitable corridors (Table A-15).

Pinch points are narrow areas within movement corridors that represent constrictions or bottlenecks. Even a small loss of area within a pinch point can seriously compromise, and potentially sever, connectivity between core areas.[124] None of the harvest areas planned for harvest before 2027 directly intersect the most intense pinch points identified with our Pinchpoint Mapper analysis. However, there are numerous highly-stocked stands that encompass pinch points (Table A-9). Conservation of these parcels should be prioritized to preserve critical links between mountain goat subpopulations.

Centrality analysis

Core areas and LCPs are considered highly central to a habitat network or metapopulation if they are disproportionately important to maintaining connectivity between them.[55] Our Centrality Mapper analysis shows that the Takshanuk and Chilkoot-Ferebee ranges are the most critical for ensuring connectivity across the metapopulation, followed by the Four Winds and Hiteshitak areas. The least central is the northern part of the Nourse region, suggesting it may be the most isolated from the rest of the network. The most central LCPs of the network connect the Takshanuk and Chilkoot-Ferebee areas to each other and the Chilkoot-Ferebee to the southern Nourse region. LCPs of very high centrality also exist close to the U.S.-Canada border, one of which intersects the Single 15-Turnaround planned harvest area. Research has shown that centrality measures offer a reliable ranking of the most important patches and linkages as a function of their contribution to connectivity.[125] Therefore, maintaining the most central core areas and corridors are critical for keeping the GCW's mountain goat metapopulation connected.

Winter habitat

As noted in the introduction, removal of intact, forested winter mountain goat habitat can negatively impact forage quality, the winter survival of individuals, and consequently, population growth rates. Fox et al. (1989) recommended that harvest activities be directed away from goat wintering sites wherever possible.[77] Additionally, other wildlife in the GCW also likely utilize these old-growth forest patches, including bald eagles, northern goshawks, marbled murrelets, flying squirrels, black bears, and wolves.[10]

As wildlife conservation is a stated goal of Haines State Forest management, the impacts of the upcoming harvests of the Chilkat Ridge 2 sale, and with lesser importance (due to small size), the 4 Winds Opener, Kelsall Pocket, and Kelsall 100CW sales should be given serious consideration. Combined, these planned harvests would eliminate 275 acres of critical goat winter habitat. Additionally, a number of highly-stocked stands should be removed from future harvest consideration based on their inclusion of suitable winter habitat (Table A-10). The largest number of parcels are within the Takhinsha subpopulation's winter habitat which has recently experienced steep population declines that triggered the closure of the hunting season.[126] Winter is the time when goats are most vulnerable to starvation, so the availability of suitable habitat with nutritious forage during this time is crucial for individual and population survival.[77] This is especially important in the GCW where severe winters have previously decimated goat populations.[78]

Climate change

Finally, climate change poses a significant threat to mountain goat survival. Although a reduction in snowfall and winter severity would appear to benefit goat populations, White et al. (2017) found that negative impacts from increases in summer temperatures will be disproportionately larger than any positive effects of reduced snowfall.[80] Therefore, it is anticipated that suitable habitat will continue to shrink, further limiting connectivity, and making the pursuit of timely conservation even more important.

Limitations

A major limitation to our study is the lack of specific resistance values in the literature pertaining to *jánwu* (mountain goats) in our study region and/or Alaska. The best available values we could find apply to *jánwu* (mountain goats) in the state of Washington.[127] Values determined based on GPS-collared individuals within or close to our study area would deliver more accurate results. The addition of other relevant parameters (i.e., distance to escape terrain) to our model could be considered to improve our results. Similarly, performing a sensitivity analysis of our model parameters would yield greater specificity in our outputs.

Overall, more research in this region is needed, not only for *jánwu* (mountain goats), but also for other wildlife and the watershed's physical characteristics. We hope this study will encourage more researchers to look at habitat connectivity and conservation opportunities in the GCW. We believe this unique, biodiverse region would benefit from more scientific and conservation attention.

Future research

Future directions could determine how clear-cut logging impacts goat movement and behavior. Quantifying how clear-cutting affects landscape resistance to movement for *jánwu* (mountain goats) would be extremely valuable and would allow us to compare corridors before and after a range of planned and potential logging scenarios. Being able to examine alternative corridors would give land managers more options when attempting to balance timber extraction and wildlife conservation. Finally, given an increase in regional and statewide interest in carbon sequestration markets, a study that compares the economic benefits of timber harvest and carbon storage would be incredibly helpful in guiding future management decisions. We begin this process by completing an initial analysis in the “Economic Value of Carbon Sequestration” section later in this paper.

Conclusion

Our study sheds important light on the potential impacts of clear-cut logging within the Haines State Forest on the area’s mountain goat subpopulations. We found that a number of forest stands planned for harvest between now and the end of 2026 are within or very close to goat movement corridors modeled by Linkage Mapper. Additionally, many highly-stocked stands of merchantable timber were also found to be in or near corridors, some containing critical pinch points, and these parcels may be targeted for harvest in future management schedules. We recommend that Haines State Forest management give special conservation consideration to these parcels, given their importance for animal movement. We also found that three upcoming timber sales would directly remove goat winter habitat, and many highly-stocked stands encompass suitable winter habitat as well. As the availability of winter habitat is extremely important for goat survival, we recommend LCC and partners consider possible conservation actions that could aid in their protection.

3. *Xóots (brown bears)* Habitat Connectivity

Introduction

Riparian old-growth forests with salmon resources in the Greater Chilkat Watershed have the potential to support *xóots* (brown bear) populations twice the density of similar ecosystems without salmon.[128] This inherent connection between salmon and bears in this region makes efforts to manage and conserve them intertwined. As of 2009, the Alaska Department of Fish and Game (ADF&G) considers *xóots* (brown bears) in Unit 1 (encompassing the Greater Chilkat Watershed and the communities of *Dzantik'i Héeni* (Juneau), *Shg̱agwei* (Skagway), *Kichx̱áan* (Ketchikan), and *Wanachích T'aak Héen* (Gustavus)) as stable with "evidence of population increase on the *Jilkaat* (Chilkat) peninsula."[129]

In communications with ADF&G staff, we have learned that they are working on a resource selection function model for *xóots* (brown bears) in the GCW, but as it has yet to be published, we were not allowed access to their data. Therefore, we have endeavored to complete a habitat connectivity analysis with the best publicly-available data. To date, there have been no studies of habitat connectivity for *xóots* (brown bears) in the region so our analysis offers new insight that will be valuable to agencies and managers.

Notably, brown bear-human conflicts surrounding the town of *Deishú* (Haines) reached a peak during 2020, when salmon and berry harvests were uncharacteristically low. In fact, salmon yield in 2020 for the *Deishú* (Haines) region was one of the worst ever recorded.[130] As bears began to look elsewhere for food, at least 30 bears were killed by local law enforcement and residents, while 19 were harvested by hunters, the total dead representing approximately 20% of the population.[130,131] Killing *xóots* (brown bears) "in defense of life and property" is allowed by state law without a permit.[130] Of the bears collared and monitored by ADF&G, about 23% were culled.[132] In a typical year, brown bear harvest is limited to a maximum of 16 and had previously never exceeded 22.[132]

Also encompass suitable winter habitat 2020 were female (and if their cubs are very young, they are usually killed as well), which raises concerns about whether or not the population will be able to recover.[132] These environmental conditions have been exacerbated by climate change, which will continue to negatively impact the abundance of brown bear food sources.[131] Hungry bears are less likely to hibernate and if they do, retreat to their dens much later, and an increasing number of brown bear conflicts during winter have been reported in recent years.[131] If logging and mining activities in the area remove highly suitable brown bear habitat and/or reduce their access to remaining food sources, conflicts could continue to rise with potentially devastating ramifications for the local brown bear population. Therefore, the identification of suitable habitat and movement corridors between them will inform land managers looking to manage the wildlife impacts of extractive activities in these areas.

Data

Table 3. Data Types and Sources. This table depicts the data used for both our determination of core areas and creation of our resistance raster.

Data Type	
Determination of Core Areas	**Resistance Raster**
Haines State Forest Ownership, State of AK, 2021	USGS 5m DEM, 2022
USFS Tree Canopy Cover, 2011	Land Cover Resistance Values from the Washington Statewide Habitat Connectivity Working Group (2010) and Lewis et al., 2015
ADF&G Anadromous Waters Catalog, 2022	USGS National Land Cover Database, 2018
	USFWS National Wetlands Inventory, 2019

As stated prior, the Greater Chilkat Watershed is a relatively data-poor area due to geographic and seasonal inaccessibility and minimal resources for data collection. As such, this analysis relies on data provided by primarily federal agencies: USGS's National Land Cover database, USFWS's National Wetlands inventory, USGS's 5m DEM for the state of Alaska, USFS's Tree canopy cover data (2011), and ADF&G's Anadromous Waters Catalog. The Haines State Forest's GIS database and management schedule were also used to identify planned and potential harvest areas for analysis comparison. Additionally, we used resistance land cover values identified in the Washington Connected Landscapes Project Statewide analysis. Further information on the data used can be found in Table A-14.

Methods

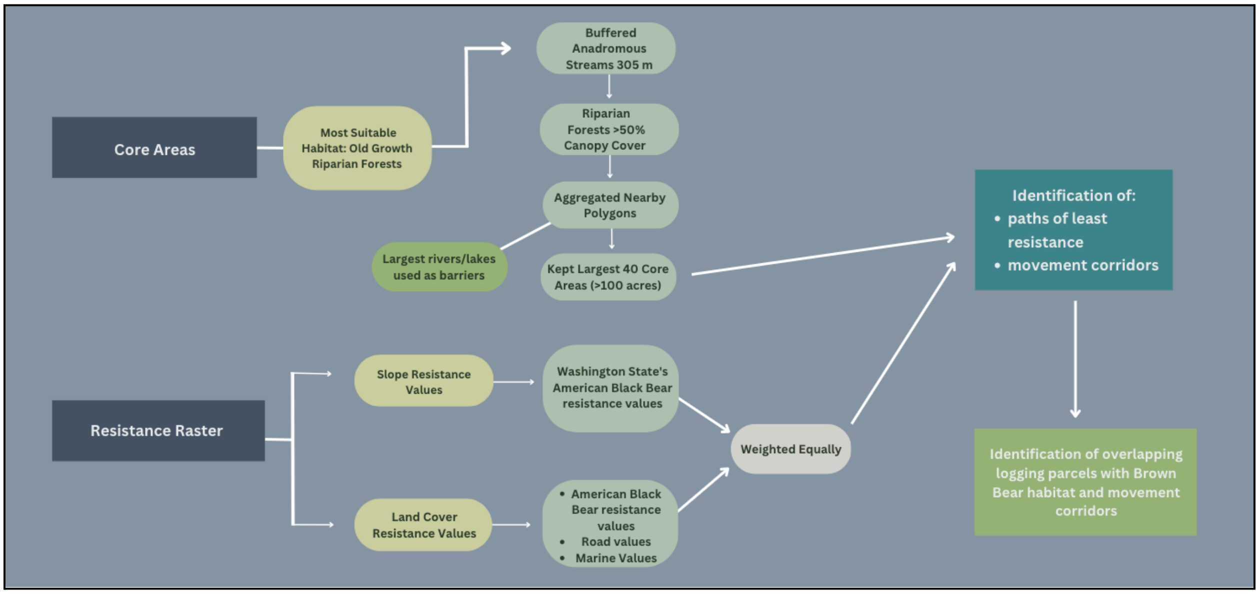

Figure 17. Methods for brown bear Linkage Mapper analysis: Methods for creation of core areas and the resistance raster that were used in the Linkage Mapper toolkit in ArcGIS Pro.

Determination of core areas

Core areas of brown bear habitat in the region were identified after a literature review determined that old-growth riparian forest is the most suitable habitat for the species.[90] Per Flynn et al. (2007), in the absence of complete watershed protection, no-cut stream buffers of a minimum of 305 m (1000 ft) are required to support healthy brown bear populations.[133] Therefore, we buffered anadromous streams within the Haines State Forest by 1,000 ft to isolate this important riparian habitat.

Due to a lack of data identifying old-growth parcels within the HSF, riparian forests with greater than 50% canopy cover were found to be an acceptable proxy for riparian old-growth forest.[90] Canopy cover data from the National Land Cover Database/U.S. Forest Service (2011) was filtered to identify 30 m pixels with canopy cover greater than 50%.[134] The intersect tool was used to find the areas of riparian habitat that also have a canopy cover of 50% or more. The resulting polygons were used in our analysis to represent old-growth riparian.

Nearby polygons were combined using the aggregate polygons tool with the following parameters: a 400 m aggregation distance, minimum area of 0, and a minimum hole size of 1,000,000 square meters to prevent the retention of holes in core areas. Per our literature review, we did this purposefully to retain polygons in low-lying riparian areas. Additionally, an anadromous stream layer was filtered to retain the largest freshwater rivers and lakes of the HSF relevant to our study – the *Jilkaat* (Chilkat river), *Gathéeni* (Tsirku), and *L'ehéeni* (Klehini) Rivers, and Chilkat Lake. This layer was used as a barrier to aggregation to prevent core areas from combining across these freshwater expanses. After aggregation, the 40 largest polygons with an area over 100 acres each were filtered and retained for use as core areas in our Linkage Mapper analysis.

Creation of resistance raster

The resistance raster for *xóots* (brown bears) was created based on slope angle and land cover resistance values from the Washington Connected Landscapes Project Statewide Analysis as well as Lewis et al., 2015.[135,136] Resistance values for American black bears were used as a proxy for coastal *xóots* (brown bears) as no relevant species-specific literature could be identified. We use the spatial analyst 'slope' tool to calculate slope angles of the landscape from our Digital Elevation Model (DEM). Our DEM came from USGS's State of Alaska DEM at 5-meter resolution; it was resampled to 30 x 30-meter resolution to match our land cover layers. A value of 1 was added to all resistance values as a value of 0 cannot be used in Linkage Mapper. The calculated slopes were then reclassified with resistance values per Table A-12.

A resistance raster based on land cover classifications was created to use in tandem with our slope resistance raster. Land cover resistance values from the Washington Connected Landscapes Project Statewide Analysis[120] (Tables A-13 & A-14) and Lewis et al., 2015[136] were applied by reclassification of land cover data from USGS's National Land Cover Database (NLCD). Buffered roads in the GCW were assigned resistance values based on secondary highways as provided in the Washington Connected Landscapes Project Statewide Analysis.[120] In Lewis et al. (2015), marine and ice were identified as complete barriers to brown bear movement and thus have a very high resistance value.[136] Therefore, this land cover category was assigned a resistance value of 1001. As the NLCD land cover layer did not identify marine and ice, we used the mosaic operator tool to combine our NLCD land cover raster with a land cover raster from US Fish and Wildlife Services' (USFWS) National Wetlands Inventory Data (NWID). Using this tool, we pulled NWID's marine and ice layer values and overlapped them with our NLCD values.

Finally, we combined our land cover and slope resistance rasters, weighted equally at 50% each, using the weighted overlay tool. This final resistance raster was used as an input layer in our Linkage Mapper analysis.

Identification and creation of planned and potential harvest polygons

Previously identified planned and potential harvest polygons were used in this analysis. See the mountain goat methods section for details.

Linkage Mapper Toolkit analysis

After the creation of our core area and final resistance layer, we used the Linkage Mapper toolkit to run analyses.[60] Results of the Build Networks and Map Linkages (or "Linkage Pathways") tool identified likely movement corridors and least-cost paths (LCPs) between core areas using the Circuitscape algorithm. We utilized a 20 km truncated corridor width in our parameters, as this value was used in a study on grizzly bear habitat connectivity near the Washington-Idaho-Montana border with British Columbia.[137]

LCPs were ranked by quality according to two metrics – the cost-weighted distance (CWD) to Euclidean distance ratio and the CWD to LCP length ratio.[120] Methods associated with the CWD to Euclidean distance and CWD to LCP length ratio can be found in the mountain goat analysis within the methods section. Locations of LCPs and corridors were compared to planned and potential harvest areas, and areas of overlap were noted for further analysis.

Pinchpoint Mapper identified pinch points, narrow areas where movement is likely to be funneled, within corridors using Circuitscape. Centrality Mapper results determined core area and LCP centrality within the network produced by the Linkage Pathways tool.

Comparison of core areas to planned and potential harvest areas

The core areas were clipped by the planned and potential harvest polygons to identify areas of highly suitable brown bear habitat that either will be harvested between now and 2026 or are highly stocked and may be considered for harvest in the future.

Results

We identified 40 core areas of highly suitable brown bear habitat within the Haines State Forest that were used in our Linkage Mapper toolkit analysis. Linkage Mapper results display least cost paths (LCPs) and corridors of brown bear movement between core areas. Initial visualization of watershed-wide results indicates that there are multiple LCPs and corridors that are actively threatened by planned or potential clear-cuts in the Haines State Forest (Figure 18).

