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EDITED BY
Jill L. Tao,
Incheon National University,
Republic of Korea

REVIEWED BY
Ahmad Sururi,
Sultan Ageng Tirtayasa University, Indonesia
Tanguy Sandré,
UMS3342 Observatoire des sciences de l'univers de l'UVSQ (OVSQ), France

*CORRESPONDENCE
Benjamin Sovacool
✉ sovacool@bu.edu

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Climate change interventions at the "top of the world": exploring risk–risk tradeoffs in Arctic coastal protection and forest carbon removal in Alaska

Benjamin Sovacool*

Center on Forced Displacement, Boston University, Boston, MA, United States

Alaska, the largest geographic state in the United States, experiences climate change and global warming two to three times that of the global average, leading to thawing permafrost, wildfires, and more severe storms. However, managing climate interventions in Alaska is riddled with challenges that threaten to create risk–risk tradeoffs. Based on semi-structured expert interviews (*N* = 24), site visits in Alaska (*N* = 3), and photography, including within one Indigenous group in the Arctic Circle, this study investigates the concept of risk–risk tradeoffs involved in Arctic climate interventions. It does so by examining two case studies: one of a $360 million plan for coastal protection and adaptation via seawalls, revetments, and beach nourishment in Utqiagvik (formerly Barrow), as well as another case study of plans to expand the management of Alaskan boreal forests across the Tanana Valley and Matanuska-Susitna Valley to provide about $50 million worth of carbon removal services. The study explores how climate protection interventions have a target risk to be mitigated—such as flooding, storm surge, coastal erosion, accelerated global warming—but also involve adverse or countervailing risks such as permafrost thawing, sea level rise, inward human migration, wildfires, invasive species, and insect outbreaks. The study then discusses implications of these results in terms of differential risk dynamics, intersecting risks, and uncertainty. In doing so, it reveals a recurring and capricious challenge in terms of climate policy, climate protection, and risk management. It highlights creative adaptation of local policy instruments to combat climate change, and illustrates the value of engagement with non-governmental entities to fortify policy measures.

KEYWORDS

climate mitigation, comparative risk analysis, energy security, low-carbon transitions, risk tradeoffs

1 Introduction

Alaska offers an exemplary site for climate change interventions given that it is experiencing global warming two to three times that of the global average (U.S. Energy Information Administration, 2024). Alaska's coasts are now vulnerable to changing high water marks, ground erosion, flooding and even cyclone damage (Horen et al., 2022). The Arctic homeland is not only changing in terms of measurable weather extremes and climate, it is altering the things that its Indigenous residents viscerally and qualitatively see, hear, and smell (Buscham, 2022). Thawing permafrost is releasing 70 more percent carbon dioxide now than 50 years ago, but the state also has the second highest rate of energy consumption in the United States and the fourth most carbon emissions per capita, at 47.6 tons (U.S. Energy Information

Administration, 2024). Nevertheless, managing climate interventions there is fraught with difficulty, given that it is more than twice as large as the state of Texas, and it also occupies about one-fifth of United States territory (Dagnino, 2023).

This study explores climate protection in Alaska through the conceptual approach of "risk–risk" tradeoffs. Graham and Wiener (1995: p. 23) define a risk–risk tradeoff as "the change in the portfolio of risks that occurs when a countervailing risk is generated (knowingly or inadvertently) by an intervention to reduce the target risk." Put another way, risk–risk tradeoffs refer to when new risks are created while addressing existing ones (Hansen et al., 2008). Attempts to address a target risk can lead to new, unintended, or even more dangerous risks that increase net risk to society, rather than ameliorating risk (Sovacool, 2025). In the context of climate change adaptation, interventions can erode resilience to climate hazards (Matin et al., 2018; Sovacool et al., 2015) and generate cycles of vulnerability and impoverishment among rural communities (Rao and Enelamah, 2024).

This study investigates the dilemma of risk–risk tradeoffs in the implementation of two sets of climate change interventions in an underexamined context of the "top of the world," the Arctic: coastal protection against erosion and storm damage in Utqiagvik (formerly Barrow) on the North Slope, and afforestation, reforestation, and forest management in Tanana Valley and Matanuska-Susitna (commonly referred to as "Mat-Su") Valley boreal forests in the Alaskan interior. In each case, based on original qualitative and photographic data, the study investigates how climate protection interventions have a target risk to be mitigated but also involve, or fail to address, adverse or countervailing risks. It begins by summarizing its selection of two case studies and qualitative research design before presenting its results conceptualized via the risk–risk framework identifying target risks and adverse countervailing risks in Section 3 (coastal protection case study) and Section 4 (forestry case study). In Section 5, it discusses differential risk dynamics, intersecting and compounding risks, and uncertainty in future predictions. Section 6 concludes with policy implications as well as recommendations for risk management.

