POLICY FORUM

The Taku River of northern BC, Canada, and south Alaska, USA, contains high mineral potential and retreating glaciers, opening up habitats for salmon.

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ENVIRONMENTAL POLICY

# Mining stakes claim on salmon futures as glaciers retreat

## Future ecological value of emerging habitats must be considered as climate change transforms the planet

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As climate change warms Earth, the melting cryosphere creates nascent ecosystems that have future value as habitat but that are also the frontlines for resource extraction (*1*). For example, glacier retreat uncovers rivers and valleys that go through rapid ecological succession to provide new habitats for important species, such as moose and Pacific salmon (*2*–*5*). However, mining companies are looking to retreating glaciers for newly exposed mineral deposits (*6*). This proglacial mining is a global pressure, from Greenland to Kyrgyzstan to western Canada (*6*). Yet environmental and mining policies might fail to consider the future ecological value and capacity of emerging habitats. We illustrate these issues below by exploring the overlap of glacial retreat, Pacific salmon future habitats, and mining pressures in western Canada and southern Alaska. Stewardship of glacierized landscapes, and other ecosystems that are being transformed by climate change, urgently need forward-looking science and environmental policy.

Migratory Pacific salmon support economies, cultures, and ecosystems and are expanding into and populating rivers in western North America as glaciers retreat (*2*–*4*). Sixty to 100% of glaciers are predicted to disappear from western Canada by 2100 (*7*). Although glacier retreat will decrease water storage and cooling capacity that poses downstream risks to people and aquatic ecosystems (*8*), linked models of climate change, glacial retreat, and salmon habitat forecast the creation of thousands of kilometers of new salmon rivers over the coming decades in western North America (*4*), a potential partial offset for losses in other salmon populations due to climate warming and other stressors. If these emerging river systems are protected, they can provide future habitats for important aquatic species such as salmon and also early-succession riparian habitats and wetlands that support moose and other wildlife (*5*).

The future capacity of these emerging habitats could be profoundly altered by industrial mining. Although mining can provide materials critical to humanity, including those to support low-carbon technologies, mining can destroy habitat, alter hydrology, and contaminate soils and water (*9*). Mining companies may also remove glacier ice with machinery or explosives to access mineral deposits or protect infrastructure (*6*).

Although prior research has documented where and when future salmon habitats will be created with glacier retreat (*4*), studies have not yet assessed where and how these future habitats intersect with mining pressures. Here we (i) identify the geographic overlap of glacier retreat, salmon habitat gains, and potential mining pressure; and (ii) examine the policy barriers and opportunities for linking this information to action. These analyses provide specific geospatial information to inform proactive land-use planning and conservation and reveal critical policy gaps and opportunities. We focus on the transboundary region of North America where rivers and potential mining impacts cross the boundaries of northern British Columbia (BC), Canada, and southern Alaska (AK), USA. In this 96,525 km$^2$ heavily glacierized region, projected salmon habitat creation is substantial (*4*) and contains the "Golden Triangle," a mining hotspot of mineral-rich geology in the western Stikine terrane. Most mining in this region appears to be targeting gold despite only 8% of global gold being used for societally important technology (*10*).

### POLICY CONTEXT

This transboundary region predominantly occurs in BC, Canada. A critical BC policy is the Mineral Tenure Act, whereby mining is currently a free-entry process and claims can be staked through an online portal by companies or individuals for a nominal fee without consultation. Mining claims grant the right for exploration, which can have its own environmental impacts (*9*). Mine claims also give companies the right for future mineral development; even if claims are speculative or stagnant, they thus pose barriers for forward-looking planning and conservation. Staking is generally allowed on all types of land, unless explicitly forbidden such as in protected areas or No Registration Reserves. Indeed, mining companies can currently stake claims on the unceded territories of First Nations and preemptively on glaciers before land is exposed.

Prior to development, mines may go through a provincial or federal environmental assessment and are subject to other environmental policies that could regulate potential impacts. However, neither BC nor

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Canadian environmental assessment laws mandate incorporation of climate change forecasts and future habitat values into evaluation of environmental risks. Further, once a project is deemed "substantially started" by BC, the environmental assessment certificate that grants the rights to mine development can be held in perpetuity. Thus, current policies do not regulate potential mining impacts on the future habitat values of locations that are being transformed by rapid climate change.