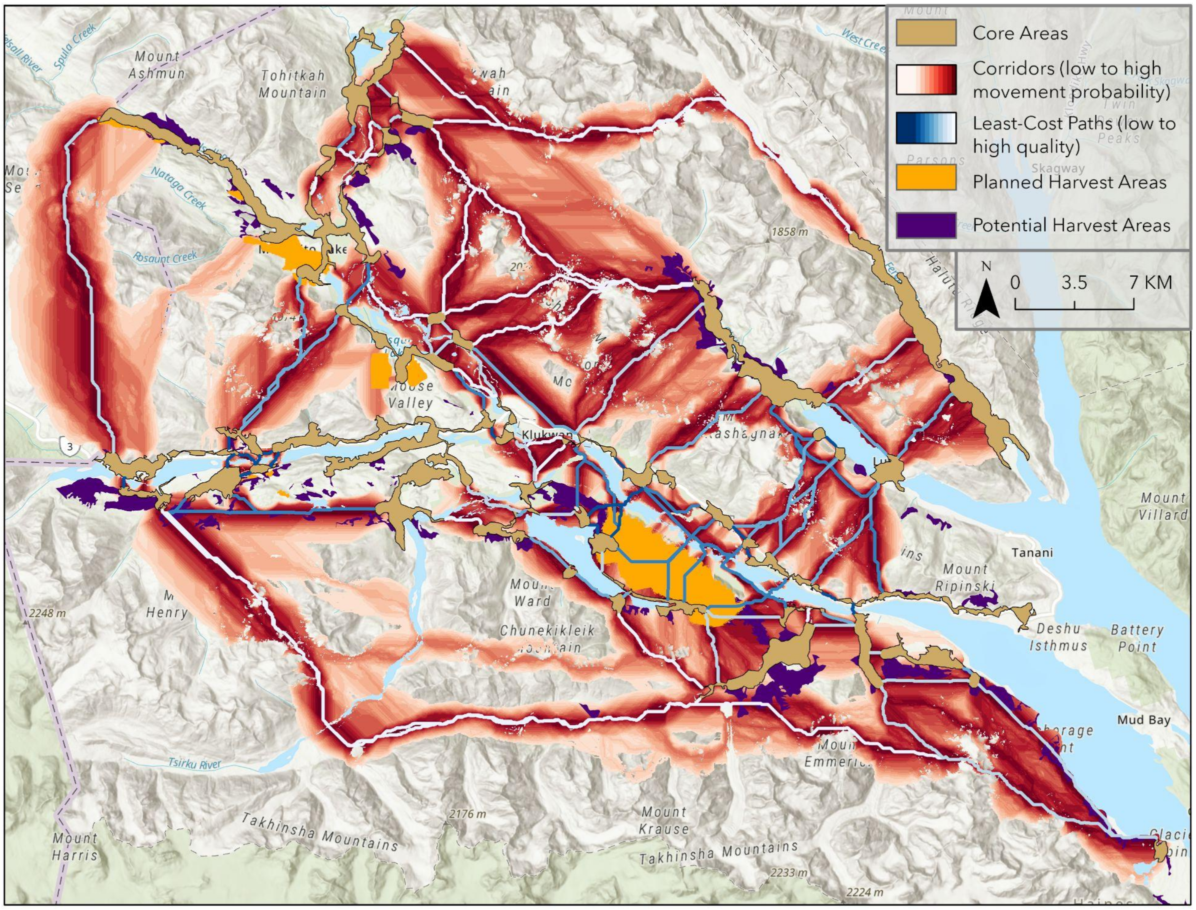

Figure 18. Greater Chilkat Watershed overview with Linkage Mapper results. An overview of the study's region of interest shows the core areas of brown bear habitat, as well as corridors of modeled brown bear movement, least-cost paths, and planned and potential harvest areas.

Further analysis reveals two noteworthy areas where core habitat for *xóots* (brown bears) and LCPs occur in planned or potential harvest areas in the Haines State Forest. Figure 19 details (A) the Chilkat Ridge harvest which will clear-cut approximately 1,000 acres of forest, including portions of multiple core areas for of brown bear habitat and some important LCPs connecting the area around Chilkat Lake to other riparian habitats, and (B) the overlap of the Kelsall Pocket and 100CW planned harvest areas with multiple brown bear habitat polygons. Also visualized in this figure is a large number of potential harvest areas ('highly-stocked stands') intersecting LCPs and/or corridors identified by Linkage Mapper, and a complete list of these parcels can be found in Table A-15.

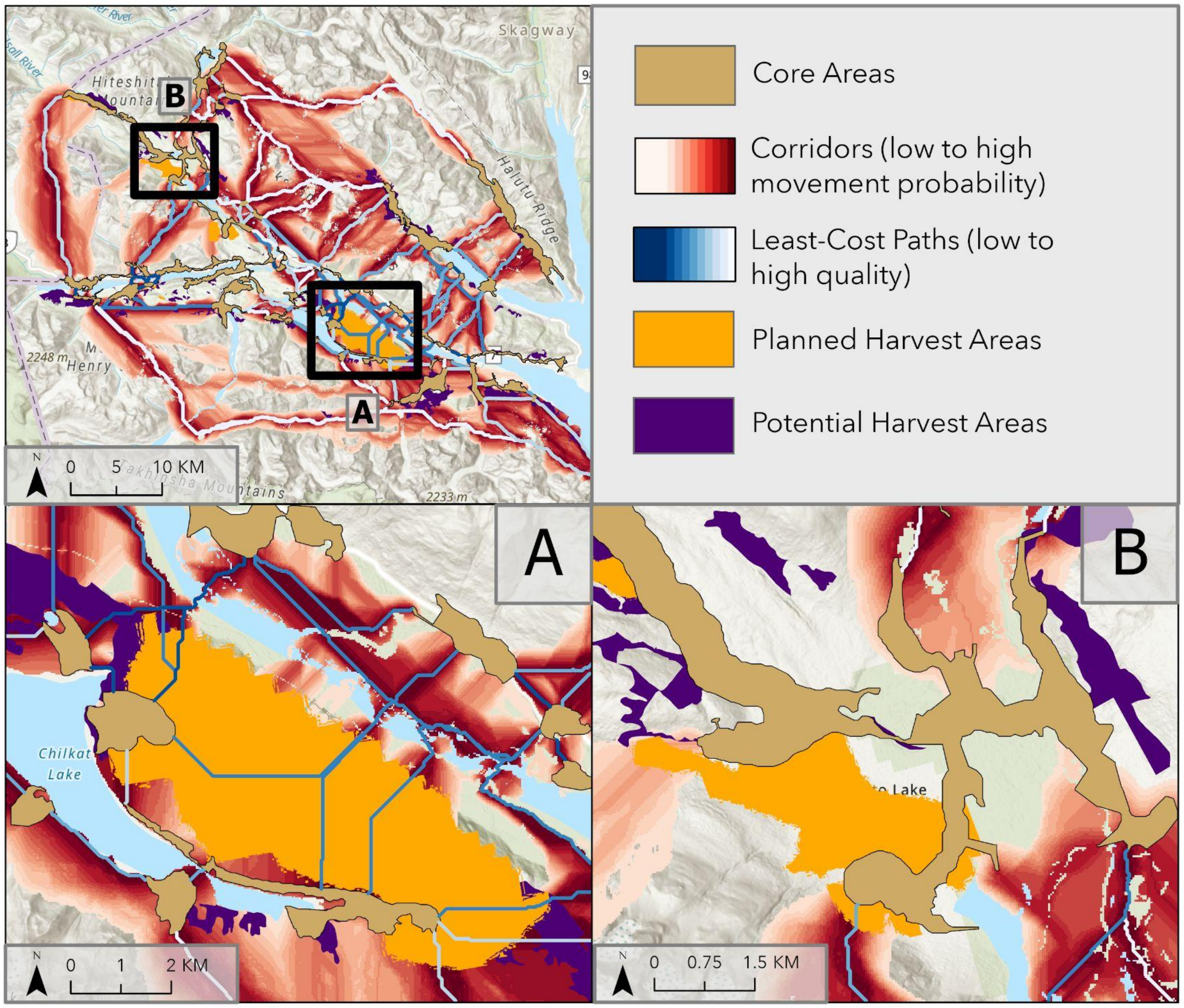

Figure 19A-B. Chilkat Ridge and Kelsall insets. Map A shows the Chilkat Ridge clear-cuts (2024 & 2026) which comprise 1,000+ acres of forestland that includes core habitat and several least-cost paths. Map B shows the Kelsall Pocket and 100CW harvests slated to begin in 2023 and extend through 2025

A pinch point analysis revealed significant constriction of current flow within numerous brown bear movement corridors in the GCW. As illustrated in Figure 20, connectivity appears especially constricted in the riparian areas bordering the *Jilkaat Heeni* (Chilkat River), the corridors along the Ferebee and Takhin Rivers, along the shores of Chilkoot Lake, and areas north and south of Mosquito Lake. Special attention should be given to these areas to prevent habitat alterations that could reduce or eliminate the ability of *xóots* (brown bears) to move successfully through them. Notably, two pinch points are located within the Chilkat Ridge planned harvest areas. Additional potential harvest areas containing pinch points are listed in Table A-16.

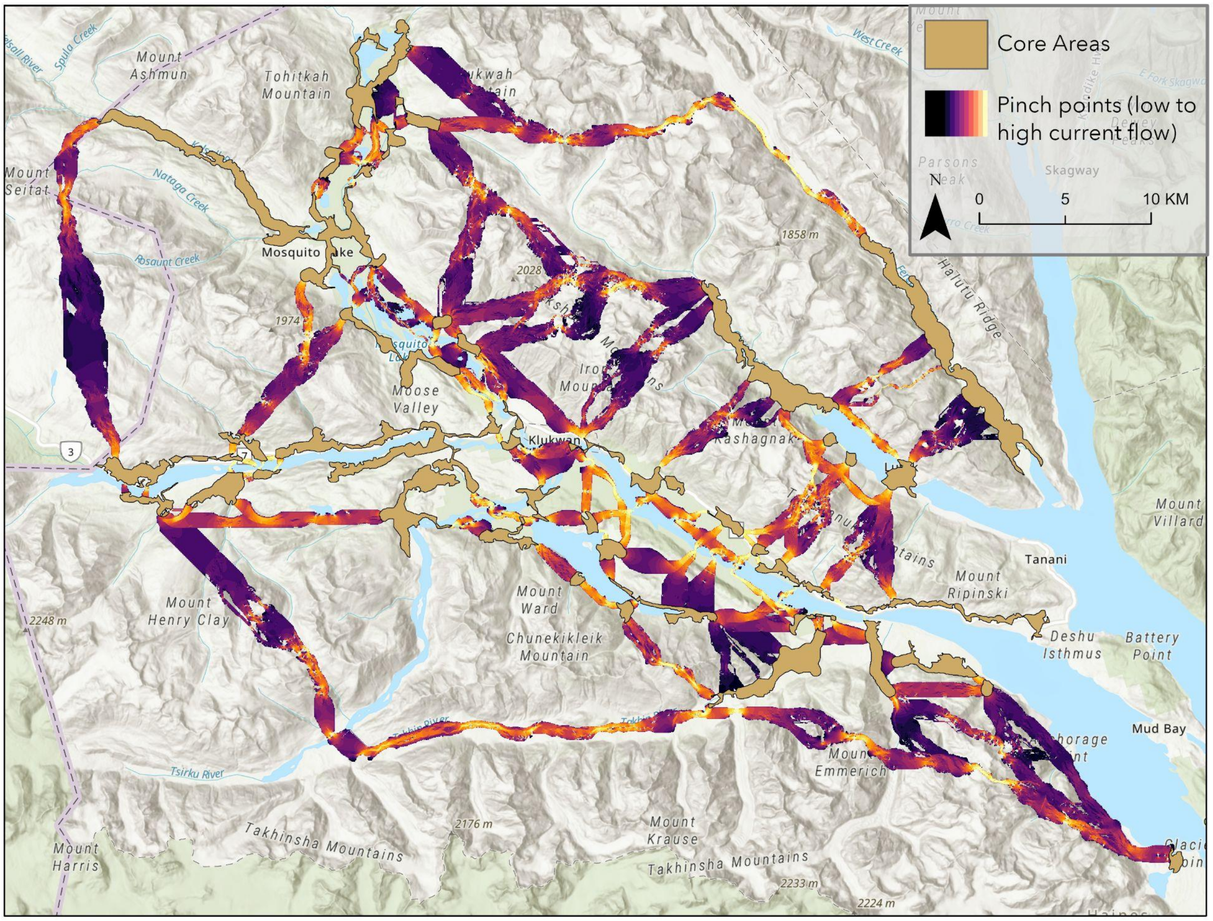

Figure 20. Pinch points to brown bear movement within corridors. Many modeled corridors contain pinch points, indicating that there are numerous narrow regions (yellow) through which bear movement is likely to be funneled, making connectivity tenuous. A loss of area within one of these pinch points could have serious ramifications for connectivity between core areas. Pinch points appear especially plentiful in the riparian areas bordering the *Jilkaat Heeni* (Chilkat River), the corridors along the Ferebee and Takhin Rivers, along the shores of Chilkoot Lake, and areas north and south of Mosquito Lake.

Results of the Centrality Mapper tool (Figure 21) demonstrate the core areas and LCPs that are most "central," meaning that they are most important for keeping the entire network connected. Among core habitats, areas along the eastern *L'ehéeni* (Klehini) River, *Yéil Héeni* (Kelsall River), and upstream of Chilkoot Lake, are the most critical for ensuring connectivity across the metapopulation. A majority of the most central LCPs are located around Mosquito Lake, Chilkat Lake, and the area surrounding *Tlákw.aan* (Klukwan) at the confluence of the Chilkat and *L'ehéeni* (Klehini) Rivers.

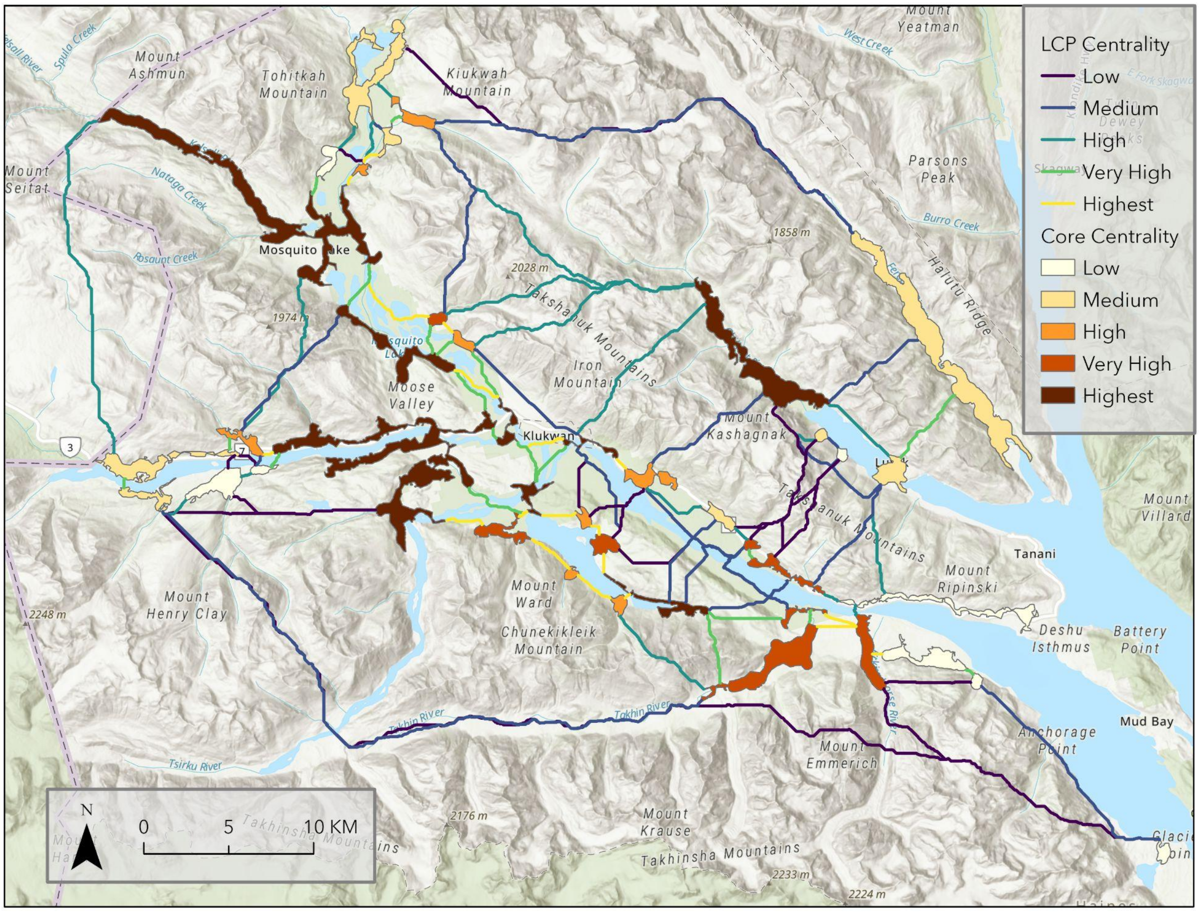

Figure 21. Core and LCP centrality. Core areas are visualized to reflect the results of the centrality analysis, with brown areas signifying the highest centrality and light orange indicating low centrality within the network produced from Linkage Mapper. Similarly, LCPs are symbolized to represent centrality, with yellow representing the highest centrality and dark purple as low centrality.

Finally, a spatial overlap of planned and potential harvest areas with core areas found that the planned Single 15 (2025) and Turn Around (2026) harvests would remove approximately 360 acres of bear habitat along the Kelsall River. Additionally, the Chilkat Ridge (2024 & 2026) and Kelsall Pocket/100CW (2023 & 2024) cuts would remove almost 300 acres of highly suitable habitat each. A complete list of the potential harvests areas that would remove important brown bear habitat can found in Table A-17.