In doing so, the study aims to make empirical, conceptual, and policy contributions. Empirically, it draws on original field research covering two case studies that have not yet been examined in the energy and climate policy literature, including the use of original qualitative data from one Indigenous Group (the Inupiat) in one community in the Arctic Circle (Utqiagvik). Conceptually, it extends current thinking on risk–risk tradeoffs, which tend to frame them in terms of population exposure (shifting from one group to another), to a broader set of dimensions including non-human infrastructure, ecosystems, temporality, and space. It also raises a set of policy relevant concerns that climate change planners along with those involved in land use management, forestry, technology and innovation policy, industrial strategy, and climate resilience need to become more aware of. It highlights creative adaptation of local policy instruments to combat climate change and illustrates the value of engagement with non-governmental entities to fortify policy measures.

2 Study location and research design

Within Alaska, the study investigated locations piloting two types of climate interventions: Arctic coastal protection and adaptation in Utqiagvik, and carbon forest management in the Tanana Valley and Mat-Su Valley State forests. This selection of cases was chosen to reflect geographic diversity (one coastal community, two forests on the Interior), climatic diversity (one North Slope location with a tundra and permafrost climate, one forest with a permafrost climate, one forest with a temperate climate), technological diversity (coastal protection measures, forestation measures), and availability and accessibility (all three sites were willing to host the research team).

Two other criteria for case study selection were novelty and generalizability. In terms of novelty, the Utqiagvik case is interesting because it is a unique blend of "hard" infrastructure measures (seawalls, revetments, storm surge barriers) with soft measures (beach nourishment); the forest case equally interesting for its "ecosystem management" approach which has a simultaneous focus not only on trees but soils, habitats, and other environmental services.

In terms of generalizability, although the place-based circumstances surrounding Alaska—and particularly Utqiagvik—are unique, the types of coastal protection technologies being used (seawalls, revetments, beach nourishment) has relevance for thousands of other communities and locations given that coastal areas are home to a considerable portion of the U.S. population, with about 40 percent of the population living in coastal shoreline counties, which are also sites of $8.3 trillion of economic activity (U.S. Government Accountability Office, 2019), but also face the same threats of coastal storms and flooding that confront Utqiagvik. Moreover, examining Alaskan boreal forests is vital because they have been framed as the "next frontier" for carbon removal markets where the state could even become the national leader in generating carbon credits (Dagnino, 2023).

2.1 Coastal protection and adaptation in Utqiagvik

Utqiagvik (formerly Barrow), translated from the Inupiat language to mean "the place where snow owls are hunted," is in the Chukchi Sea coast and is the northernmost community in the United States. It has a legacy going back thousands of years as a critical archeological site containing dwelling mounds that were occupied as early as 500 years after the birth of Jesus Christ (AD 500) by subsistence hunters, who sought out bowhead whale, seals, walruses, and birds. Oil and gas revenues from Prudhoe Bay as well as a local gas field brought additional wealth in the 1960s and 1970s, along with the siting of the Naval Arctic Research Laboratory there in 1946. Utqiagvik was incorporated as a "First Class City" in 1958, and it currently has a population of approximately 5,500 people, of which about 70% are Inupiat. Athabaskans have traditionally lived in the area as well (Meek, 2012). The city operates as an economic, administrative, and transportation center for the entire North Slope region.

Utqiagvik was selected as a case study because it has suffered damage from multiple severe storms which have accelerated erosion of its coasts, to the point where a massive federal and state project is underway to provide coastal protection via the "Barrow Coastal Storm Damage Reduction Project," which is seeking to build a series of seawalls, revetments, and beach nourishment activities. The city is built literally on top of permafrost, which means water pools because it does not drain, and if one digs down fifteen feet, they will hit permanent ice, which is why all houses are recommended to be built on pylons or pilings, or else they sink in and freeze; it is also why the city has no paved roads, other than a one mile patch in front of the Wiley Post–Will Rogers Memorial Airport. The community has a unique Utilidor project that provides hot water, steam, heat, and electricity to most houses; those unconnected to it are still dependent on "honey buckets" for human waste, which means they do not have access to sewage or indoor plumbing, and need water delivered and waste removed in buckets. Lastly, the community resides within an Arctic desert climate with very little humidity or precipitation.

Discussions about storm damage reduction in Utqiagvik have been ongoing for more than 50 years. In October of 1963, a powerful cyclonic storm brought 90 miles per hour winds, flooding, and extensive erosion: seawater moved 400 feet inland into parts of the town, causing more than $25 million in damages to homes, roads, the water system, radio towers, and utilities (U.S. Army Corps of Engineers, 2010). Storm reduction efforts began in earnest in the late 1990s and early 2000s after further storms caused damage to the city's infrastructure. Planners spent another $28 million to facilitate offshore dredging, beach nourishment, the construction of berms, and the construction of large geotextile "supersacks" laid on the bank slope, surplus wooden utilidors filled to create a seawall, old tar barrels laid on the upper beach slope, and Longard geotextile tubes laid along the beach (U.S. Army Corps of Engineers, 2007).

Utqiaġvik's situation become even more precarious in 2018 when a series of multiple severe storms destroyed the seawall that protected parts of the downtown area and threatened the integrity of the Old Barrow Landfill and the only fresh water source in Utqiaġvik (Lavrakas, 2023). The community had been spending millions of dollars every year to build temporary berms by bulldozing beach sand but wanted to consider designs for a more permanent solution.