These colonial policies are being applied to Indigenous lands and waters—almost all of BC is on lands whose rights and title have never been ceded by First Nations. The BC Declaration on the Rights of Indigenous Peoples Act and the Canadian Constitution recognize the inherent rights of Indigenous Peoples to steward their territories, but these recognitions have yet to be incorporated into many colonial environmental policies such as the Mineral Tenure Act. With the increased recognition of Indigenous laws, the lands and resources in this region are governed by legal pluralism.

## FUTURE SALMON HABITAT AND MINING PRESSURE

We determined where there is overlap between future salmon habitat, mining claims, and mineral potential (*4*) (see supplementary methods). Hundreds of kilometers of future salmon habitat have been staked by mining companies for mineral exploration (see the figure). Across the 114 subwatersheds forecasted to have new salmon habitat, 25 had more than 50% of future habitat within 5 km of mining claims, and 17 had more than 90%. The overlap of mining claims and future salmon habitat varied immensely across the eight focal watershed regions. For example, 99% of 114 km of future salmon habitat were within 5 km of claims in the Nass and 62% of 279 km in the Taku, but 12% of 472 km in Central Southeast Alaska (CSE AK) and 10% of 2011 km in the Alsek (see the figure and table S1). There was also high variation within subwatersheds (see the figure). For example, for the 14 subwatersheds within the Stikine, from 0 to 100% of future salmon habitat was within 5 km of mining claims (table S2). Across all watershed regions, 564 km of future salmon habitat (out of 4973 km) were staked (11%) within 5 km, and 286 km had claims directly on them (6%) (table S1). Thus, mining companies have already staked claims over substantial future salmon habitats.

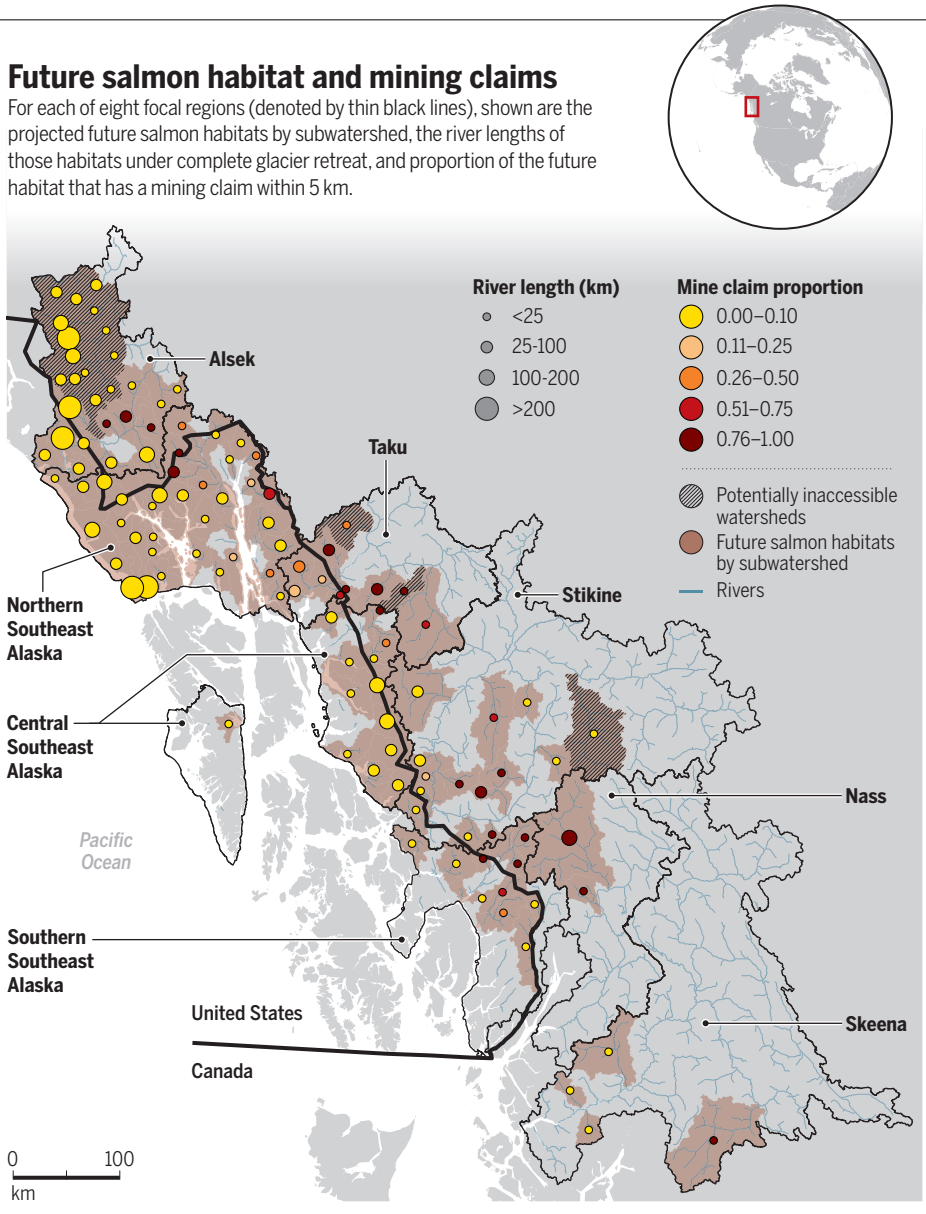
The majority of future salmon habitats also have considerable mineral potential, an additional index of future mining pressure. Of the future salmon habitat that has been assessed for mineral potential (Canada only, 2303 km), 53% of future salmon habitats were directly assessed as either high (634 km) or medium (570 km) mineral potential (tables S1 and S2). Mineral potential varied across watershed regions and was particularly high in the Stikine (82%; this and the following are the future salmon habitat directly assessed as high or medium mineral potential) and Taku (94%).