Discussion

Our results demonstrate that multiple planned and potential harvest areas are within or near areas of brown bear core habitat, LCPs, movement corridors, and/or pinch points. These findings have conservation implications for brown bears in the GCW.

Habitat

Riparian, old growth forest habitat that is threatened by harvesting activities in the Haines State Forest is used extensively by *xóots* (brown bears) for foraging, cover, and denning.[90] Studies have shown that bears in *Lingít Aaní* (Southeast Alaska) very rarely use clear-cuts for these fundamental behaviors, and even avoid post-harvest successional stands ranging from 25-100 years in age class because of the poor forage associated with less-intact understories.[90] While natural forest clearings are attractive foraging areas for *xóots* (brown bears), clear-cut scars do not have the same appeal.[138]

Researchers in *Lingít Aaní* (Southeast Alaska) recommend avoiding logging within 300 meters of areas of brown bear habitat for this reason,[133] but the Haines State Forest only uses a 100 meter buffer.[139] A large buffer offers important cover for female bears with cubs foraging in this area.[133] Unrestricted access to spawning salmon is essential to the maintenance of healthy and productive brown bear populations.[133] If bear access to salmon is further restricted in the HSF by clear-cutting near anadromous streams, managers could expect to see an increase in conflict between male and female bears for limited resources, a decrease in reproductive rates and cub survival, and a subsequent increase in overall mortality rate for the population.[133] Beyond the population impacts, a reduction in bear density would have ramifications for the surrounding environment as bears are central to healthy ecosystem functioning in this region. Therefore, we recommend that HSF managers update their regulations to increase buffers around anadromous streams to better preserve this critical habitat for brown bears.

Connectivity

Clear-cutting activities also have significant impacts upon brown bear dispersal and habitat connectivity. One study of brown bear dispersal that tracked individual movement found that the species is least likely to travel in clear-cuts and young forests.[90] The significant planned construction and maintenance of logging roads required for timber harvests also creates disturbances while implementing permanent barriers to brown bear dispersal.[127] Dispersal impacts from timber harvests can be mitigated when less timber is harvested in a given area and/or newly constructed roads are closed to recreational uses after harvest activities are completed.[140] These findings all indicate that selective cutting and/or other, less impactful harvesting methods may be of benefit to regional brown bear population connectivity in the GCW and should be considered by HSF management.

We also encourage the consideration of our results in light of planned and potential harvest activities to avoid the alteration of corridors between habitat patches that are necessary to maintain gene flow, access to salmon resources, and the connectivity of the network at large. Forested areas with low human alteration are crucial for maintaining brown bear habitat and connectivity[121], and these areas should be targeted for conservation actions in the HSF and GCW.

Human-wildlife conflicts

Increased densities of regional logging roads as planned by the Haines States Forest will increase the potential for human-wildlife conflicts. In 2020, conflicts spurred by poor salmon and berry harvests led to law enforcement and residents killing at least 30 brown bears.[130,132,131] Harvest activities alone increase human-bear conflict and push the species to travel in search of other habitat, with additional effects from logging roads creating additional recreational access to bear habitat.[138] Additionally, the impacts of mining on brown bear populations and behavior are similarly negative, with mineral extraction and its associated activities impacting access to forage, salmon populations, decreasing denning habitat, and displacing bears.[44] Mining activities and associated infrastructure typically increase human-bear conflict.[141] As brown bear habitat is increasingly threatened by logging and mining, conflict between brown bears humans will likely increase[138,142] unless concerted efforts are made to conserve and increase access to habitat with plentiful resources.

Limitations and next steps

Our study used resistance values for American black bears, as these were the most comprehensive values available. However, our results would be improved with the incorporation of resistance values for coastal brown bears in Alaska. Additionally, more information on brown bear behavior in relation to harvest activities in Alaska would help us assess the impacts of varying forest management and harvest plan iterations. Performing a sensitivity analysis of our model parameters could help yield greater specificity in our outputs by guiding the refinement of our model.

An extension of our analysis should seek spatial data of brown bear-human conflict in the GCW. These locations could be analyzed alongside our connectivity results for further prioritization of areas in need of conservation. Finally, incorporating ADF&G’s Resource Selection Function for *xóots* (brown bears), once published, would facilitate more specific and accurate identification of core areas while also providing information on the biotic and abiotic features most significant in determining brown bear distributions.

Conclusion

Results of our analyses demonstrate the negative potential effects of HSF harvest activities on brown bear populations in the GCW. Several state forest parcels planned for harvest or that may potentially be harvested overlap with highly suitable areas of brown bear habitat and/or connectivity. The most significant of these activities is the aforementioned Chilkat Ridge cut. Additionally, other important areas for habitat connectivity are identified, including pinch points and LCPs that should be prioritized for conservation to benefit this species. We recommend that the Haines State Forest, the Bureau of Land Management, the University of Alaska, and other area land managers consider these specific areas for conservation, given their importance to brown bears. Conservation in this region could take the form of conservation easements or participation in carbon markets that may help the state and community recuperate economic losses from the cessation of clear-cut logging in areas identified by this study.

4. Economic Value of Carbon Sequestration

Introduction

Concerns over rising carbon dioxide levels have led to the establishment of carbon markets across the globe.[143] For forest managers, the determination of carbon storage values and annual carbon sequestration rates is key to participating in a carbon credit market.[143] The process of trees removing carbon dioxide from the atmosphere and storing it as carbon is called sequestration. This carbon can be stored aboveground (trunk, branches, leaves), belowground (roots), within the soil, or as dead organic material (i.e., snags).[144] When land cover is altered, such as during forest harvests, the carbon stored in these areas is largely released back into the atmosphere - accounting for one of the largest contributors to atmospheric CO_2.[145]

One ton of sequestered carbon is equivalent to one credit within a US carbon market.[146] A carbon credit represents a certain amount of sequestered carbon within a given year. An entity will often purchase carbon credits as a means of offsetting its annual carbon emissions and lowering its net carbon footprint.[146] The annual amount of carbon sequestered (in US tons) is the aspect of the carbon cycle that can be monetized and sold as a carbon credit.

As a land grant university, the University of Alaska (UA) is tasked with managing its current land for revenue streams that will support students through scholarships and funding.[147] Historically, university lands have earned revenue from timber sales, mining, real estate, and other miscellaneous activities.[148] In the Greater Chilkat Watershed, the University of Alaska's Land Management (UALM) department owns 5,309 hectares of forestland and there is increasing interest in a carbon credit program.[149] In a December 2022 press release, UALM released a public notice about the potential launch of a statewide carbon credit program.[150] 58% of UALM's land in the GCW are candidates for this potential carbon credit program.[149] Table A-19 identifies the parcel name and area that UA has identified for this potential carbon credit program within the Chilkat Valley.

Additionally, the Haines State Forest is planning to harvest approximately 1,012 hectares in the next five years.[139] Approximately 8,000 more hectares of high-stocked stands may be harvested in the next several decades (see mountain goat analysis).[151] Salmon, bear, and mountain goat analyses outputs are overlapped with these confirmed and potential harvest areas within the Haines State Forest. To supplement these analyses, we examine the non-timber economic values of a carbon credit program for these potential harvest parcels. Modeling carbon storage and carbon sequestration on these forestlands may guide the Haines State Forest and the University of Alaska alternatives to clear-cutting.

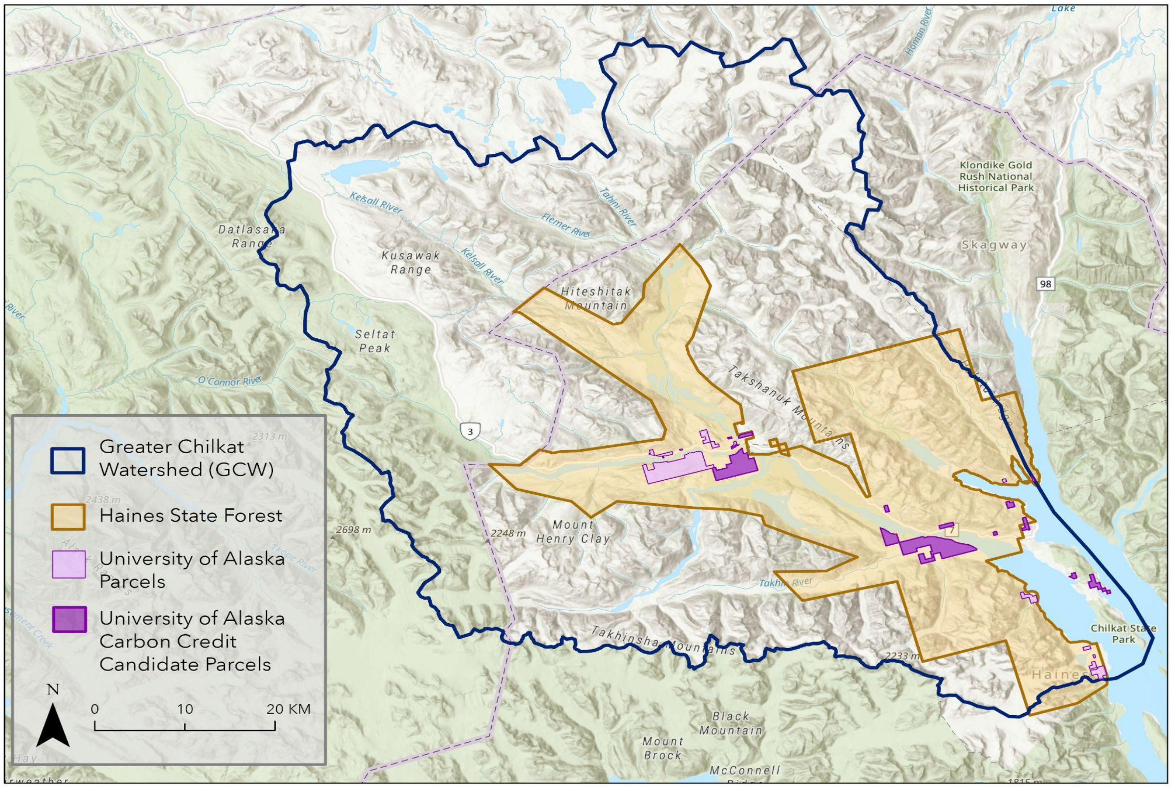

Figure 22. Region of Interest for carbon storage and sequestration analyses. This map shows the parcels owned and managed by the University of Alaska in the Haines State forest (light purple), while also highlighting the parcels that the University of Alaska's Land Management has selected for its carbon program within both the Haines State Forest and the Greater Chilkat Watershed (purple). Data Source: Alaska GIS Portal and Lynn Canal Conservation.

Data

As previously discussed, Alaska (and more specifically, the GCW) is a data-limited region. Accordingly, these carbon analyses rely on wide-scale data provided by federal governments and academic institutions. Data were collected from the United States Geological Survey (USGS), Natural Resources Canada (NRCan), Commission for Environmental Cooperation's (CEC) North American Land Cover Monitoring System (NALCMS), the Oak Ridge National Laboratory, and EnvirometriX Ltd. Additionally, boundary shapefiles of the University of Alaska's Land Management parcels, the Haines State Forest, the Haines State Forest highly stocked stands, and the Greater Chilkat Watershed were all provided by Lynn Canal Conservation and the State of Alaska Open Data Geoportal.

Table 4. Data types and sources. This table showcases the data used in calculating the amount of carbon stored and sequestered within four key study areas. Further details can be found in Table A-18.

Data Type		
Carbon Rasters	**Land Use/Land Cover (LULC)**	**Boundary Files**
ORNL Aboveground Biomass 272m, 2020	NALCMS 2010 Land Cover 30m, 2020	Greater Chilkat Watershed
ORNL Belowground Biomass 272m, 2020		Haines State Forest
EnvirometriX Ltd Soil Organic Carbon Stock 250m, 2018	NALCMS 2015 Land Cover 30m, 2020	University of Alaska owned Parcels
		State of Alaska Division of Forestry Forest Inventory (Highly Stocked Stands)

Methods

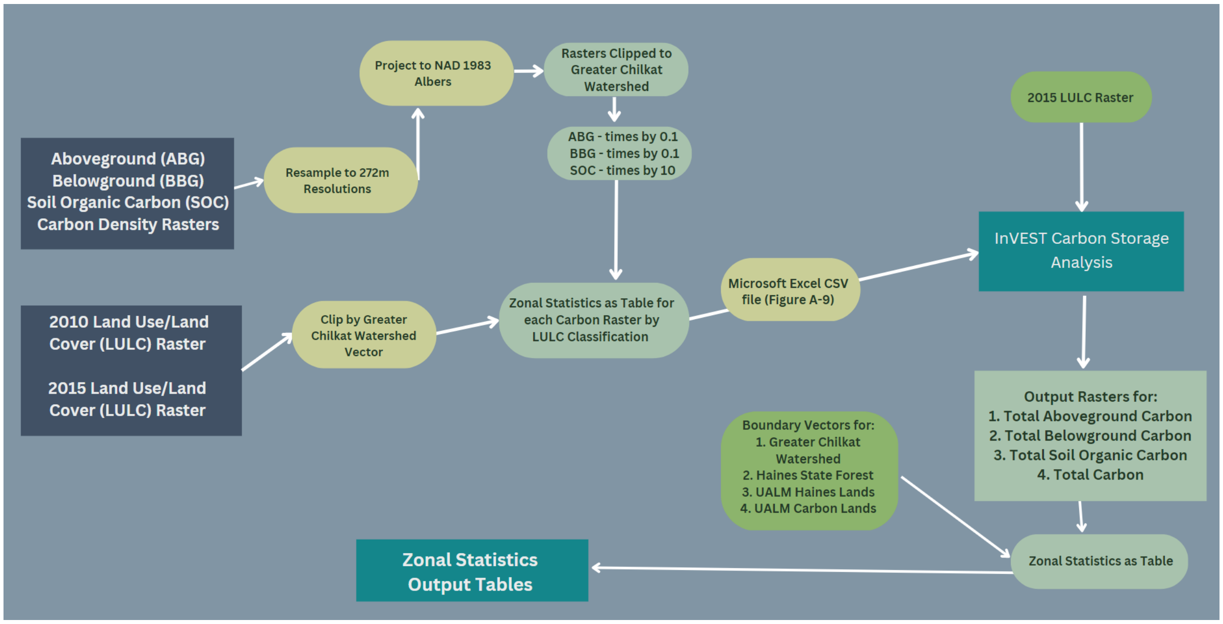

Figure 23. Methods for carbon storage InVEST analysis. Methods for calculating the total amount of stored carbon within the Greater Chilkat Watershed, Haines State Forest, Haines State Forest highly stocked stands, the University of Alaska Haines Lands within the GCW, and University of Alaska Carbon Credit Lands using ArcGIS Pro and InVEST to aggregate carbon storage results. Aboveground (Mg C), belowground (Mg C), and soil organic carbon (Mg C) were calculated separately, InVEST aggregated all results into a Total Carbon raster (Mg C).

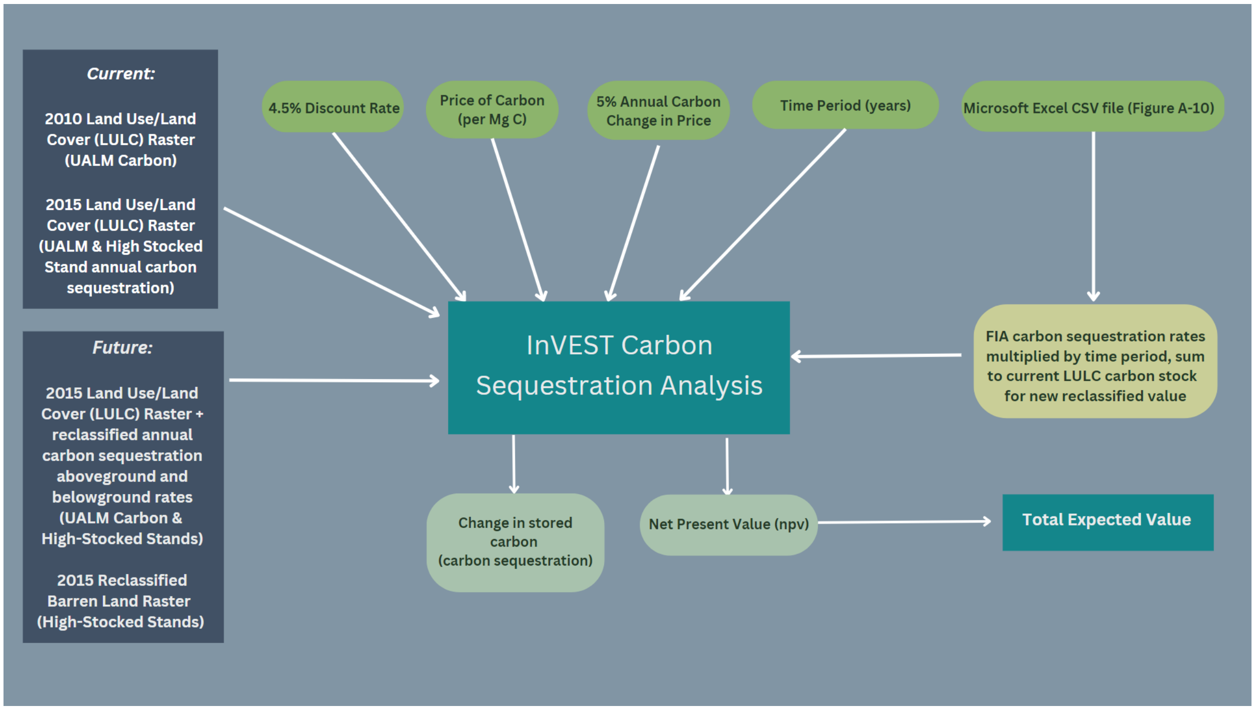

Figure 24. Methods for carbon sequestration InVEST analysis. Methods for calculating the total amount of annual carbon sequestration (Mg C), total release of carbon due to clear-cutting (Mg C), net present value ($), and total expected value ($) for the University of Alaska carbon credit candidate parcels and the Haines State Forest highly stocked stands using ArcGIS Pro and InVEST to aggregate carbon storage and calculating change in carbon results from two different land cover (LULC) rasters, “current” and “future”. Total expected value was calculated from modeled net present value.