Plans from the North Slope Borough, Alaskan state government, and federal government coalesced to commence upon the Barrow Coastal Storm Damage Reduction Project (also sometimes referred to as the "Barrow Coastal Erosion Protection Project"). Indeed, Utqiagvik has been recognized as one of 31 Alaskan Native Villages deemed to be "facing imminent threats of flooding and erosion that may eventually face relocation" (Garland et al., 2022). The project, at a cost between $328.6 million (U.S. Army Corps of Engineers, 2019) and $364.3 million (Lavrakas, 2023; Rosen, 2023), seeks to implement three interventions (U.S. Army Corps of Engineers, 2010; Press Release, 2022; Press Release, 2023):

- Deployment of a revetment to protect bluffs from slumping, niching, and major erosion, with materials to be used including rocks, supersacks, and articulated concrete mats. This would provide additional strength to existing homes and buildings. Plans would be to provide protection of the entire bluff face, and planners note this aspect of the project would have easy construction needs with land-based equipment, and it would be easy access to inspect for damages and to repair.
- The use of dredging and beach nourishment to place material from the sea bottom into Barrow beaches, this would replenish sand and land previously lost to erosion. This part of the project assists in returning the beach to its original state. This would have the added benefit of reducing wave impacts at the base of bluffs, and of building up sediment and possibly raising beach elevation resulting in milder wave climate at the base of the bluffs.
- Construction of a seawall with supplementary offshore breakwaters to protect infrastructure, reduce wave impacts and erosion, and prevent the loss of further land. This would also provide a large and ostensibly permanent area of flood protection.

Funding and approval for the project have been via the Comprehensive Plan and Capital Improvement Plan for Utqiagvik, as well as the U.S. Army Corps of Engineers Barrow Coastal Erosion Feasibility Study and lastly the 2022 Disaster Relief Supplemental Appropriations Act under the Infrastructure Investment Act (Garland et al., 2022).

In its most recent incarnation, the project will protect five miles of coastline, rehabilitate the bluff area, and raise and revert one of the lost roads, Stevenson Street. Construction has already begun, and the project is expected to reach completion in 2031 (Lavrakas, 2023). In late 2022 and 2023, the United States Senate included an update to the Water Resources Development Act as part of the National Defense Authorization Act to add in a 10 percent cost sharing option for economically disadvantaged communities like Utqiaġvik, meaning the federal government will cover 90% of expected costs. The entire project is expected to include a rock revetment structure along a section of the Utqiaġvik shoreline consisting of about 23,200 cubic yards of fill placed in the intertidal and subtidal zones, 11,900 cubic yards of armor rock, 6,600 cubic yards of B stone, 2,300 cubic yards of core rock, and 2,400 cubic yards of gravel (Lavrakas, 2023).

2.2 Afforestation, reforestation, and carbon removal in Alaskan state forests

Our second case includes two Alaskan state forests, or more technically boreal forests, forests that are adapted to survive in frigid temperatures year-round, with a mix of deciduous trees (such as birch and aspen) as well as conifers (such as white and black spruce) (WWF, 2024). According to the forest governance literature, Alaska has amazing forests, due to very large areas of intact habitats (Vynne et al., 2021; Carstensen et al., 2014; Deal et al., 2014), although this statement has its own linkages to colonialist value judgments. Nevertheless, due to its size, Alaska hosts one-third of all federal lands, most of the country's intact wild lands, 62% of the country's terrestrial ecosystem carbon stocks, and 63% of the nation's wetlands (Dagnino, 2023). These numbers actually underestimate the full extent of forest cover in Alaska, given that the 1971 Alaska Native Claims Settlement Act transferred millions of acres and nearly a billion dollars to newly formed regional and village corporations, and the 1980 Alaska National Interest Lands Conservation Act designated another 104 million acres in Alaska for conservation, creating numerous national parks, wildlife refuges, and wilderness areas allowing for traditional subsistence uses by rural residents. Collectively, such federal and native forests are home to caribou reindeer and other animals that can migrate long distances every winter, especially birds and bears.

These forests are critical sites of potential carbon removal and storage because of the 126 million acres of forestland in Alaska, one-quarter of all federal forestland and 43 percent of all state-owned forestland in the country is found there (FS-R10-FHP, 2021). The Alaskan Department of Natural Resources has identified the Tanana Valley State Forest, and the Mat-Su Valley Forest, as two key locations that it believes could generate carbon offsets. The Tanana River Basin is in the east-central part of Alaska outside of Fairbanks. The Matanuska-Susitna Borough, or Mat-Su forest, is centrally located between Anchorage and Denali National Park and Preserve in Southcentral Alaska.

Efforts at utilizing Alaskan forests for carbon storage and carbon markets solidified in 2023 with Governor Mike Dunleavy's implementation of SB48, formally entitled the "Carbon Offset Program; Carbon Storage Bill," but commonly known as just "The Tree Bill" (George, 2023). The Tree Bill authorized the Department of Natural Resources to lease land for carbon management purposes, and it established a carbon offset program that also authorized the use of land and water within state forests for carbon storage purposes. The Alaska Department of Natural Resources (2022) has identified three such state forests as sites for the first phase of the plan: the Haines States Forest near Juneau, the Tanana Valley Forest near Fairbanks, and the Mat-Su Valley Forest near Anchorage. We visited two of these three forests: the Tanana Valley and Mat-Su Valley. The Alaska Department of Natural Resources (2022) estimates that the Tanana Valley Forest in south-central Fairbanks could produce more than 830,000 carbon credits over a decade, bringing in $24 million in revenues, which assumes a conservative growth rate of forest and a 25% rate of harvesting. Mat-Su Forest could generate a similar volume of 870,000 credits at a slightly higher amount of revenue at $25 million.