These analyses focus on projected salmon habitat quantity with glacier retreat, and the timing of its availability will vary with emissions scenarios (*4*). The quality of salmon habitat is also likely evolving rapidly. As glaciers retreat, downstream floodplain succession and channel stabilization may further improve salmon habitat over decades (*2, 3*), a potentially large-scale change that is a key research priority. Complete loss of glaciers may also increase vulnerability of downstream aquatic ecosystems to droughts and heat waves (*3, 8*).

Here we reveal the degree to which mining claims and mineral potential overlap with emerging salmon ecosystems, but how much of this potential risk will translate to direct impacts? Some claims are exploratory or speculative and may never be developed. However, the study area is undergoing a gold rush with many new explorations and major mines and substantial mineral potential, indicating that development of claims into major mines is quite possible (*9*). The region is remote, and access could limit mining development, but there have been major investments in northern BC for thousands of kilometers of transmission lines to enable mining development (*9*). Mining companies are also increasingly under pressure from their

## Future salmon habitat and mining claims

For each of eight focal regions (denoted by thin black lines), shown are the projected future salmon habitats by subwatershed, the river lengths of those habitats under complete glacier retreat, and proportion of the future habitat that has a mining claim within 5 km.

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investors to improve their environmental, social, and governance responsibility (*11*); however, mining has a long history of profoundly degrading and contaminating both terrestrial and aquatic habitats (*9*) and has been criticized for continuing to underestimate environmental risks and failing to effectively mitigate damages (*9, 12*). The scale and type of mining will also determine environmental impacts that could be either smaller or cumulatively larger than the 5-km buffer used in this analysis (*9*). Glacial retreat can also increase hazards such as glacial lake outburst floods or landslides that compound environmental risks posed by mines (*6*). Thus, the actual impacts of mining on future salmon habitats will be determined by the efficacy of current and future policies.