Calculating baseline carbon storage values

All land use/land cover (LULC) and carbon density rasters were projected and resampled to a uniform 272m resolution in a NAD 1983 Albers projection. The aboveground and belowground carbon biomass rasters were then divided by 10 as the authors of this data had reduced the scale size for downloading purposes.[149] The soil organic carbon raster was converted from kg C/m^2 to Mg C/ha. Using zonal statistics, LULC raster files were tabulated to calculate organic carbon per hectare for each land cover class for each of the three carbon storage rasters within the Greater Chilkat Watershed (Table A-20). The mean values of carbon (Mg C/ha) from each LULC class were compiled into a reference comma-separated values (CSV) table for InVEST processing. The carbon pool CSV table was entered into InVEST, alongside a clipped 2015 LULC raster. The InVEST model applies the four carbon stocks to the land cover map and summarizes these results into raster outputs of total storage.[64] While computing these results, InVEST changes the carbon storage units from megagram per hectare (Mg C/ha) to megagrams of carbon (Mg C) by converting the area of each pixel (in square meters) to hectares and then multiplying by the aggregated carbon stock value to achieve megagrams of carbon per pixel (Figure 25). Then, the five study areas were overlaid on the total carbon raster and an output attribute table was created with the total area of each study area and the value of each study area's carbon pool (Table 5).

Calculating carbon sequestration rates for the University of Alaska and Haines State Forest High Stocked Stand parcels

InVEST models carbon sequestration based on changes in LULC and carbon storage over a set time frame.[64] The InVEST model applies the four carbon stocks to the "current" land cover map and summarizes these results against the "future" land cover map and calculates total sequestration, change in carbon storage values, and net present value.[64] While calculating these outputs, InVEST changes the carbon storage and sequestration units from megagrams of carbon per hectare to megagrams of carbon. The carbon storage methods detailed above were repeated to calculate the total amount of aboveground, belowground, and soil organic carbon after a year of carbon sequestration. To achieve this, annual carbon sequestration values from "Timberland at 5-inch DBH aboveground and belowground annual net carbon growth" averages from the Chugach National Forest were provided using the Forest Inventory Analysis (FIA) database.[152] These FIA carbon sequestration values were multiplied by the defined time period and then summed to the original land cover average values. These new values were given a new land cover classification (Table A-21). InVEST then calculated the difference in carbon between the normal and newly reclassified rasters, classifying this change as carbon sequestration over a defined period of time.

To calculate the net present values of carbon sequestration, InVEST requires the monetary value of carbon sequestration, a discount rate, and an annual change in the carbon price. The California Air Resources Board's (CARB) value for carbon was chosen for this model as CARB is one of the leading institutions in developing a carbon marketplace.[153] Currently, CARB has set Tier 1 emissions of carbon as $51.92 per US ton.[154] This value was converted to metric tons for a price of $47.10 per metric ton (or megagram). Based on British Columbia's Ministry of Forests, Washington State's Department of Natural Resources, and a forestry discount rate economic article, the discount rate mean of these three reports of 4.5% was selected for this analysis.[155–157] A value of 5% was used for the annual change of carbon's value based on section 95913(h)(5) of CARB's Cap-and-Trade Regulation document.[158] The model output produced a raster of net present values for carbon sequestration on the University of Alaska forest parcels. Additionally, InVEST outputs include the current and future carbon stocks and the change in these carbon stocks over the defined period.

To model the annual revenue of carbon sequestration based on the price of carbon for both the University of Alaska and the Haines State Forest high stocked stands, the 2015 LULC raster file was used for both the current and future land cover in InVEST. The annual carbon sequestration values for both aboveground and belowground were added to the current CSV carbon pool to model one year of carbon sequestration. The rasters, carbon pool CSV, discount rate, annual change of carbon, and the price of carbon per megagram were inputted into InVEST. The output produced the net present value which was converted to total estimated annual profit.

To determine the current total carbon sequestration value of the University of Alaska's parcels, the 2010 LULC raster file was used as the current raster for InVEST. The updated 2015 raster was used as the future and the FIA annual carbon sequestration values were multiplied by 13 and summed with the original LULC values for aboveground and belowground and added to the new land cover classifications to represent carbon sequestration of intact forestlands. InVEST produced a net present value which was then converted to total value.

To analyze how much carbon would be released if these highly stocked parcels in the Haines State Forest were clear-cut, the 2015 LULC raster was reclassified from a forested to a barren classification. Starting with the current condition of these parcels, with discount rate at 4.5%, the cost of carbon at $47.10, and the annual change of carbon at 5%, the time period was set to a 100-year standard rotation of the Haines State Forest.[159]

Results

Carbon storage

The results of this analysis yielded total aboveground biomass, belowground biomass, and soil organic carbon pool values for the entire Greater Chilkat Watershed, including the Haines State Forest, Haines State Forest High Stocked Stands, all UALM lands within the GCW, and the UALM parcels that are candidates for a carbon credit program (Table 5). The largest concentration of carbon within the watershed was modeled to be 1,608 Mg C with the lowest being 0 Mg C. This 0 value was due to the land classifications of water and urban development being assigned zeros for the carbon stock pool file (Table A-20, Figure 25). Figures showing amounts of stored carbon for aboveground, belowground, and soil organic carbon values can be found in the appendix (Tables A-20, A-21, A-22).

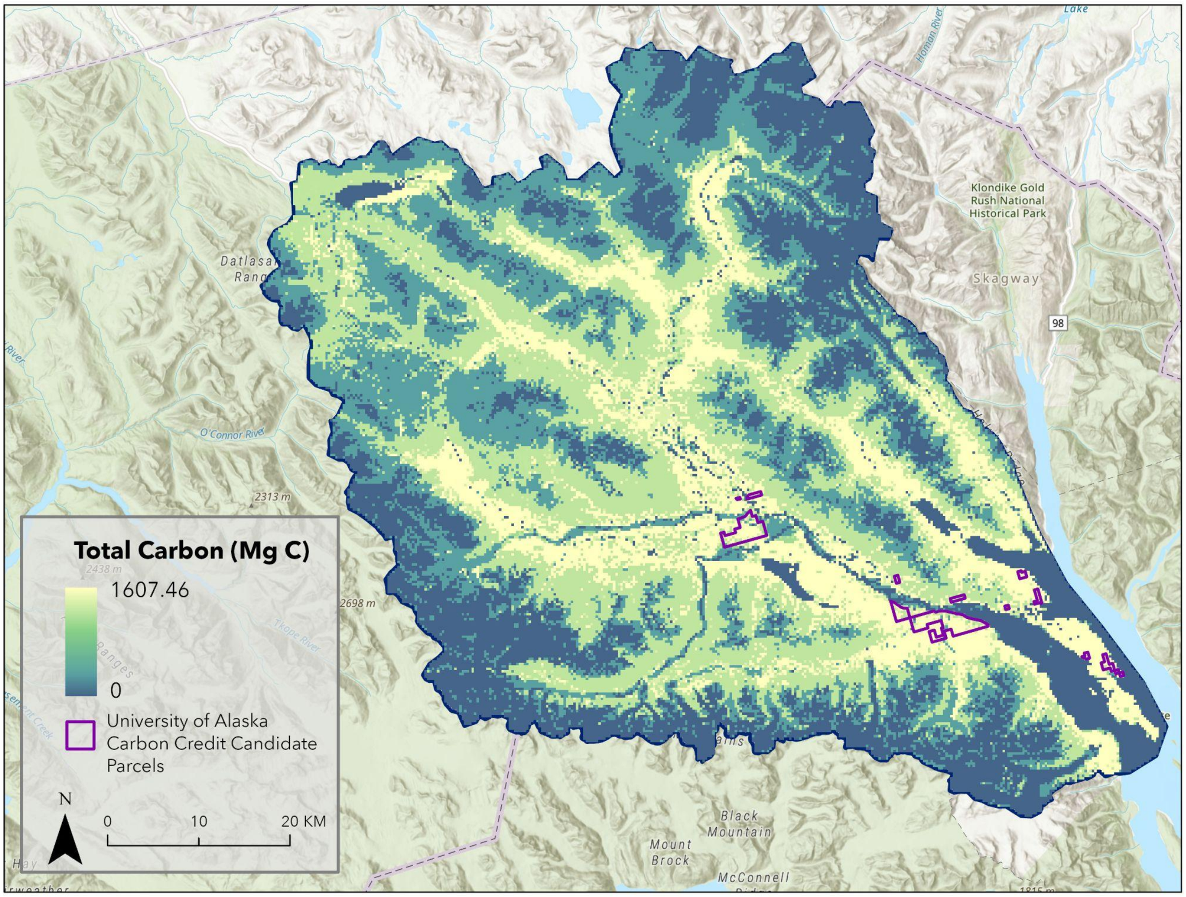

Figure 25. The total amount of stored carbon within the Greater Chilkat Watershed. The total amount of carbon (aboveground, belowground, and soil organic carbon) throughout the Greater Chilkat Watershed. The University of Alaska's Carbon Credit candidate parcels are outlined in purple.

Table 5. Carbon storage totals by study region. Summary of total aboveground, belowground, and soil organic carbon density pools for 2015 by study region.

Land Boundary	Total Area of Study Region (hectares)	Sum of Total Carbon Density Pool (Mg C)	Mean Total Carbon (Mg C/ha)
Greater Chilkat Watershed	489,249	53,823,329	110.01
Haines State Forest	133,812	19,554,585	146.13
Haines State Forest Highly Stocked Stands	7,990	2,434,697	304.72
All UALM GCW parcels	5,308	1,178,715	222.06
UALM Carbon Credit Parcels	3,090	683,929	221.34

Carbon sequestration and economic value of University of Alaska carbon parcels

The total modeled 2010 net present value for the proposed University of Alaska Carbon Credit Lands, was $1,594,627.[64,152,154] This npv converted to total value of these candidate parcels in 2023 is estimated to be $2,825,991. Over those 13 years, the InVEST model estimated that 34,049 Mg C was sequestered on UALM carbon credit candidate parcels (Table 6). Additionally, InVEST modeled that these UALM candidate parcels sequester 1,784 Mg C annually with a total predicted annual profit in 2023 of $87,864 (Table 7).

Table 6. University of Alaska InVEST analysis findings. Summary of the total value for the University of Alaska carbon credit candidate lands from InVEST 3.12.1 modeling for 2010-2023.

UALM Carbon Credit Parcels	California Air Resources Board Tier (per Mg C)	Total Area of Study Region (hectares)	Total Carbon Sequestration Value 2010-2023 (USD)	Mean Carbon Sequestration Value 2010-2023 ($/hectare)	Total Current Carbon (Mg C)	Total Future Carbon (Mg C)	Carbon Change (Mg C)
	$47.10	3,090	$2,825,991	$914.56	661,790	695,840	34,049

Table 7. InVEST results for annual economic value of carbon. Summary of annual sequestration profits in the University of Alaska carbon credit candidate lands modeling for 2023 -2024.

UALM Carbon Credit Parcels	California Air Resources Board Tier (per Mg C)	Total Area of Study Region (hectares)	Total Annual Carbon Sequestration Profit (USD)	Mean Annual Carbon Sequestration Profit per hectare	Total Current Carbon (Mg C)	Total Future Carbon (Mg C)	Change in Carbon (Mg C)
	$47.10	3,090	$87,864	$28.44	672,644	674,428	1,784

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Carbon sequestration and economic value of HSF highly stocked stands parcels

The total modeled annual revenue from carbon sequestration within the Haines State Forest highly stocked stands is projected to be $308,149 for 2023 with 5,935 megagrams of carbon sequestered annually on these parcels. (Table 8). Should these timber stands be clear-cut, the total emission of carbon into the atmosphere is estimated to be 1,832,585 megagrams of carbon (Table 9).

Table 8. Haines State Forest highly stocked stands InVEST analysis findings. Summary of potential carbon sequestration profits for the Haines State Forest high-stocked Stands from 2023 -2024.

California ARB Price ($/Mg C)	Area of Highly Stocked Stands (ha)	Annual Carbon Sequestration Value	Current Carbon Stock (Mg)	FutureCarbon Stock (Mg)	Sequestration Value (Mg)
$47.10	7,990	$308,149	2,434,696	2,440,632	5,935

Table 9. Haines State Forest highly stocked stands clear-cutting results. Summary of total modeled emitted carbon from potential clear-cutting in the Haines State Forest High-Stocked Stands.

Total Area of Study Region (ha)	Total Stored Carbon: 2015 (Mg C)	Total Stored Carbon After clear-cut (Mg C)	Change in Carbon Storage (Mg C)
7,990	2,434,697	602,112	-1,832,585

Discussion

Southeast Alaska's coastal forests have a carbon density that is 36 times greater than the world average.[160] Results from these models demonstrate that the low-elevation regions of the GCW can store a significant amount of carbon compared to parcels at higher elevations. Thus, prioritizing parcels near the *Jilkaat Heeni* (Chilkat River) and its tributaries for the proposed University of Alaska carbon credit program will achieve the greatest benefit for stakeholders compared to preserving parcels with lower carbon storage capabilities. With an estimated 2023 value at $2.8 million and with the increasing cost of carbon growing at 5% annually, there is clear evidence that a carbon credit program is economically feasible. Moreover, the University of Alaska has reported $46.5 million in timber sales on their approximately 60,702 hectares of owned land from 1987-2017.[148] This approximates to an annual profit of $25.53 per hectare - $1.67 less than what the University of Alaska could potentially earn from a carbon credit program for the 2023-2024 fiscal year. Therefore the University of Alaska should commit to establishing a carbon credit program for these parcels while also continuing to research other possible co-benefits that arise from keeping a second-growth forest intact. As mentioned earlier in this report, any parcels of land near the Chilkat River or its tributaries with at least 305 meters of intact riparian habitat is valuable for brown bear and salmon conservation. Of the total UALM candidate parcels 11 out of the 14 have a tributary within them.

Moving from the University of Alaska to the Haines State Forest, to calculate the estimated value of timber on HSF's high stocked parcels, Washington state's stumpage valuation rates were used as there was no current available data for post-COVID Alaskan timber prices. For 2023, the state of Washington listed western hemlock and Sitka spruce at a baseline price of $331 per MBF.[161] Data from the Haines State Forest classified the timber volume of these highly stocked stands at a total of 742,723 MBF.[151] We estimate based on this available data that these high stocked parcels are currently valued at $245,841,313. Comparing this price to establishing a carbon credit program, we modeled a comparison of creating a carbon credit program for 100 years, the typical stand rotation for the region. Under the assumption that the price of carbon will rise by 5% each year, with the price of one megagram of carbon being as high as $6,503 in 2123. Using this assumption, the total net present benefit of a 100-year carbon credit program in 2023 on these highly stocked stands is valued at $28,848,006. In order to break even on 2023 potential timber revenue projections, this carbon credit program starting in 2023 would need to run for 76 years - less than the 100-year rotation period for each parcel.

In all, the University of Alaska carbon candidate parcels and the highly stocked stands should be placed under protection for both conservation and carbon credit market purposes. In addition, future management decisions should be geared towards preserving these parcels in perpetuity through a conservation easement or an alternative method of protecting these parcels while they continue to thrive and work for both the Haines State Forest and the University of Alaska.

Limitations

A major limitation to this analysis is inherent in the InVEST model. InVEST oversimplifies the carbon cycle and sequestration rates by assuming a linear relationship between time and sequestration (Figure A-9). In reality, these rates may reach a limit and slow to a steady rate which we tried to emulate in this analysis through the reclassified LULC classes using FIA's annual aboveground and belowground carbon sequestration rates. Moreover, sequestration rates depend on a number of variables including the physiology of the tree species and climate, which are not incorporated into the InVEST model. To make these models more accurate, more detailed forest stand research needs to be conducted in the Greater Chilkat Watershed such as updated land cover rasters, growth and recruitment rates of western hemlock and Sitka Spruce, annual carbon sequestration rates for biomass, soil, and total amount of dead organic material within the GCW and the Haines State Forest. This model relied heavily on known carbon sequestration rates from the Chugach National Forest. The Haines State Forest is adjacent to the Tongass National Forest and 400+ miles away from the Chugach National Forest. We selected carbon sequestration rates from the Chugach National Forest as the forest contains environmental characteristics closer to the Haines State Forest compared to the Tongass. The Haines State Forest, like the Chugach National Forest, is a transitional forest with a drier climate compared to the Tongass National Forest. We believed the total makeup of western hemlock and Sitka spruce within the Haines State Forest was more similar to the Chugach National Forest compared to the Tongass. Within the Tongass National Forest, 5 million acres of old growth forest remain intact. In addition, due to wetter climate conditions, this forest is able to sequester more carbon due to its location along the North Pacific Coast as a Pacific temperate rainforest.[162] Furthermore, the growth rates of the Tongass National Forest is significantly higher than that of the Chugach National Forest.[162]

Further limitations of these analyses were due to the remoteness of this region and the watershed itself being an international watershed. With limited data, we used global carbon density rasters for these analyses which were at varying low resolutions compared to our land cover resolution rasters. While our land cover rasters can be downloaded at 30-meter resolutions, we needed to resample this to match the 272-meter resolution of the aboveground and belowground carbon biomass data. The low resolution of this data could have caused higher carbon land cover classifications such as forestland to be resampled to lower carbon land cover classifications such as water, barren, or wetland. This would result in a lower precision of modeling carbon storage and carbon sequestration.