SB48 and its carbon forest projects were stated to have two unique advantages over other forest programs globally. Firstly, the Alaska Department of Natural Resources Division of Forestry and the United States government are known for having well governed, transparent, and accountable forest management programs (Overdevest and Rickenbach, 2006; Davis et al., 2017; Halofsky et al., 2018; Abrams, 2019). Secondly, both the Tanana Valley and Mat-Su forests are sites of afforestation and reforestation in addition to just conservation. These efforts ensure that Alaskan forests never shrink (in theory), they only maintain their current size or grow.

2.3 Qualitative research design

With our cases identified, we proceeded to execute a research design consisting of expert and community interviews, site visits, and the use of photographs.

Firstly, the research team conducted 24 semi-structured qualitative expert and community interviews over the course of July and August 2024. For each location (Utqiagvik, Tanana Valley, Mat-Su), we sought to interview a broad range of stakeholders including representatives from:

- Federal government, e.g., U.S. Department of Agriculture, the US Fish and Wildlife Service or the National Oceanic and Atmospheric Administration.
- State government, e.g., Alaska Division of Forestry.
- Local government, e.g., the North Slope Borough, Arctic Slope Native Association or the City of Utqiagvik City Council (former members) or UIC-Science.
- Research institutes or academic departments at the University of Alaska Fairbanks or the Pacific Northwest Research Station.
- Civil society organizations such as the Alaska Fire Science Consortium, Boreal Forest Council, or the Ecological Society of America.

Recruitment of respondents was purposive, rather than fully representative, although all interviews were recorded and fully transcribed for qualitative analysis. Although anonymized for research ethics purposes, Supplementary Table S1 shows the respondent numbers, dates of the interviews, and types of institutions of those being interviewed, as well as their expertise pertinent to either case study. Interview questions focused not only on technical performance and innovation for each climate intervention but also barriers and risks, policy and governance, and public and stakeholder involvement. Supplementary Table S2 showcases our interview discussant guide and questions.

Although many of our interviews were done in person and face to face, when requested some were done via Zoom. In most cases, when consent was given, the research interviews were digitally recorded, generally lasted between 30 and 90 min, and participants were guaranteed anonymity to protect their identity and encourage candor. Every transcript was coded, and then analyzed thematically. Interview statements were taken at face value. That is, we did not attempt to correct or problematize interview statements, even when they may have been "wrong," to avoid censoring our results and discussion. This also ensured we met the justice principle of recognition, namely that the concerns of all respondents were respected and treated as valid.

Secondly, to supplement the interviews, the authors conducted site visits to each of the three core locations. The intent of the site visits was the opportunity to triangulate the insights of the interviews with naturalistic observation, helping correlate stated preferences (interviews) with revealed preferences and context (the site visits). Figure 1 depicts the settings at three of the locations visited.

Thirdly, the study presents numerous photographs related to its case studies, collected during our fieldwork. Although these were not analyzed systematically, the use of photographs is a common feature of academic work across disciplines such as advertising and marketing, anthropology, communication studies, ethnography, geography, and sociology. For in these fields, photographs act as important "physical evidence" that can "develop a more precise understanding" of the topic being studied (Yin, 2003: p. 96). Photographs can uncover a form of "visual ethnography" that reveals the meaning behind events in ways that words cannot (Pink, 2007). Moreover, because human beings experience their world through both words and images, the exclusion of "visual elements" from the argumentation process artificially narrows the research process (Birdsell and Groarke, 1996). As Prosser and Schwwartz (1998: p. 116) wrote:

> [Photographs] can show characteristic attributes of people, objects, and events that often elude even the most skilled wordsmiths. Through our use of photographs we can discover and demonstrate relationships that may be subtle or easily overlooked. We can communicate the feeling or suggest the emotion imparted by activities, environments, and interactions. And we can provide a degree of tangible detail, a sense of being there and a way of knowing that may not readily translate into other symbolic modes of communication.

FIGURE 1
Selected locations of site visits in Alaska, July 2024. Source: All photographs taken by the authors during field research. **(A)** Shows the City of Utqiagvik; **(B)** its coast. **(C)** Shows the Tanana Valley State Forest; **(D)** a state forestry official showing the research team around the Mat-Su Valley Forest.

Rose (2008) adds that photographs play such a "major role" in many social science disciplines because their use can help readers better comprehend "what is this place like?" Photographs offer both a transparent window into places readers would never otherwise see, as well as prisms that refract what is seen in distinct ways, which is why this study features them alongside its textual data.