## POLICY OPTIONS FOR PROTECTING CLIMATE FUTURES

Our analyses delineate the locations of overlap between mining claims and future values for salmon and other species. Notably, these habitats that are emerging from ice may be considered of negligible current value to salmon and other species during risk assessments and thus omitted from protections offered by environmental laws such as BC and Canadian environmental assessment laws and the Fisheries Act. These policies focus on risks for activities to harm the current ecosystems, but do not mandate consideration of risks to future habitat values. Given that mining impacts can persist for decades to centuries or more (*9*), our analyses identified the key subwatersheds where environmental risk evaluations should consider potential harms to future salmon habitats. More broadly, there is an urgent need to mandate that risk assessment policies incorporate the best available scientific understanding of forthcoming climate change transformations to balance the protection of future environmental values and benefits with mining and other industrial pressures.

This study also identified many subwatersheds that contain unstaked future salmon habitat (table S2), representing opportunities for targeted protection of future salmon habitat through land-use plans or protections before stakes are claimed. Once claims have been staked, land protection is challenging given the current mining legislation; governments can potentially buy out claims for large sums of money only if mining companies are willing. Across the vast and remote study region, we identified locations of extensive areas that could be protected with land-use designations for salmon futures before they are staked. There is precedence for such targeted protections—habitats emerging from the retreating Mendenhall Glacier, a tourist destination near Juneau, AK, recently received protection from mining development by US federal agencies. Policy options in Canada include No Registration Reserves under the Mineral Tenure Act, Section 17 designations under the Lands Act, protections under the Park Act, and Ecologically Significant Areas under the Fisheries Act.

Indigenous Protected Areas (IPAs) are an important policy option for forward-looking conservation in the current context of legal pluralism, including where colonial governments are beholden to mineral interests which have been staked without Indigenous consultation or consent. Indigenous groups are witnessing rapid climate change and are declaring IPAs for proactive protection of future salmon habitats as changes to habitat quantity and quality play out in real time. For example, in 2021, Gitanyow Hereditary Chiefs declared that the Wilp Wii Litsxw Meziadin IPA in the Nass was off-limits for mining because of recent observations of increases in salmon associated with glacier retreat. Although two historically important salmon creeks were already protected thanks to the Gitanyow Lax'yip Land Use Plan in 2012, recent data revealed that substantial sockeye were actually spawning in Strohn Creek owing to glacier retreat, which historically had not been a substantial spawning habitat. In addition, in 2023, the Taku River Tlingit declared the T'akú Tlatsini IPA, an extension of previous protections to include glaciers and future salmon habitat. It remains to be seen to what degree the BC government will support or impede these forward-looking protections.

An alternative proactive policy option would be for the US and Canada to provide broad legislative protection of glaciers and the habitats that arise from them, in accordance with other countries such as Argentina (*13*).

Our findings also highlight the urgent need to reform the Mineral Tenure Act of BC (*14*). Gitxaała First Nation and others have challenged the Mineral Tenure Act in court on the basis that it violates their fundamental and constitutional Indigenous rights to steward their own waters, lands, and resources and called for the reform of free-entry claim staking that enables mineral exploration without consultation. Other First Nations are also working with mining industries and the BC government in new consent-based decision-making processes that advance Indigenous rights and environmental sustainability. Overhaul of the Mineral Tenure Act and incorporating mineral claim-staking into broader government-to-government land-use planning efforts would help to advance Indigenous rights and enable forward-looking and balanced land-use planning rather than having landscape trajectories be driven by market values and mining companies.

## CONCLUSION

The nexus of glaciers, salmon, Indigenous rights, and mining is a globally relevant example of the urgency of forward-looking science and policy for climate resilience and environmental justice. Here we provide the spatial information to inform proactive stewardship of climate futures for Pacific salmon even as they struggle in much of their range with climate change and other stressors, and we identify policy options and reforms to protect future habitat in glacierized watersheds. From glacier retreat to sea-ice retreat, rapid climate transformations are exacerbating industry pressures, and current policies are lagging behind the rapid pace of change. There is an urgent and widespread need to critically evaluate and reform colonial policies that were built on a static and extractive view of ecosystems and are barriers for climate adaptation. Concurrently, there is a recognized need for global action to reduce greenhouse gas emissions to slow the pace and magnitude of climate change transformation (*7, 15*). The proactive protection of climate futures demands policy reform to enable forward-looking environmental decision-making for resilience and adaptation (*1*). ■

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### SUPPLEMENTARY MATERIALS

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