Part 3: Moving Forward in the Greater Chilkat Watershed

Data Gaps

A lack of data presented significant challenges throughout this study, and access to improved or currently non-existent data would improve our analyses. These data gaps can provide valuable insights into the most needed information for informed decision-making. A summary of these data can be found in Table A-25.

In the case of analyzing biological value and presence of *x̱áat* (Pacific salmon) in the Chilkat Valley, missing data can make it difficult to quantify the best indicators of habitat quality. This includes stream velocity and discharge, substrate composition and size, water turbidity, dissolved oxygen concentration, stream depth, and environmental DNA to determine the geographical distribution of the five species of salmon in the GCW. Remote sensing can be a valuable tool for addressing some of these gaps, especially when resources are limited. Recent studies have shown promise in using drones and thermal-red imagery to survey stream reaches.[152,153]

For our mountain goat and brown bear analyses, data gaps include resistance values specific to our species of interest within Alaska, GPS-collared wildlife locations, traffic data to assess road usage, and remote sensing data that bridges the United States-Canada border. Standardized international land cover classifications and remote sensing data are needed to facilitate cross-border analyses and management of ecological systems. For our brown bear analysis, identification of old-growth forest parcels and/or the results of ADF&G's Resource Selection Function would refine our core areas. Spatial data detailing brown bear-human conflicts would inform our management recommendations, too. Furthermore, information on where the Haines State Forest plans to build roads for planned harvests would improve our anticipation of their ecosystem impacts in all of our analyses.

Finally, forest regeneration and carbon sequestration rates unique to the GCW would improve the accuracy of our carbon analysis results. Pricing data for Sitka spruce and western hemlock lumber within Alaska would allow us to make a more robust comparison of economic benefits between harvest and sequestration scenarios. Overall, addressing these missing data gaps within the GCW will be essential for implementing effective conservation and management strategies in the future.

Recommendations

For Haines State Forest and University of Alaska management

Alternatives to clear-cutting

In their management plan, Haines State Forest management states that clear-cutting is the best method for forest regeneration and commits to protecting “some” of the remaining old-growth forest on its lands from harvest.[139] This policy is contrary to research demonstrating the myriad environmental benefits of alternative forms of harvest to clear-cuts.[43] clear-cutting operations in *Lingít Aaní* (Southeast Alaska) have distinctive impacts on highly-valued species in the GCW, including *ch'áak'* (bald eagles), *x̱áat* (Pacific salmon), and *jánwu* (mountain goats).[38,41,165] Minimizing the impacts of these harvest activities will improve ecosystem health and functions.[166]

Viable clear-cutting alternatives include shelterwood cuts, green tree retention, and patch cutting.[166] While these treatments are less efficient and their associated harvesting costs are greater, site disturbance impacts are mitigated, including soil composition, compaction, and nutrient leaching. These alternative cuts also leave behind more-intact wildlife habitats.[166] We recommend that Haines State Forest management considers updating their harvesting methods to reduce disturbance to wildlife and their habitat.

Expanded Riparian Buffers

In addition to less-intensive harvesting methods, our research demonstrated that ecologically sensitive species - particularly *x̱áat* (Pacific salmon) and *xóots* (brown bears) - benefit when protection buffers of at least 300 meters are created adjacent to riparian corridors that conserve valuable habitat.[103,133] Current Haines State Forest policy calls for a 100-meter buffer along anadromous fish-bearing streams, and an approximately 150-meter buffer along anadromous fish-bearing lakes.[40] Therefore, in their management policies, we recommend that the Haines State Forest expand their standard buffer distance for streams and lakes to 300 meters (approximately 1000 feet) to achieve a variety of ecological benefits.

Planned and potential harvest areas of concern

In the most recent five-year management schedule, the Haines State Forest identified areas for clear-cut harvest. The following planned harvest areas overlap with important movement corridors, LCPs, winter habitat, and/or highly suitable habitat for both *jánwu* (mountain goats) and *xóots* (brown bears): Kelsall Pocket (2023), Chilkat Ridge 1 & 2 (2024 & 2026), Kelsall 100CW (2024), Single 15 (2025), and Turnaround (2026). Of these, the riparian areas around both Kelsall cuts have also been identified as *x̱áat* (Pacific salmon) hotspots, reinforcing their importance for watershed-level conservation for our species of interest. We encourage Haines State Forest management to reconsider clear-cutting practices in these areas to preserve habitat connectivity for these charismatic species.

Additionally, parcels that are not currently planned for harvest but are considered highly stocked by HSF management were identified. There are a number of these potential harvest areas that should be prioritized for conservation due to their importance for the mountain goats and brown bears of the GCW. See Appendix Table A-26 for a complete list. Of these, parcels identified by STAND ID 2323, 2344, and 2590 overlap with salmon hotspots and represent important habitat for all three species of interest in this study. Planned and potential harvest areas of conservation concern are illustrated in Figure 26.

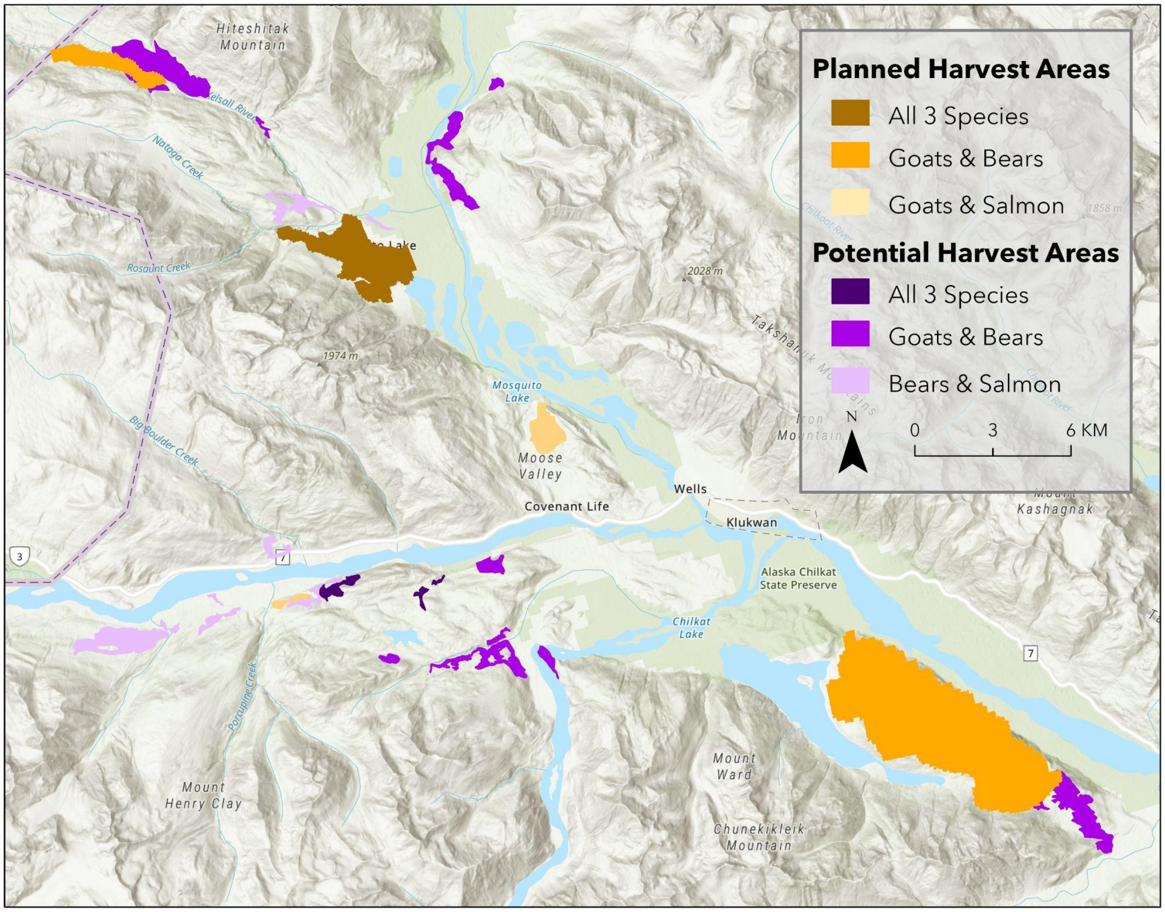

Figure 26. Planned and potential harvest areas of significance for 2 or more of our species of interest. Darkest colors indicate parcels of importance for salmon, brown bears, and mountain goats, while lighter colors show areas of utility for the listed subset of species.

The promise of carbon sequestration

Recent studies, including Leighty et al. (2006) have estimated that the carbon sequestration values of *Lingít Aaní* (Southeast Alaska) forests may be greater than the forests' timber values.[48] This dynamic will only be exacerbated as regional mill closures make monetization of timber products a more difficult endeavor. Thus, we encourage Haines State Forest management to investigate the viability of using their forest resources for carbon sequestration and other conservation values as opposed to commercial logging. This switch would have ecosystem benefits in addition to providing revenue to the state.

The University of Alaska, as a regional land manager, has expressed interest in carbon sequestration values and could obtain and/or convert land previously set aside for timber harvest for that purpose.[110] The results of our carbon sequestration analysis estimate the potential value that could be gained by the University of Alaska or Haines State Forest's participation in a carbon market. We recommend these two entities consider our findings and start the initial stages of establishing a carbon credit market. The expected economic and ecological benefits make this an area worthy of further research and consideration.

Next Steps for Lynn Canal Conservation

To ensure that the next steps (provided in Table 10) are understood and implemented by the Chilkat Valley Working Group and other researchers in the area, it's important to expand upon each analysis. This may involve providing more detail on the specific methods used, the key findings and conclusions, and any limitations or uncertainties associated with the results. By doing so, future efforts can build upon the strengths and weaknesses of the current analyses and continue to refine and improve conservation planning in the Chilkat Valley watershed.

In addition, providing guidance on prioritization and integration into a comprehensive conservation planning strategy can help ensure that the next steps are aligned with broader goals and objectives. This may involve identifying key stakeholders, establishing clear metrics and benchmarks for success, and developing protocols for ongoing monitoring and evaluation. By taking a comprehensive approach to conservation planning, the Chilkat Valley Working Group can ensure that its efforts are well-coordinated and effective.

Finally, recommendations for ongoing monitoring and evaluation are crucial to ensuring that conservation efforts remain effective and relevant over time. This may involve identifying key indicators to track progress, developing data collection and analysis protocols, and establishing a framework for adaptive management. By monitoring progress and adjusting strategies as needed, the Chilkat Valley Working Group can ensure its conservation efforts respond to changing conditions and emerging threats.

These further steps can have a lasting impact and contribute to ongoing efforts to protect and preserve this important ecosystem.

Table 10. Suggested next steps for LCC and other researchers looking to continue or extend each analysis.

Analysis	Recommended Next Steps
Xáat (Pacific salmon)	● Obtain data from watershed modeling entities for more accurate biological value assessments ○ Diane Whited at the University of Montana - Riverscape Analysis Project ○ David Foster Hill at Oregon State University - Southeast Alaska Coastal River Discharge Model ● Include a Euclidean distance function to the impacts of logging on salmon-bearing streams and consider impact due to edge effects and land use change generally. ● Create a partnership with Southeast Alaska Land Trust to expand conservation easement development in the GCW ● Use climate models to project how biological value will be impacted by alterations in hydrology as a result of climate change
Jánwu (mountain goats)	● Determine how clear-cut logging impacts goat movement and behavior and assign a resistance value to these areas. ● Find or determine (via collared animal data) landscape resistance values for mountain goats in the GCW or a similar watershed in Alaska. ● Project core areas of mountain goat habitat under various climate change scenarios to analyze future connectivity.
Xóots (brown bears)	● Obtain results of resource selection function from ADF&G to more reliably determine core areas of habitat. ● Find or determine (via collared animal data) landscape resistance values for brown bears in the GCW or a similar watershed in Alaska. ● Compare locations, quality, and centrality of LCPs and corridors before and after logging scenarios. ● Identifying locations of brown bear-human conflicts and comparing them to connectivity results as a means of prioritizing areas for conservation.
Carbon Sequestration	● Identify carbon credit markets within the state of Alaska to better establish prices of carbon. ● Examine the annual carbon sequestration rates for aboveground and belowground biomass. ● Determine how much dead organic material is within the GCW so it can be applied to the InVEST model in megagrams of carbon per hectare. ● Use climate change models to predict how forests will move and how it will impact carbon storage and carbon sequestration rates.

Conclusion

These findings highlight the current extractive threats and conservation opportunities within the Greater Chilkat Watershed. If implemented, our recommendations stand to benefit not only *x̱áat* (Pacific salmon), *xóots* (brown bears), and *jánwu* (mountain goats), but also the other wildlife, clean water, and pristine environment on which the GCW's residents depend. Importantly, this research identified key gaps in our understanding of the GCW, including data needs, which must be bridged to empirically demonstrate this region's ecological value. Improving the communication of this watershed's unique attributes will attract the attention of researchers, policymakers, and others that can advocate for this region's future protection. We hope this study can serve as a starting point for further data collection and analyses to inform decision-making that results in the preservation of this valuable and productive ecosystem.

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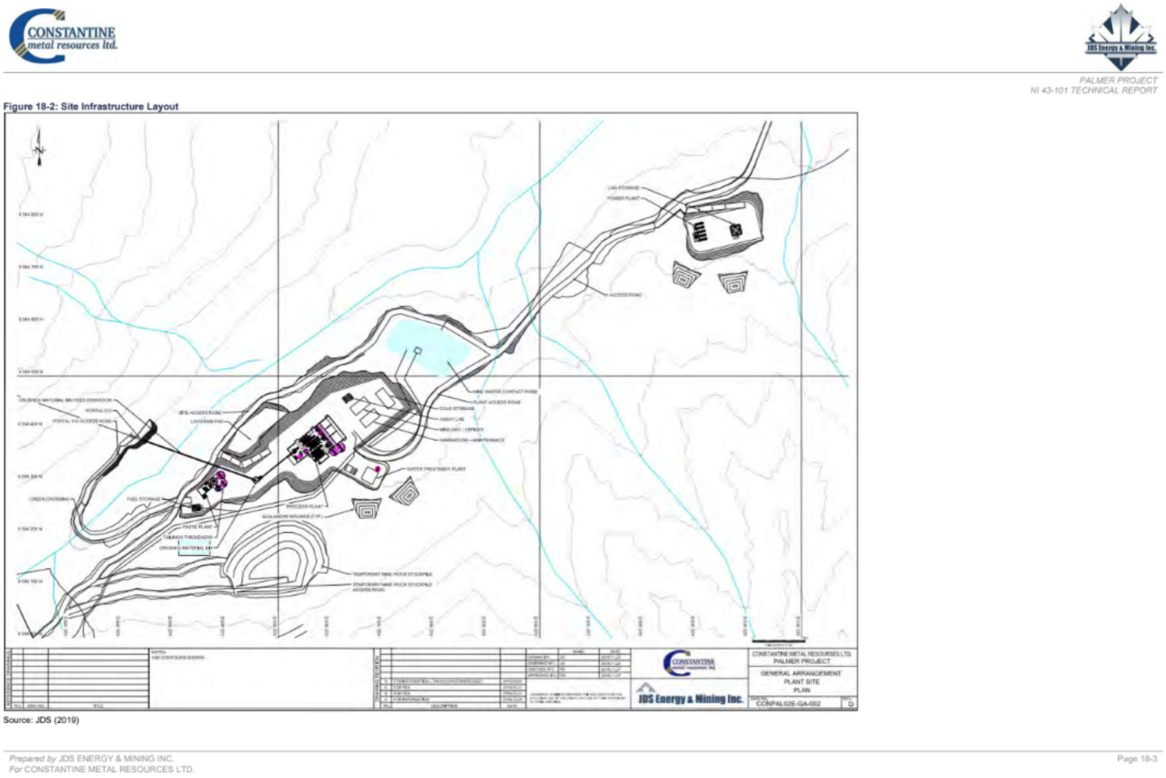
Appendix

Appendix for xáat (Pacific salmon) analysis



PALMER PROJECT
NI 43-101 TECHNICAL REPORT

Figure 18-2: Site Infrastructure Layout

Source: JDS (2019)

Prepared by JDS ENERGY & MINING INC.
For CONSTANTINE METAL RESOURCES LTD.

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Figure A-1. Map 1 from Constantine Metal Resources Ltd. displays the site infrastructure layout for the proposed Palmer Project in their Amended NI 43-101 Technical Report, 2022.

Table A-1. Data inputs to salmon hotspot analysis.