That said, when presenting original photographs throughout the manuscript, it is not the author's intent to portray them as coldly objective documentation of events, people, and places. Instead, it is to adhere to Cleland and MacLeod's call to move beyond "linguistic imperialism" of textual narrative and to embrace a more visual medium capable of conveying different levels of meaning. The author's technique falls within what Cleland and MacLeod (2021) term the researcher driven "photo-documentation" approach. This is where the researcher themselves determines which settings, scenes, people, or objects they find personally interesting, or that have sufficiently salient meaning to convey about a topic or theme. It differs from other techniques such as photo-elicitation (using photographs as prompts in an interview), photovoice (where respondents take photographs themselves), or grounded, visual pattern analysis (a systematic way of analyzing visual images). By contrast, the approach adopted here was subjective, done by the author, and non-systematic.

2.4 Research ethics statement

The Alfred P. Sloan Foundation has supported this research via the "Mapping the Social Landscape for Net Zero and Climate Change Resiliency" project, grant number G-2021-16777. This project has also received funding from the European Union's Horizon 2020 research and innovation program under the European Research Council (ERC) Grant Agreement No. 951542-GENIE-ERC-2020-SyG, "GeoEngineering and NegatIve Emissions pathways in Europe" (GENIE). Thus, it was approved by the Institutional Review Board at Aarhus University 2021-13 as well as by the Ethics Committee at the European Research Council. Written formal consent was obtained from all expert interview respondents. Ethical dimensions associated with researching Indigenous People were also taken into consideration. Informed consent was obtained in writing for all research participants, and there was also shared benefit in that interview respondents were remunerated for their time and offered US$100 for each interview. Moreover, transcripts of the interviews were shared with all participants to guarantee their accuracy and to ensure that any statements made would not harm any of the participants. Lastly, given that the project was partly funded by a European Research Council project, extra privacy protections have been instituted to ensure compliance with the

General Data Protection Regulation (GDPR), a stringent European Union law that protects personal data and privacy for individuals.

3 Results of the first case study: Arctic coastal protection and climate change adaptation in Utqiagvik

In the case of coastal protection in Utqiagvik, the climate intervention involves the Barrow Coastal Storm Damage Reduction Project. For this case study, the risk–risk framework identifies target risks (mentioned in Section 3.1) such as reducing the impact of storms, flooding and coastal erosion, preserving cultural heritage, and protecting critical community infrastructure. However, countervailing adverse risks (identified in Section 3.2) include sea level rise, thawing permafrost, inward migration and community disarticulation.

3.1 Target risks: coastal erosion and storm damage, cultural heritage, and community survivability

Three target risks identified in our interviews, site visits, and document analysis relate to a reduction of erosion and flooding damages from more severe storms, protection of cultural heritage, and enhanced community survivability, especially for critical infrastructure.

3.1.1 Storms, flooding and coastal erosion

The clearest target risk is a reduction of both coastal erosion and flooding from severe storms, threats that have been exacerbated not only by accelerated climate change and global warming, but also human activity, such as mining for gravel on the beach and bluff around Utqiagvik (U.S. Army Corps of Engineers, 2007). As respondent AK6 stated, "Since living here, I have seen 300 feet of the coast disappear in front of my house, that's a size of beach lost already greater than a football field." AK7 added that "previous efforts to protect the coast have proven ineffective, noting that planners first installed sandbags, but those broke apart; then they installed metal tanks, but those floated away; then they filled the metal tanks with sand, but those cracked and eroded." Indeed, we saw visual evidence of all three trends during our site visit (see Figure 2).

In its own assessment of changes to shorelines and coasts, the United States Geologic Survey has warned that the North Slope of Alaska is losing about 4–5 feet of coastline per year (Lavrakas, 2023). Another study estimates erosion as great as 9.5 meters (about 31.1 feet) a month (Rosen, 2023). This means, in comparative terms, that the North Slope has some of the fastest rates of erosion measured in North America and even the world. The reasons behind such accelerated erosion are manifold, and include a reduction in landfast sea ice, which protects the coast from waves, winds and currents; more severe storms with more powerful storm surge; stronger waves; and more precipitation falling as rain and mist rather than snow, further weakening the ground (Rosen, 2023). Sea ice loss is particularly harmful, as more open water creates more opportunities for waves to hit the beach and contact permafrost bluffs. As the U.S. Army Corps of Engineers (2007: p. 23) concluded, "Near shore pack ice can prevent the formation of waves during storm event; however, when the pack ice remains further offshore for longer periods of time severe storms can generate wind driven waves that can cause significant shoreline."

Given these factors, the U.S. Army Corps of Engineers (2010) predicted an increase in storm surge elevation from 2.3 feet in 2030 to greater than 3.5 feet by mid-century. The expected loss of land and coast over a 50 year period could be substantial, with the U.S. Army Corps of Engineers (2010) anticipating at least a loss of 7.4 acres of land due to bluff retreat, as well as stage-frequency curves showing a flood elevation of 12 feet during an extreme storm event, all placing a multitude of homes and roads at risk to both erosion and flooding. AK5 therefore saw the new seawall project as "vital" to the protection of the city, and AK7 believed that it was "absolutely necessary."