Short Dataset Description	Created by	Long Dataset Description	Date Created	Website Download
Biological Value				
U.S. National Land Cover Database	U.S. Geological Survey	2016 USGS raster layer (revised in 2020) with comprehensive land cover classifications for all of Alaska. Resolution of the layer is 30 square meters. The 21 listed categories, or classes, used by the NLCD are from a modified Anderson Land Cover Classification.	2020-02-13	https://www.sciencebase.gov/catalog/item/5f64cffa82ce38aaa23bdff2

2020 Land Cover of Canada	Government of Canada / Canada Centre for Remote Sensing	30 m resolution land cover data for the country of Canada for 2020. Includes 15 distinct classifications.	2022-08-11	https://open.canada.ca/data/en/dataset/ee1580ab-a23d-4f86-a09b-79763677eb47/resource/a5fcfcf9-b59f-4df6-84c1-e0a97770639b
Anadromous Waters Catalog	State of Alaska, Department of Fish and Game	Shapefiles of anadromous streams within Southeast Alaska, with the inclusion of species present.	2022	https://www.adfg.alaska.gov/sf/SARR/AWC/index.cfm?ADFG=maps.dataFiles
USGS 5 Meter Alaska Digital Elevation Model	U.S. Geological Survey	Tiled elevation raster at 5-meter resolution covering Alaska. Projections represent the bare earth's surface.	2022-12-15	https://data.usgs.gov/datacatalog/data/USGS:e250fffe-ed32-4627-a3e6-9474b6dc6f0b
Takshanuk Watershed Council GCW Stream Temperature Data	Takshanuk Watershed Council	Data from remotely operated monitors collecting stream temperature data daily at nineteen sites. Three HOBO Water Temp Pro v2 data loggers were deployed at each site, with two submerged in the water and one suspended in the air. Temperature loggers record continuously at 30-minute intervals.	2019	Personal Correspondence
Threats				
Haines State Forest parcel inventories	State of Alaska, Division of Forestry, Southeast Region, Haines Office	Shapefile of individual parcels in the Haines State Forest with accompanying inventory, age class, and other relevant forestry data	2021-11-10	https://gis.data.alaska.gov/datasets/SOA-DNR::hainesvegpolys-ownership/about
Proposed Palmer Project Site	Constantine Metal Resources, Ltd	Shapefile of Palmer Project site layout and location	2019	https://dnr.alaska.gov/mlw/mining/large-mines/palmer/pdf/palmer-poo-p2.pdf
Anadromous Waters Catalog	State of Alaska, Department of Fish and Game	Shapefiles of culverts located within anadromous streams within Southeast Alaska.	2022	https://www.adfg.alaska.gov/sf/SARR/AWC/index.cfm?ADFG=maps.dataFiles
Roads within watershed	TIGER/Line Shapefile, 2019, nation, U.S., Primary Roads National Shapefile	Shapefiles of roads within Southeast Alaska.	2019	https://catalog.data.gov/dataset/tiger-line-shapefile-2019-nation-u-s-primary-roads-national-shapefile

Table A-2: Scoring guide for salmon hotspot analysis.

Analysis	Variable	Score
Biological Value Assessment		
Land Cover Type	evergreen	3
	deciduous	3
	mixed forest	3
	moss	0
	moss	0
	woody wetlands	1
	emergent herbaceous wetlands	1
	pasture/hay	0
	cultivated crops	0
	barren land	2
	developed, open space	0
	developed, low intensity	0
	developed, medium	0
	developed, high	0
Stream Temperature	7 °C - 12 °C	3
	4°C - 6 °C	2
	13°C - 15 °C	1
	16°C - 19 °C	0
Stream Gradient	Slope (%) greater than 4%	0
	Slope less than or equal to 4%	3
Threats Assessment		
Road Density	1st quantile (2.25 - 3)	3
	2nd quantile (1.5 - 2.25)	2
	3rd quantile (0 - 1.5)	1
	No roads present	0

Culvert Density	1st quantile (3- 16)	3
	2nd quantile (1-3)	2
	3rd quantile (0-1)	1
	No culverts present	0
Timber Extraction	Presence of a Planned or Potential harvest stand	3
	Absence of a planned or potential harvest stand	0
Mining Risk	Distance to mine (1st quantile)	3
	Distance to mine (2nd quantile)	2
	Distance to mine (3rd quantile)	1
	Outside of downstream flow path	0

Table A-3. Landowner status and size for parcels identified by salmon hotspot analysis.

Land Owner	Number of Parcels
Private	252
University of Alaska	59
State	25
Mental Health Trust	19

Appendix for jánwu (mountain goat) analysis

Table A-4. Data inputs to mountain goat analysis.

Short Dataset Description	Created by	Long Dataset Description	Date Created	Website Download
Species & Habitat Data				
Mountain goat summer resource selection function (binary)	White and Gregovich, 2018	Binary representation of a resource selection function that identifies the presence or absence of suitable summer mountain goat habitat on a 10x10 meter pixel level.	2018-02-27	Data shared via personal correspondence
Mountain goat winter resource selection function (binary)	White and Gregovich, 2018	Binary representation of a resource selection function that identifies the presence or absence of suitable winter mountain goat habitat on a 10x10 meter pixel level.	2018-02-27	Data shared via personal correspondence
Land Cover Data				
U.S. National Land Cover Database	U.S. Geological Survey	2016 USGS raster layer (revised in 2020) with comprehensive land cover classifications for all of Alaska. Resolution of the layer is 30 square meters. The 21 listed categories, or classes, used by the NLCD are from a modified Anderson Land Cover Classification.	2020-02-13	https://www.sciencebase.gov/catalog/item/5f64cffa82ce38aaa23bdff2
2020 Land Cover of Canada	Government of Canada / Canada Centre for Remote Sensing	30 m resolution land cover data for the country of Canada for 2020. Includes 15 distinct classifications.	2022-08-11	https://open.canada.ca/data/en/dataset/ee1580ab-a23d-4f86-a09b-79763677eb47/resource/a5fcfcf9-b59f-4df6-84c1-e0a97770639b
DEM				
USGS 5 Meter Alaska Digital Elevation Model	U.S. Geological Survey	Tiled elevation raster at 5 meter resolution covering Alaska. Projections represent the bare earth's surface.	2022-12-15	https://data.usgs.gov/datacatalog/data/USGS:e250fffe-ed32-4627-a3e6-9474b6dc6f0b
Timber Harvest Areas				
Haines State Forest parcel inventories	State of Alaska, Division of Forestry, Southeast Region, Haines Office	Shapefile of individual parcels in the Haines State Forest with accompanying inventory, age class, and other relevant forestry data	2021-11-10	https://gis.data.alaska.gov/datasets/SOA-DNR::hainesvegpolys-ownership/about
Resistance Values				
Landscape Resistance Values	Washington Statewide Habitat Connectivity Working Group	Resistance values assigned to land cover types and elevation classes based on literature review and expert judgment. They used an analysis of genetic data from their study area (Shirk et al. 2010) to assist in parameterization for jánwu (mountain goats).	2010-12-01	https://waconnected.org/statewide-analysis/

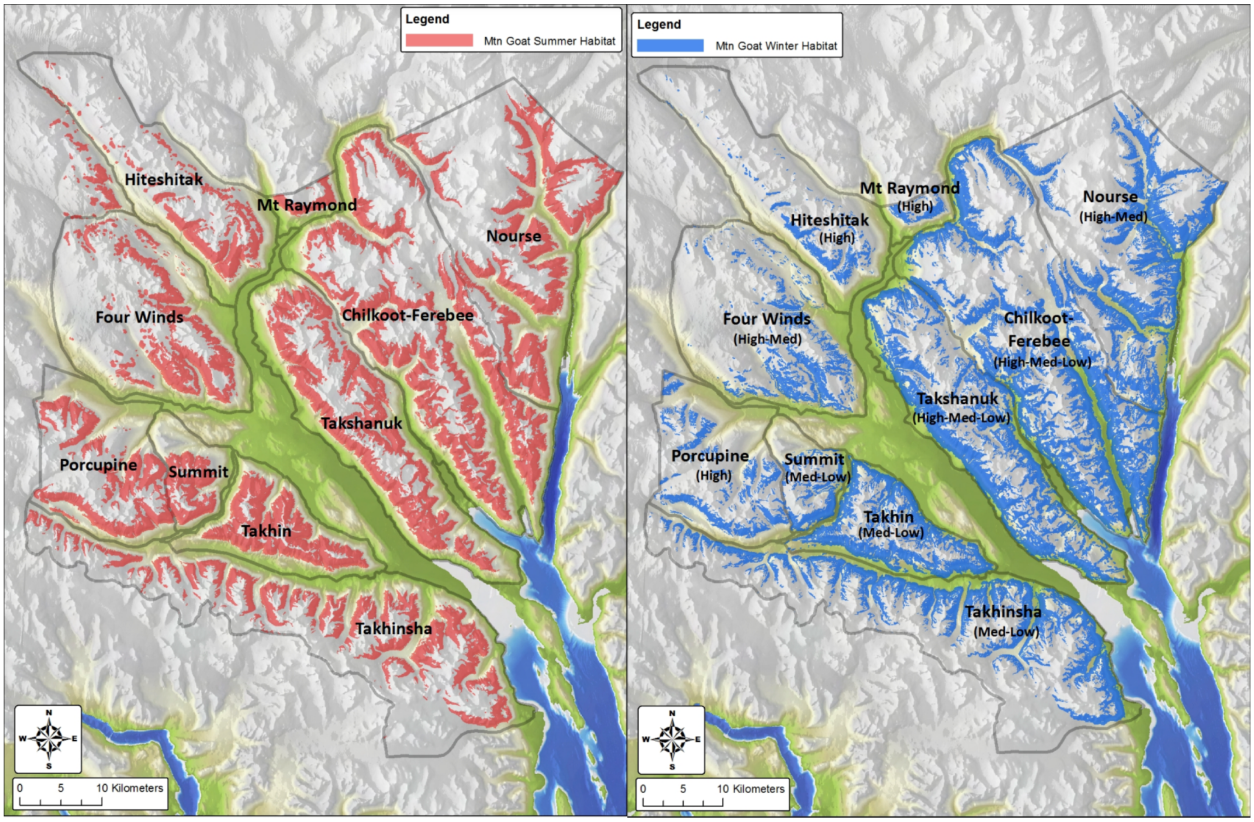


Figure A-3. Mountain goat summer and winter habitat from White & Gregovich (2018). These binary layers were inputs to our analysis. The regional names are often used to refer to the goat subpopulations of the GCW.

Table A-5. Land Cover types from Canada Centre for Remote Sensing, along with corresponding land covers from USGS National Land Cover Database joined for uniform feature classifications across international boundaries. Additional dataset details are available in Table A-4 above.

Canada Land Cover Types	**Class Code**	**Corresponding US Land Cover Types**	**Class Code**
temperate or sub-polar needleleaf forest	1	evergreen	42
sub-polar taiga needleleaf forest	2	N/A	N/A
temperate or sub-polar broadleaf deciduous forest	5	deciduous	41
mixed forest	6	mixed forest	43
temperate or sub-polar shrubland	8	dwarf scrub	51
temperate or sub-polar shrubland	8	shrub/scrub	52
temperate or sub-polar grassland	10	grassland/herbaceous	71
sub-polar or polar shrubland-lichen-moss	11	moss	74
sub-polar or polar grassland-lichen-moss	12	moss	74
sub-polar or polar barren-lichen-moss	13	moss	74
wetland	14	woody wetlands	90
wetland	14	emergent herbaceous wetlands	95

cropland	15	pasture/hay	81
cropland	15	cultivated crops	82
barren lands	16	barren land	31
urban and built up	17	developed, open space	21
urban and built up	17	developed, low intensity	22
urban and built up	17	developed, medium	23
urban and built up	17	developed, high	24
water	18	open water	11
snow and ice	19	ice/snow	12

Table A-6. Land Cover resistance values for mountain goat passage from the Washington Connected Landscapes Project.[135]

Land Cover/Land Use	Mountain Goat Resistance Value
Agriculture	1
Urban/Developed/Roads	8
Water	8
Sparsely vegetated	0*
Alpine	0*
Riparian	0*
Wetland	8
Grass and Shrub dominated	0*
Wet and Dry Forest	0*

**For a successful model run, there can be no resistance values of zero. However, within our study region, there were no areas of zero resistance between core areas, so adding 1 to our resistance values (as we did later in the brown bear analysis) was unnecessary.*

Table A-7. Elevation resistance values for mountain goat passage from the Washington Connected Landscapes Project.[135]

Elevation	Mountain Goat Resistance Value
0-250 Meters	2
250-750 Meters	1

750-2,500 Meters	0
2,500-3,300 Meters	1

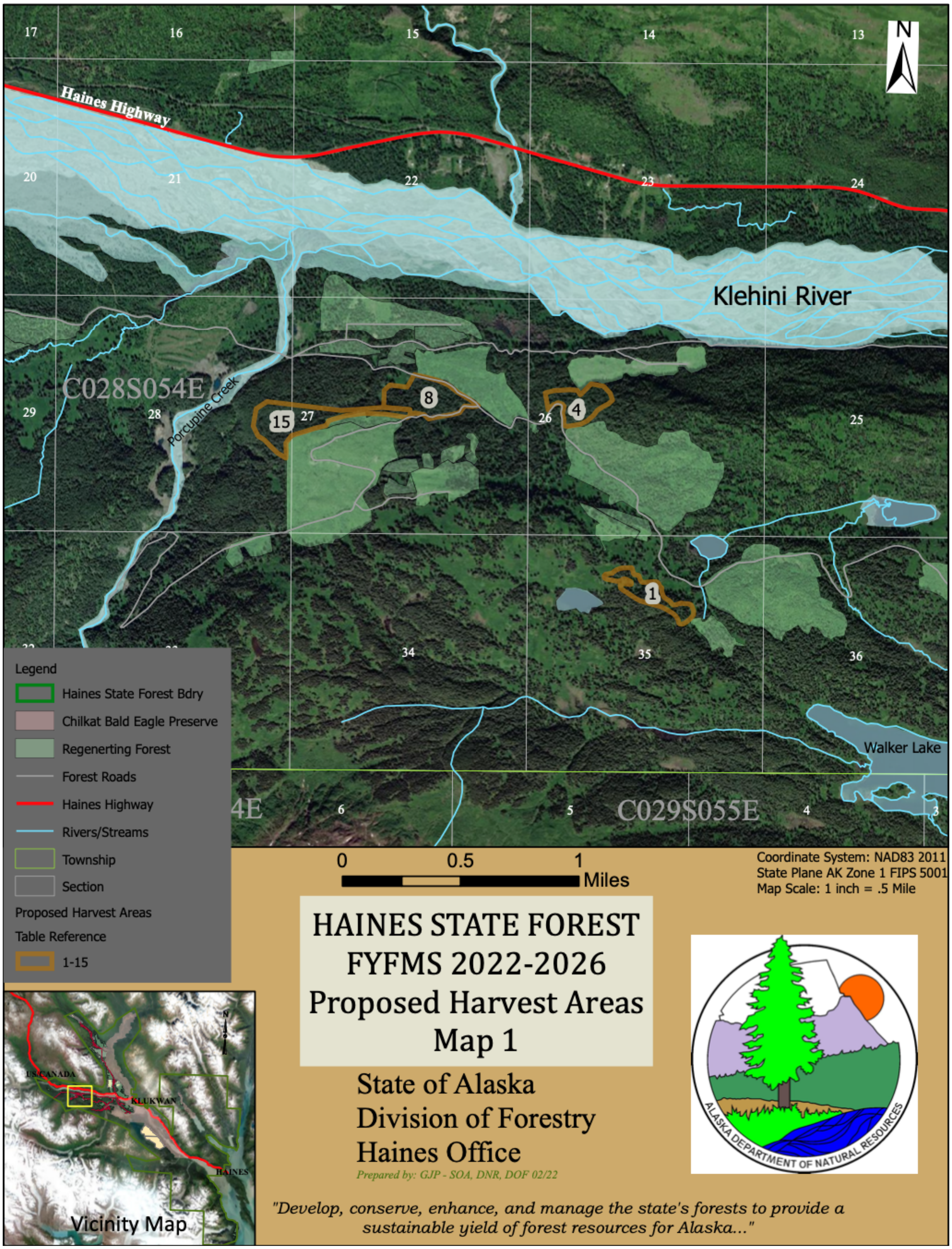


Figure A-4. Map 1 from the Haines State Forest Five-Year Management Schedule for 2022-2026.