3.1.2 Cultural heritage and trauma prevention

A second target risk was to prevent the erosion of culture and trauma facing residents of Utqiagvik, a majority of whom are Inupiat. The preservation of Indigenous culture is particularly important given that Alaskan Natives have had to confront waves of colonialism and exploitation, dating from settler occupation from the Russians and Americans to battling with oil and gas corporations, fighting against plans to explode thermonuclear bombs on the edge of Native villages, litigating against political plans to flood Native homes, struggling to receive adequate remuneration for the *Exxon Valdez* oil spill disaster, and perpetually resisting government efforts to stop subsistence fishing or hunting (Purvis, 2024). This puts the Inupiat at the veritable frontline of environmental justice activism when it comes to confronting such threats (Hauser et al., 2023; Sandré et al., 2025).

The Alaska Native Inupiat are known for their subsistence hunting of the bowhead whale. As AK4 explained:

> Culturally, Utqiagvik is the cradle of civilization for bowhead whale hunting, that economic way of being in the world. Marine mammals just come here and have been coming here for thousands of years. It's one of the only places in the world where the beluga whales also surface in breaks in the ice sheet not only once a year, but twice a year. It's also a place where local hunters still chase and catch seals, walruses, and other animals for subsistence.

Indeed, we observed in our site visit many slogans showcasing the appealing nature of Indigenous lifestyles and whaling, as well as the active drying and use of seal meat (see Figure 3). This element of cultural protection has become even more paramount given that many other decentralized Indigenous villages and communities, who do not have a Utilidor or access to a natural gas power grid, have seen their populations dwindle due to causes such as declining health, aging populations, and the fall of regional fish and game populations related to energy development (Sovacool, 2006; Cuomo et al., 2008; Walker et al., 2016; Kruse et al., 1982), to the point where dispersed community survival is not guaranteed. In this light, Utqiagvik offers a refuge for Indigenous peoples from Anaktuvuk Pass, Atqasuk, Kaktovik, Nuiqsut, Point Hope, Point Lay and Wainwright a place to reside that is still within the Borough, rather than having to permanently relocate outside of the region (U.S. Army Corps of Engineers, 2010).

Affirming the salience of this target risk, Garland et al. (2022) utilized Participatory Applied Theater and focus groups during three consecutive summers 2016–2018 to evaluate the risk perceptions

FIGURE 2
Visual evidence of coastal erosion and failed previous attempts at reducing the risk of erosion and flooding. Source: Authors. **(A)** Shows the broken sandbags, **(B)** the empty tanks, **(C)** the filled metal tanks with signs of fatigue and cracking, **(D)** a fully eroded and closed road.

and interpretations towards coastal changes and relocation as an adaptive response in the Barrow area. They indeed noted that respondents felt that coastal protection was one of the most important measures being adopted to address cultural risks to the community. That study also underscored perceptions among respondents that leaving their home, via forced relocation, would be highly traumatic. As one of this study's participants said, "for the folks who are going to have to move their homes, it's going to be a traumatic experience because there's a connection to the land and because it belonged to their ancestors and their people, the people they loved."

3.1.3 Community survivability and vitality

A final target risk is that of community vitality and survivability, given that much critical infrastructure sits very close to the ocean; the project also has the promise of bringing improved community benefits such as better emergency response, navigation, and protection of the city's Utilidor. Buzard et al. (2021) note that communities in Northern Alaska have all seen critical infrastructure needs expand, with runways doubling in their size to accommodate larger aircraft, bulk fuel tank farms expanding to meet population growth, wastewater lagoons increasing in their size, and landfills being installed alongside water systems, schools, homes, and roads. However, for a community such as Utqiagvik, these are almost always located closer to the shorelines.

Rural communities such as Utqiagvik are also unique in their remoteness and disconnection from road systems, meaning they are only accessible by plane year-round, and during the summer months by barge for supplies. They also tend to have isolated grids for utilities and infrastructure, in this case a 3-mile-long tunnel of water, sewer, and electrical pipes known as the Utilidor (see Figure 4). At a cost of $800 million, funded mostly by oil and gas money, the Utilidor is Utqiagvik's most valuable asset (Kunze, 2020). When one monetizes such critical infrastructure, it more than exceeds the cost of the project, with the U.S. Army Corps of Engineers (2019) estimating "over $1 billion of critical infrastructure, access to subsistence areas, and cultural and historical resources" within the community.

Without backup options, these critical facilities, especially the Utilidor, are essential to the community's survival. AK4 explained that this is why the project is taken so seriously within the community: "Yes, the project is expensive, but it's essential, it's key to our survival." AK7, who lived in one of these homes, emphatically stated that:

> Parts of our land have already collapsed due to erosion, this is why we need the seawall and revetment project, we are about a 3-foot wave away from taking the front of my property, fissures opening up into the yard, our bird haven, we have just inches left between where the sled is and the edge. I am already taking things of value out of the house, as my husband jokes, I can fish out of my front

FIGURE 3
Cultural heritage and pride throughout the Indigenous community of Utqiagvik. Source: Authors. **(A)** Shows hanging seal meat outside of one of the homes, **(B)** positive messages about local hunting lifestyle, and **(C)** artistic depictions of whale harvesting in the local museum. **(D)** Shows whale bones and traditional Inupiat whaling boats.

> window … I get scared every time it rains, rushes of water dragging down sand and dirt causing more cracks in the land.