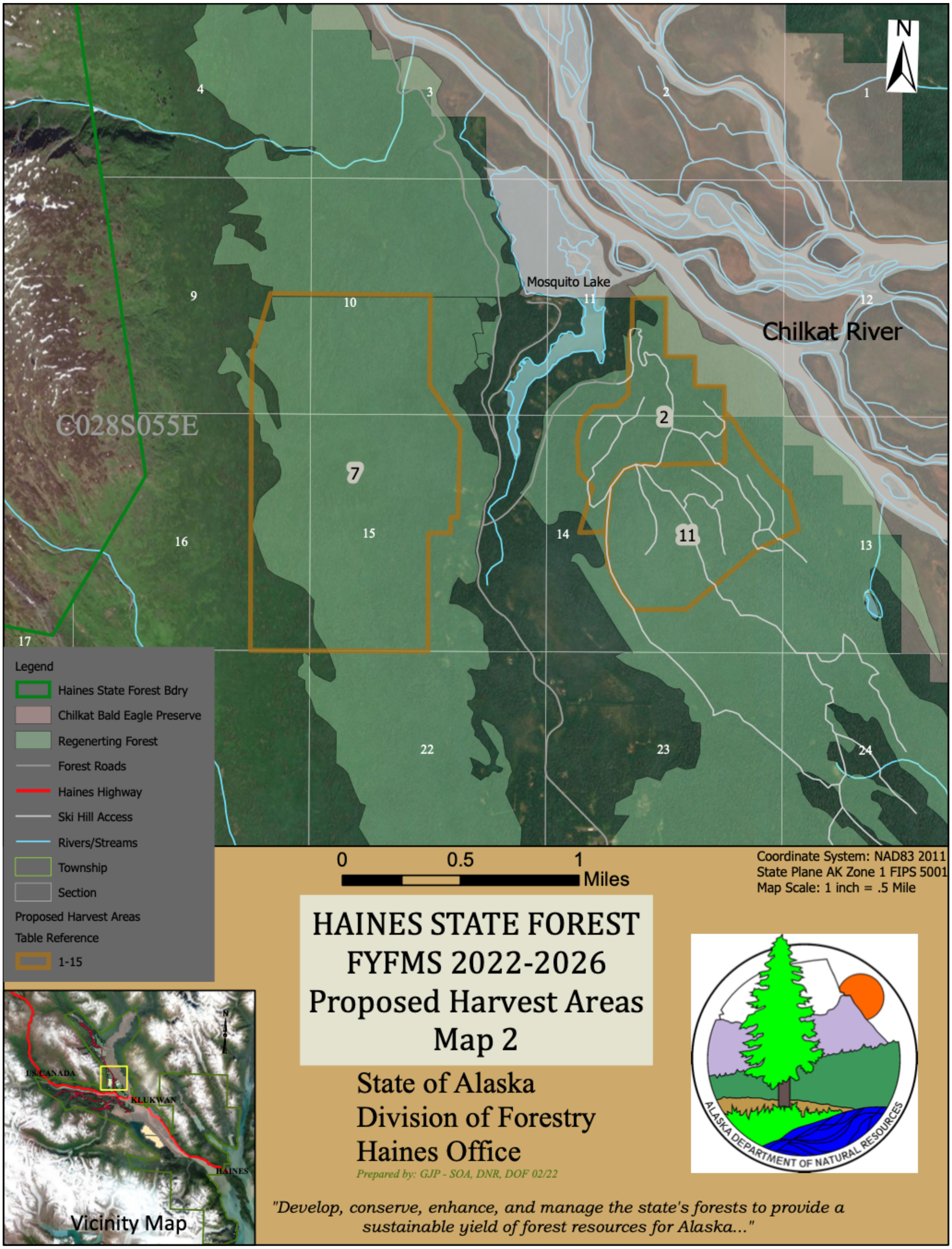


Figure A-5. Map 2 from the Haines State Forest Five-Year Management Schedule for 2022-2026.

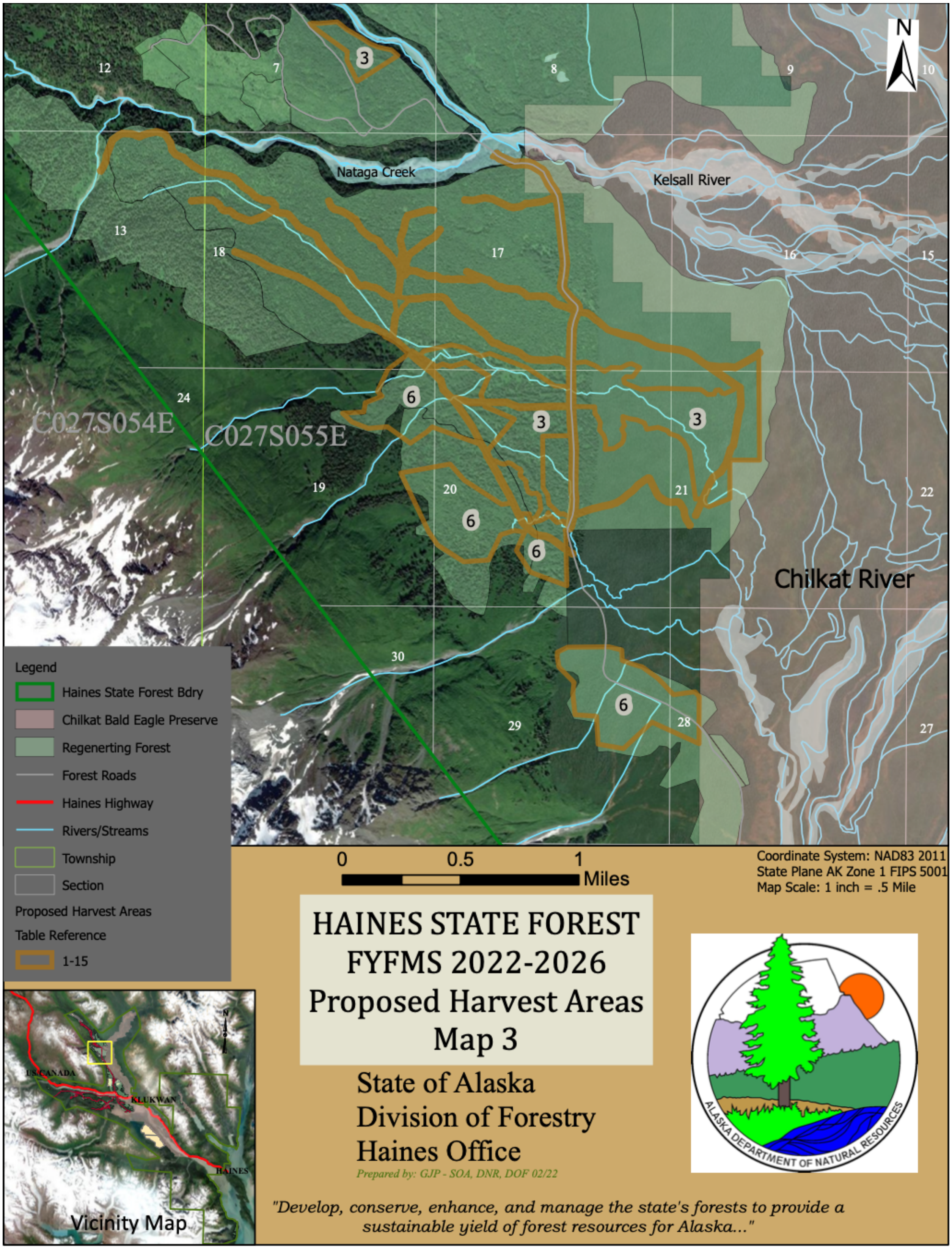


Figure A-6. Map 3 from the Haines State Forest Five-Year Management Schedule for 2022-2026.

Figure A-7. Map 4 from the Haines State Forest Five-Year Management Schedule for 2022-2026.

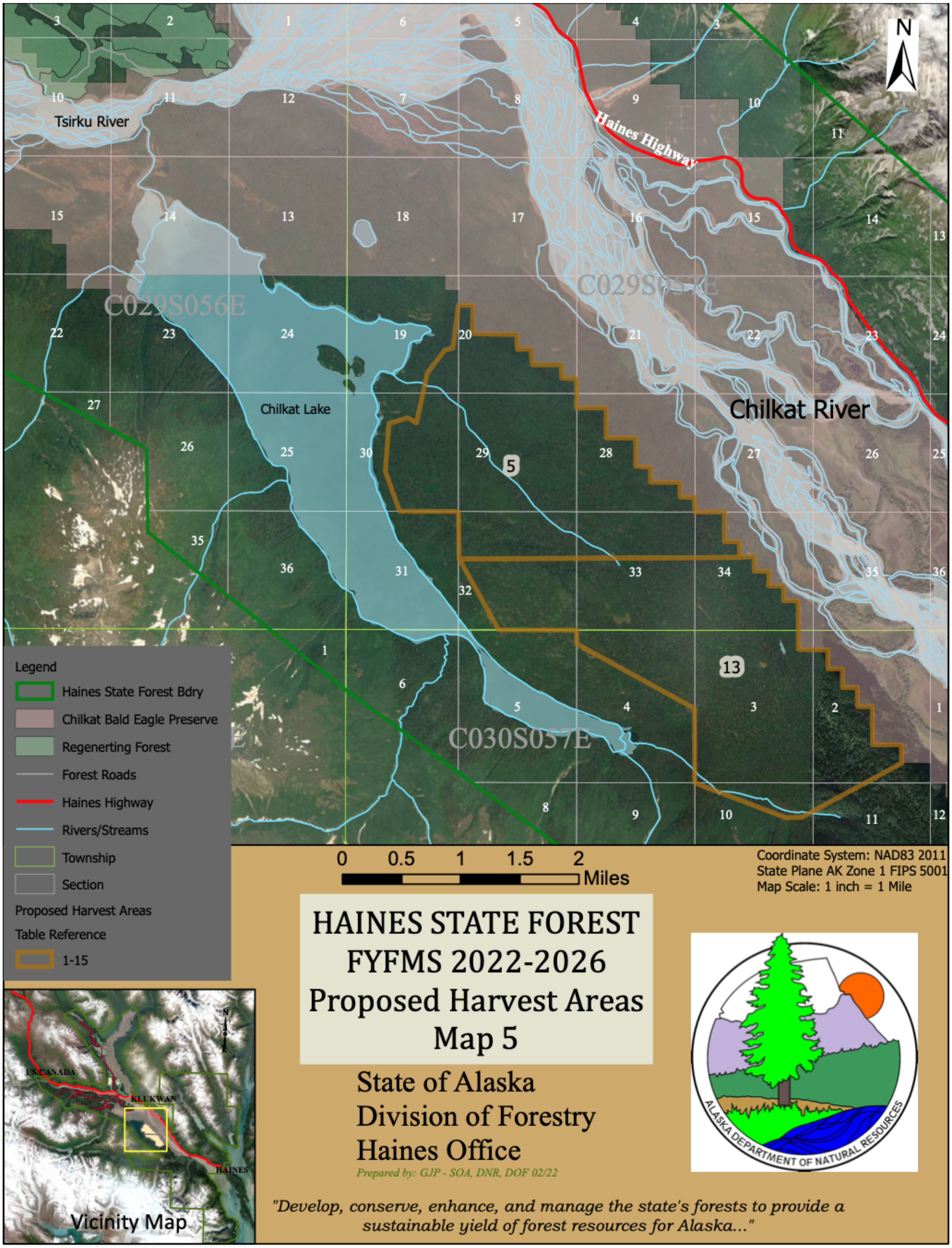
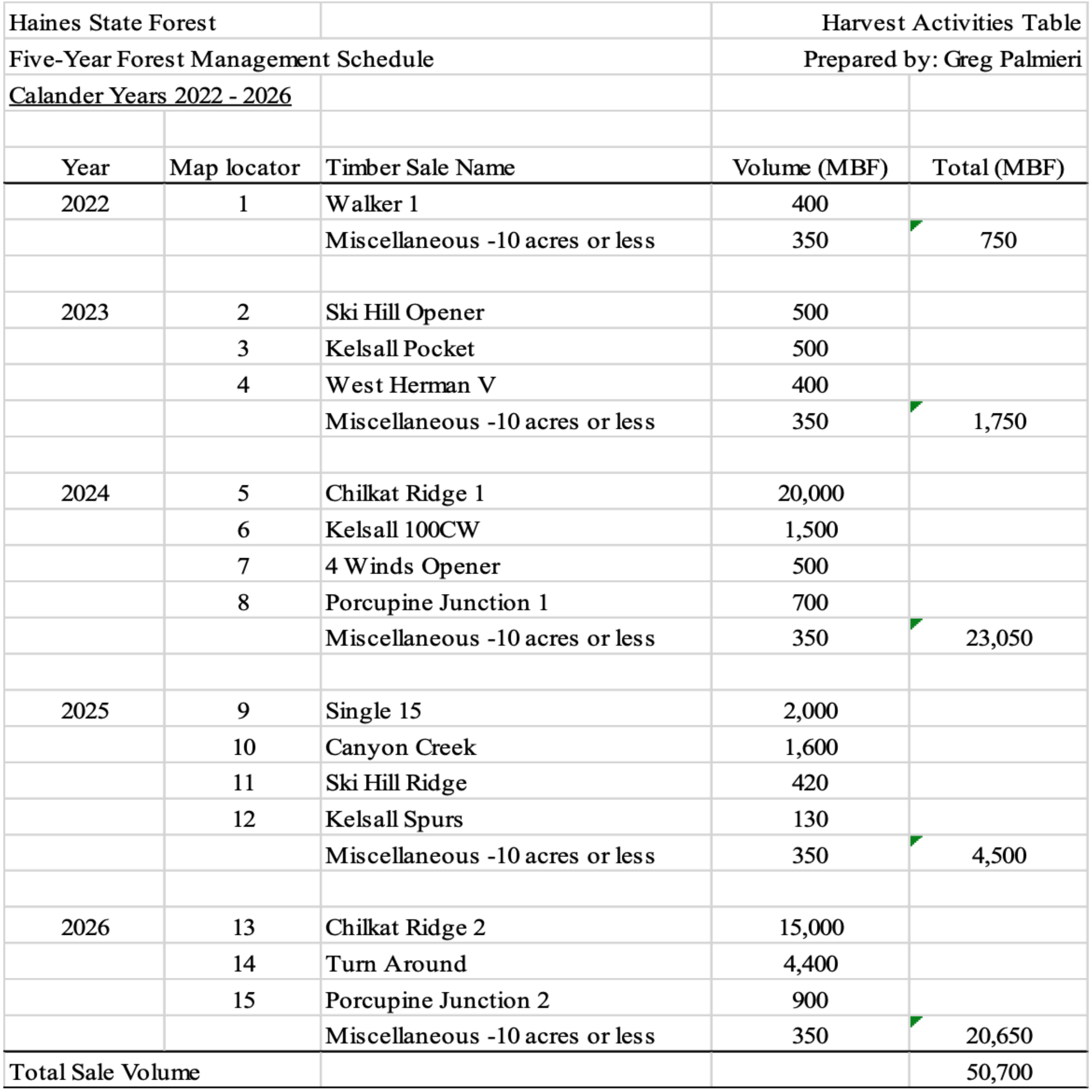


Figure A-8. Map 5 from the Haines State Forest Five-Year Management Schedule for 2022-2026.

Table A-8. Harvest Activities Table from the Haines State Forest Five-Year Management Schedule for 2022-2026.



Haines State Forest			Harvest Activities Table	
Five-Year Forest Management Schedule			Prepared by: Greg Palmieri	
<u>Calander Years 2022 - 2026</u>				
Year	Map locator	Timber Sale Name	Volume (MBF)	Total (MBF)
2022	1	Walker 1	400	
		Miscellaneous -10 acres or less	350	750
2023	2	Ski Hill Opener	500	
	3	Kelsall Pocket	500	
	4	West Herman V	400	
		Miscellaneous -10 acres or less	350	1,750
2024	5	Chilkat Ridge 1	20,000	
	6	Kelsall 100CW	1,500	
	7	4 Winds Opener	500	
	8	Porcupine Junction 1	700	
		Miscellaneous -10 acres or less	350	23,050
2025	9	Single 15	2,000	
	10	Canyon Creek	1,600	
	11	Ski Hill Ridge	420	
	12	Kelsall Spurs	130	
		Miscellaneous -10 acres or less	350	4,500
2026	13	Chilkat Ridge 2	15,000	
	14	Turn Around	4,400	
	15	Porcupine Junction 2	900	
		Miscellaneous -10 acres or less	350	20,650
Total Sale Volume				50,700

Table A-9. Complete list of Haines State Forest highly-stocked parcels that intersect LCPs or highly suitable movement corridors for mountain goats as identified by Linkage Mapper. Parcels are named with their STANDID as provided in the AK DNR DOF data.

75	81	84	100	180	185	188	213	230	257	751	755
783	880	991	1047	1056	1111	1133	1482	1534	1541	1543	1562
1586	1697	1705	2234	2320	2323	2335	2344	2377	2434	2438	2577
2580	2582	2590	2802	2803	2805	–	–	–	–	–	–

Table A-10. Complete list of Haines State Forest highly-stocked parcels that contain suitable winter mountain goat habitat as identified by White & Gregovich (2018). Parcels are named with their STANDID as provided in the AK DNR DOF data.

151	152	159	163	180	185	186	187	188	213	227	230
236	237	257	267	284	387	390	396	404	407	420	433
440	442	458	462	473	512	522	527	558	619	686	724
813	829	853	856	859	860	866	881	995	1056	1087	1089
1111	1139	1210	1231	1248	1311	1312	1453	1483	1489	1499	1515
1531	1541	1543	1586	1599	1601	1608	1627	1637	1640	1673	1689
1697	1702	1704	1705	1709	1714	1724	1734	1740	1742	1745	1760
1773	1784	1785	1792	1811	1818	1827	1842	1861	1865	1866	1869
1881	1896	1898	1908	1911	1916	1923	2234	2434	2436	2438	2555
2558	2561	2565	2567	2717	–	–	–	–	–	–	–

Appendix for xóots (brown bears) analysis

Table A-11. Data inputs to brown bear analysis.

Short Dataset Description	Created by	Long Dataset Description	Date Created	Website Download
Land Cover Data				
U.S. National Land Cover Database	U.S. Geological Survey	2016 USGS raster layer (revised in 2020) with comprehensive land cover classifications for all of Alaska. Resolution of the layer is 30 square meters. The 21 listed categories, or classes, used by the NLCD are from a modified Anderson Land Cover Classification.	2020-02-13	https://www.sciencebase.gov/catalog/item/5f64cffa82ce38aaa23bdff2
USFWS National Wetlands Inventory	U.S. Fish and Wildlife Service	Raster layer with the extent, location, and type of wetlands and deepwater habitats in the United States. Downloaded by state for Alaska.	2022-01-01	https://www.fws.gov/program/national-wetlands-inventory/data-download
USFS Tree Canopy Cover	U.S. Forest Service	2011 raster identifying tree canopy cover dataset for coastal Alaska.	2011	https://data.fs.usda.gov/geodata/rastergateway/treecanopycover/
ADF&G Anadromous Waters Catalog	Alaska Dept. of Fish and Game	Anadromous waters within the state of Alaska, downloaded for Southeastern Alaska. Note only the streams that have been identified as anadromous are present, not all streams have been analyzed for this aspect.	2022	https://www.adfg.alaska.gov/sf/SARR/AWC/index.cfm?ADFG=maps.dataFiles
DEM				
USGS 5 Meter Alaska Digital Elevation Model	U.S. Geological Survey	Tiled elevation raster at 5 meter resolution covering Alaska. Projections represent the bare earth's surface.	2022-12-15	https://data.usgs.gov/datacatalog/data/USGS:e250fffe-ed32-4627-a3e6-9474b6dc6f0b
Timber Harvest Areas				
Haines State Forest parcel inventories	State of Alaska, Division of Forestry, Southeast Region, Haines Office	Shapefile of individual parcels in the Haines State Forest with accompanying inventory, age class, and other relevant forestry data	2021-11-10	https://gis.data.alaska.gov/datasets/SOA-DNR::hainesvegpolys-ownership/about
Resistance Values				

Landscape Resistance Values	Washington Statewide Habitat Connectivity Working Group	Resistance values assigned to land cover types and elevation classes based on literature review and expert judgment. Additionally provided resistance values for slope and trans secondary highway buffers.	2010-12-01	https://waconnected.org/statewide-analysis/

Table A-12. Slope resistance values for American black bears. Note: All resistance values were given a value of +1 to account for Linkage Mapper and Pinch Point mapper's necessity to not have resistance values of 0.

Slope (degrees)	American black bear resistance values
0-20	1
>20-40	2
>40	4

Table A-13. Resistance values for secondary highway roads and resistance values of buffer distances near the roads from the Washington Connected Landscapes Project.[127] Note: All resistance values were given a value of +1 to account for Linkage Mapper and Pinch Point mapper's necessity to not have resistance values of 0.

Trans Secondary Highway	Resistance Value
>500-1000 m buffer	5
>0-500 m buffer	9
Centerline of the road	51

Table A-14. Land Cover resistance values for American black bears from the Washington Connected Landscapes Project.[135] Note: All resistance values were given a value of +1 to account for Linkage Mapper and Pinch Point mapper's necessity to not have resistance values of 0.

Land Cover/Land Use	American black bear resistance value
Agriculture	101
Urban/Developed	201
Water	101
Sparsely vegetated	2
Alpine	1

Riparian	1
Wetland	1
Grass-dominated	2
Shrub-dominated	2
Dry forest	2
Wet forest	1

Table A-15. Complete list of Haines State Forest highly-stocked parcels that intersect LCPs or corridors for brown bear movement as identified by our Linkage Mapper analysis. Parcels are named with their STANDID as provided in the AK DNR DOF data.

230	407	440	698	708	744	833	876	928	991	1047	1056
1087	1099	1183	1200	1203	1220	1246	1248	1254	1256	1270	1285
1300	1315	1349	1350	1367	1386	1405	1448	1488	1534	1541	1543
1562	1689	1704	1724	1740	1742	1745	1760	1773	1785	1792	1811
1827	1842	1861	1881	1896	1898	1908	1911	1916	1923	2001	2140
2520	2559	2561	–	–	–	–	–	–	–	–	–

Table A-16. Complete list of Haines State Forest highly-stocked parcels that contain pinch points to brown bear movement as identified by Pinchpoint Mapper. Parcels are named with their STANDID as provided in the AK DNR DOF data.

230	698	708	833	991	1161	1200	1203	1246	1248	1254	1256
1270	1285	1315	1349	1608	1689	1784	2520	–	–	–	–

Table A-17. Complete list of Haines State Forest highly-stocked parcels that contain high suitable mountain brown bear habitat as identified by our analysis. Parcels are named with their STANDID as provided in the AK DNR DOF data.

75	81	84	151	152	159	176	180	213	230	234	257
267	280	284	312	319	440	442	444	458	465	512	522
527	558	587	619	624	631	662	724	783	853	859	866
881	901	995	1047	1056	1089	1111	1139	1142	1147	1158	1162
1173	1210	1231	1248	1270	1300	1311	1312	1315	1489	1514	1515
1521	1586	1589	1599	1637	1662	1705	1724	1760	1784	1792	1923

1974	1980	1995	2001	2010	2143	2151	2234	2323	2344	2377	2520
2521	2590	2591	2671	2717	2804	–	–	–	–	–	–

Appendix for carbon storage and sequestration analysis

Table A-18. Data inputs for Carbon Storage and Carbon Sequestration Analyses.

Short Dataset Description	Created by	Long Dataset Description	Date Created	Website Download
Carbon Density Rasters				
Global Aboveground Biomass Carbon Density Raster	Spawn and Gibbs, 2020, Oak Ridge National Laboratory, Distributed Active Archive Center for Biogeochemical Dynamics (ORNL DAAC)	Harmonized global maps aboveground biomass carbon density for the year 2010 at 272.1195m resolution. The scale was divided by 0.1 to reduce file size for data download purposes. Units: Mg C/ha	2020-03-05	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1763
Global Belowground Biomass Carbon Density Raster		Harmonized global maps belowground biomass carbon density for the year 2010 at 272.1195m resolution. The scale was divided by 0.1 to reduce file size for data download purposes. Units: Mg C/ha	2020-03-05	https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1763
Soil Organic Carbon Stock for 0.6-1 meter depth	Hengl and Wheeler, 2018	Soil organic carbon stock at 250 m resolution at a global level. Units: kg/m^2. Ton convert to Mg C/ha, multiply by 10.	2018-12-24	https://zenodo.org/record/2536040#.Y_5RjHZKi3A
Land Cover Data				
2010 North American Land Cover Raster	The North American Land Change Monitoring System (NALCMS) is a joint initiative between 1. Natural Resources Canada (NRCan) 2. Canada Centre for Mapping and Earth Observation (CCMEO) 3. United States Geological Survey (USGS) 4. Commission for Environmental Cooperation (CEC)	2010 and 2015 NALCMS raster layers with comprehensive land cover classifications for all of the conterminous United States and Alaska and Canada. The resolution of both layers is 30 meters. There are 19 listed land cover classes.	2020-02	http://www.cec.org/north-american-environmental-atlas/land-cover-2010-landsat-30m/
2015 North American Land Cover Raster			2020-07	http://www.cec.org/north-american-environmental-atlas/land-cover-30m-2015-landsat-and-rapideye/
Shapefiles used for Clipping				
Haines State Forest parcel inventories	State of Alaska, Division of Forestry, Southeast Region, Haines Office	Shapefile of individual parcels in the Haines State Forest with accompanying inventory, age class, and other relevant forestry data	2021-11-10	https://gis.data.alaska.gov/datasets/SOA-DNR::hainesvegpolys-ownership/about

Greater Chilkat Watershed Shapefile	Lynn Canal Conservation and Richard Carleton	Shapefile of the Haines State Forest boundary.	2021-11-10	Personal Correspondence with Lynn Canal Conservation
Haines State Forest Shapefile	State of Alaska, Division of Forestry, Southeast Region, Haines Office	Shapefile of the Haines State Forest boundary.	NA	https://gis.data.alaska.gov/datasets/SOA-DNR::state-forest-boundary-public-view/explore?location=59.178974%2C-135.257170%2C8.96
University of Alaska Parcels	Lynn Canal Conservation and Richard Carleton	Shapefiles of University of Alaska's Land Management Office owned parcels	NA	Personal Correspondence with Lynn Canal Conservation

Table A-19. Parcels that the University of Alaska's Land Management Office (UALM) has identified as potential candidates for their carbon credit program within the *Deishú* (Haines)/Chilkat Valley region in *Lingít Aaní* (Southeast Alaska).

University of Alaska Parcel Name	Hectares	Contains Watershed Tributary?
HA.CP.0001	46.45	No
HA.CP.0003	129.50	Yes
HA.CP.0004	16.19	Yes
HA.CP.0005	16.18	Yes
HA.CS.0001	253.09	Yes
HA.CS.0002	1399.35	Yes
HA.HC.0001	56.66	No
HA.HC.0002	16.19	Yes
HA.HC.0003	72.97	No
HA.HH.0001	32.35	Yes
HA.HH.0004	64.75	Yes
HA.KN.0005	7.49	Yes
HA.KN.0006	61.94	Yes
HA.KS.0002	916.97	Yes
Total Area:	3090.06	

Table A-20. NALCMS 2015 land cover classes with carbon estimates in Megagrams of organic carbon per hectare (Mg C/ha).

Land Use Code	LULC Name	Mean Megagrams of carbon per hectare (Mg C/ha)			
		C_Above	C_Below	C_Soil	C_Dead
0	Unclassified	0	0	0	0
1	Temperate or sub-polar needleleaf forest	62.11	19.42	135.55	0

2	Sub-polar taiga needleleaf forest	1.75	2.18	49.09	0
5	Temperate or sub-polar broadleaf forest	35.69	15.26	125.48	0
6	Mixed forest	55.15	18.27	123.70	0
8	Temperate or sub-polar shrubland	13.30	8.63	139.76	0
10	Temperate or sub-polar grassland	2.91	4.47	156.00	0
11	Sub-polar or polar shrubland-lichen-moss	0.59	1.78	194.85	0
12	Sub-polar or polar grassland-lichen-moss	3.55	2.31	75.36	0
14	Wetlands	14.89	7.76	124.39	0
16	Barren Lands	0.71	0.95	66.75	0
17	Urban	0	0	0	0
18	Water	0	0	0	0
19	Snow and Ice	0.028	0.094	35.02	0
-99	Other	0	0	0	0

Table A-21. NALCMS 2010 land cover classes with carbon estimates and updated land cover sequestration rates for land covers that remained the same, in Megagrams of organic carbon per hectare (Mg C/ha).

Land Use Code	LULC Name	Mean Megagrams of carbon per hectare (Mg C/ha)		
		C_above	C_below	C_soil
0	Unclassified	0	0	0
1	Temperate or sub-polar needleleaf forest	62.66	10.15	136.46
2	Sub-polar taiga needleleaf forest	0.44	0.3	112.86
5	Temperate or sub-polar broadleaf forest	35.35	8.98	119.79
6	Mixed forest	55.42	9.62	122.29
8	Temperate or sub-polar shrubland	12.89	8.48	141.97
10	Temperate or sub-polar grassland	2.89	3.63	153.60
11	Sub-polar or polar shrubland-lichen-moss	0.8	1.75	142.94
12	Sub-polar or polar grassland-lichen-moss	1.87	4.31	78.30
14	Wetlands	13.82	7.47	120.47

16	Barren Lands	0.67	0.97	65.85
17	Urban	0	0	0
18	Water	0	0	0
19	Snow and Ice	0.037	0.1	32.13
-99	Other	0	0	0
131	Temperate or sub-polar needleleaf forest 1 year	63.26	10.28	175.89
135	Temperate or sub-polar broadleaf forest 1 year	35.95	9.11	155.22
136	Mixed forest 1 year	56	9.75	126.34

Table A-22. Summary of aboveground biomass carbon density pool by study region.

Land Boundary	Total Area of Study Region (hectares)	Sum of Aboveground Carbon Density Pool (Mg C)	Mean Aboveground Carbon (Mg C/ha)
Greater Chilkat Watershed	489,249	7,052,430	14.41
Haines State Forest	133,812	4,741,950	35.44
Haines State Forest, Highly Stocked Stands	7,990	668,968	83.73
UALM all Chilkat lands	5,309	311,866	58.74
UALM Carbon Credit Lands	3,090	177,669	57.50

Table A-23. Summary of belowground biomass carbon density pool by study region.

Land Boundary	Total Area of Study Region (hectares)	Sum of Belowground Carbon Density Pool (Mg C)	Mean Belowground Carbon (Mg C/ha)
Greater Chilkat Watershed	489,249	2,974,964	6.08
Haines State Forest	133,812	1,610,451	12.04
Haines State Forest, Highly Stocked Stands	7,990	194,522	24.35
UALM all Chilkat lands	5,309	97,405	18.35

UALM Carbon Credit Lands	3,090	55,857	18.08

Table A-24. Summary of soil organic carbon density pool by study region.

Land Boundary	Total Area of Study Region (hectares)	Sum of Soil Organic Carbon Density Pool (Mg C)	Mean Soil Organic Carbon (Mg C/ha)
Greater Chilkat Watershed	489,248.8	43,795,934	89.52
Haines State Forest	133,812.45	13,202,185	98.66
Haines State Forest, Highly Stocked Stands	7,990	1,571,208	196.65
UALM all Chilkat lands	5,308.58	769,445	144.93
UALM Carbon Credit Lands	3,090	450,403	145.76

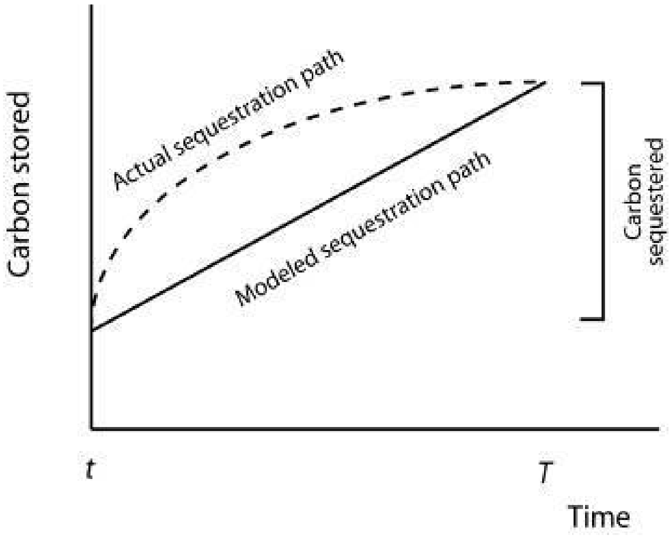


Figure A-9: The InVEST model assumes a linear change in the storage of carbon. The actual path from year to year carbon sequestration is nonlinear. Meaning the model will undervalue and then eventually overvalue sequestered carbon.

Appendix for part 3: Moving Forward in the Greater Chilkat Watershed

Table A-25. Summary of data gaps for each analysis, including potential improvements

Analysis	Type of Data	Potential Improvement of Results
Mountain Goat and Brown Bears	GPS Collar Data	Accurate representation of species movement and behavior in the Greater Chilkat Watershed would identify core habitat and other important areas for conservation.
	Specified Harvest Activity Data: Haines State Forest	Readily available shapefiles from the Haines State Forest regarding planned harvest areas, probable future harvest areas, and locations for road construction would inform more accurate identification of threats.
	Resistance Values	Localized resistance values to mountain goat and brown bear passage that are more specific to the state/region/watershed may prove more accurate. Determination of species avoidance to modified landscapes such as small communities and/or clear-cuts would specify model results.
	Traffic Patterns on Local Roadways	Data for traffic on roads throughout the watershed would inform more specific resistance values throughout the landscape.
	Internationally Standardized and/or Joined Remote Sensing Data	Uniform data or land cover classifications across international study areas like the Greater Chilkat Watershed would allow for improved connectivity and threat analyses over more landscape-level study regions.
	Areas of old growth forest in the Greater Chilkat Watershed	Identifying areas of old growth forest would allow for a more accurate representation of core areas of brown bear habitat.
Salmon	Stream Data (Velocity/Discharge, Substrate, Turbidity, Dissolved Oxygen Content)	More detailed stream data could improve the ability to determine the viability of different streams for salmon.
	Species Presence Data	Weirs dispersed within the watershed would illuminate which portions of the watershed are more vital for Pacific Salmon.
	Risk Assessment of the Palmer	A comprehensive risk assessment of the

	Project	Palmer Project and its likelihood for failure along with other potential environmental hazards would add depth to conservation priorities based on threats.
Carbon	Aboveground, belowground, and soil net annual carbon growth rates (carbon sequestration) for GCW	Chilkat-specific rates of net carbon values for accurate sequestration rates. These area-specific data would supplant the Chugach National Forest values.
	Alaska Specific aboveground, belowground, dead organic material, and soil organic carbon rasters	Alaska-specific rasters are more accurate and at a higher resolution than global rasters. This would lead to more accurate values being added to InVEST.
	Pricing data of Sitka spruce and western hemlock lumber in Alaska	Using Alaska-specific prices for lumber will allow for greater accuracy on the estimated value of timber.

Table A-26. Complete list of Haines State Forest highly-stocked parcels that were identified as being of conservation importance for both brown bears and mountain goats in the GCW. Parcels are named with their STANDID as provided in the AK DNR DOF data.

75	81	84	180	213	230	257	783	991	1047	1056	1111
1534	1541	1543	1562	1586	1705	2234	2323	2344	2377	2590	–