AK5 added that "It is definitely needed, it is currently very dangerous living in those homes near the coast, literally one day people residing there will wake up and find themselves floating in the middle of the ocean." For reasons such as this, multiple respondents spoke about how the seawall project has immense political and local support.

3.2 Adverse countervailing risks: sea-level rise, thawing permafrost, and migration

Following the risk–risk framework, adverse countervailing risks include sea-level rise, thawing permafrost and human migration.

3.2.1 Sea level rise and infrastructural risks

One adverse and possibly egregious countervailing risk is whether the Barrow Coastal Storm Damage Reduction Project can reduce the risks of flooding and erosion, given projections of sea level rise and infrastructural integrity. As AK8 stated, "current design specifications are based on projections of sea-level rise and temperature, but how reliable are those on a 50-to-100-year timeframe?" Glick et al. (2010) warned more than a decade ago that the average global "eustatic" sea level rose about 7 inches over the 20th century, which was 10 times faster than the average rate of sea-level rise during the last 3,000 years; since 1990, sea level has been rising 3.4 mm/year, twice as fast as the average over the 20th century, and it could rise a staggering 74.8 inches further by 2,100. Sea-level rise more accelerated than these trends could, in the word of AK3, "overwhelm and offset any seawall or revetment project planned now."

Moreover, the U.S. Army Corps of Engineers (2010) has warned that revetments, seawalls, breakwaters and beach nourishment activities are all susceptible to ice damage, could have high to very high maintenance requirements, and in some cases have severe tradeoffs. For instance, they note that while the seawall protects the bluff from erosion, this could come at the expense of eroding the fronting beach. They also note that a breakwater would produce a sediment deficit downdrift of the groins. Lastly, they caution that the performance of all planned interventions has great uncertainty in an Arctic environment.

3.2.2 Thawing permafrost

The Barrow Coastal Storm Damage Reduction Project, as the name implies, targets risk from storms, erosion, and flooding, but it does not account for the risk of thawing permafrost. However, thawing permafrost is occurring due to alterations in precipitation patterns from snow to rain, which sends heat from the surface into the soil, and that thawing is causing vast stretches of land to sink, pulling down the

FIGURE 4
Critical infrastructure providing essential services to Utqiagvik. Source: Authors. **(A)** Shows the community's natural gas fired power plant, managed by the Barrow Utilities & Electrical Cooperative Inc. **(B,C)** Depict the $800 million Utilidor providing energy, heat, and utility services to Utqiagvik. **(D)** Shows the municipal reservoir used for water supply.

coastline along with the rest of the landscape. Rosen (2023) report that measured sinking across the North Slope from 2017 to 2022 averaged 3 centimeters to 5.8 centimeters, depending on location. AK4 noted that "melting permafrost is a huge problem, one we do not have a solution for, pipes are bursting, roads have to be shut down, holes need filled in." Figure 5 shows many of these incidents which we witnessed during our field research. AK7 added that thawing permafrost represents one of those existential threats facing the community that "leads to one of these holy shit moments, like what can we do in the face of that?".

3.2.3 Inward migration, loss of social cohesion, and disease epidemics

A final adverse risk relates to the possibility that if Utqiagvik becomes the most livable regional hub on the North Slope, it could lead to accelerated migration into the city from other villages, something AK10 feared could "overwhelm its ability to provide services to everyone, and eroding the social cohesion of the community." Garland et al. (2022) picked up this theme as well in their own field research asking the Barrow community about perceived risks of staying in Utqiagvik versus relocating. Respondents were concerned about some risks that a seawall could not address, such as tundra fire, tsunami, and earthquake. They were also concerned about other risks that could be exacerbated, such as the spread of infectious diseases caused by an influx of people moving or visiting Utqiagvik. There is even the aggravated possibility that the seawall project makes it more livable for people to live in Utqiagvik, meaning they do not abandon it or relocate, and instead become entrenched, living in an area susceptible to more lasting permafrost melt and subsidence, which the seawall will not protect against. In the extreme, the seawall project can be critiqued for diverting resources from managed retreat, and at a cost of $364.3 million for 5,000 people, or about $72,860 per person.

4 Results of the second case study: carbon storage in Alaskan forests

The second climate intervention involves carbon storage in Alaskan forests. Again, following the risk–risk framework, Section 4.1 describes how forest carbon removal seeks to address target risks of climate change, wildlife protection, and loss of rural economic development via timber concessions and recreational uses such as fishing, hunting, and hiking. However, Section 4.2 reveals it only does so at the adverse countervailing risk of heat stress, severe storms, more wildfires and pests, and concerns over additionality.

FIGURE 5
Signs of potentially irreversible permafrost thaw and subsidence in Utqiagvik. Source: Authors. **(A)** Shows shifting graves in the local cemetery within Utqiagvik, **(B)** a home already damaged by permafrost thawing, **(C)** shows permafrost related subsidence near the community's tank farm, **(D)** large shifts in land already affecting the Utilidor.

4.1 Target risks: carbon storage, wildlife conservation, and community benefits

Three target risks arose from our original data related to carbon storage permanence and durability in Alaskan state forests, the protection and conservation of wildlife and habitats, and the provision of community co-benefits.

4.1.1 Carbon storage and climatic stability

Because of the unique properties of their soils, the climate, and their remoteness, conservation of boreal forests has become a primary mechanism to achieve carbon storage—ultimately contributing to more climatic stability and less severe climate change—given such forests operate as significant carbon sinks (Kalies et al., 2016). Even though boreal forests grow slower in the Arctic than in tropical or temperate climates, AK2 explains how they still have many advantages from a carbon storage standpoint:

> It is true that in Alaska tree growth is much slower, tree diversity much lower, with simple forest structures evident. However, unlike forests in other parts of the United States, many areas in Alaska have not received any major harvests, they have been preserved as far back as the steamship era. They are stable, highly protected, and potent yet durable ways to undertake carbon storage … the state has a very small forest products industry compared to other areas. Of the 1.8 million acres of state forest that I manage, only about a fifth have roads within a few miles, a vast majority is not accessible, making them ideal for carbon offsets.

AK21 noted that with carbon removal, they "would love to see another market and source of revenue for state forests … and we could even invest some of that revenue back into afforestation, beyond protected sites. A designation as a carbon forest would enable us to change our management scheme, which might mean we protect more forests from pests or fires, or more actively do it, or do more opportunities for tree planting, nature protection, and forest revitalization efforts."

These purported benefits to Alaskan and boreal forests (along with their soils) to carbon storage have been affirmed in independent academic studies. Vynne et al. (2021) report that the amount of carbon stored on federal lands in Alaska is approximately 62% of the total carbon stored on all United States federal lands. Vynne et al. (2021) estimate that Alaska could contribute more than 50% of the total carbon storage for the entire United States. Michaelson et al. (1996) similarly project that soils within Arctic tundra ecosystems contain about 13% of the global soil carbon pool, and that permafrost can contain up to four *times* the amount of carbon present in the active layer of trees and soils.

4.1.2 Wildlife conservation and habitat protection

Our data suggests that the protection of Alaskan state forests for carbon removal and management not only stores greenhouse gases but protects wildlife and the habitats that it depends upon. As AK20 put it:

> Carbon removal results in forest conservation which also benefits a more diverse landscape, resulting in habitat protection, wildlife preservation, and even water quality preservation. We know that tree planting for example reduces flooding, slowing runoff, improving water quality. We now recognize forests have a much broader benefit than just providing timber.

AK21 added that "Surprisingly, some parts of the forest here very dense, and they support an array of very special wildlife from bears and foxes to birds and other charismatic megafauna."

Indeed, Vynne et al. (2021) write that one added benefit to carbon storage in Alaska is that it preserves large tracts of intact habitats, which then support "complete wildlife assemblages and many of the world's healthiest wild fisheries, while also storing significant amounts of carbon." They note that such intact landscapes, found only in remote locations such as Alaska, serve critically important ecosystem functions such as remaining a stronghold for imperiled or endangered species, for supporting complete or near-complete rosters of large mammals, for supporting globally significant sites for breeding shorebirds (Alaska is a habitat for as much of 50% of all shorebirds in North America), and for conserving intact habitats that support multiple salmon runs. Wells et al. (2020) estimate that in Alaska, the biome is 80% intact, which is why it is able to host "long-distance mammal and fish migrations, healthy populations of large predators, one to three billion nesting birds, some of the world's largest lakes and North America's longest undammed rivers," in addition to "massive stores of carbon and ecological functionality." Wells et al. (2020) also posit that North American boreal forests are a major source of freshwater outflows and that protecting them has strong, positive impacts on water supply and even in moving nutrients to global marine fisheries.

4.1.3 Preservation of rural economic, recreational and cultural activities

A final target risk is stopping the erosion of rural economic, recreational, and even cultural activities. AK21 described it as follows:

> Carbon removal could become an economic engine to rural Alaskan areas, I am really excited about it, we could invest some of those proceeds back into things we need, like roads, or scarification and reforestation, planting trees, or enhancing our reforestation bond efforts, which are currently planting 450 stems per acre within 7 years. We could also use proceeds for community education or health programs.

AK23 framed carbon forests as have a strong positive role for the protection of Indigenous cultural heritage. As they said: "Native Alaskans each have their own subsistence lifestyle, which means they all use forests for their own cultural purposes, and generating additional revenue streams from carbon removal could further strengthen that aspect." McKinley et al. (2011) add that in addition to protecting habitats and storing carbon, sound forest management can also generate the use of sustainable wood and biomass for building materials and for other community uses that can bolster rural economies.

4.2 Adverse countervailing risks: extreme heat and thawing permafrost, invasive species, and concerns about additionality

Following the risk–risk framework, our data identified adverse risks to forest carbon storage in Alaska as well: heat stress, storms, wildfires, and thawing permafrost; inspect outbreaks and invasive species; and concerns about additionality.

4.2.1 Heat stress, storms and wildfires, and thawing permafrost

Tragically, and perhaps ironically, the very target risk carbon storage seeks to mitigate—climate change and global warming—also pose a significant and often existential hazard to the forest itself. AK15 remarked that they believe as many as 90% of current Alaskan trees are experiencing aggravated stress due to climate change:

> Contrary to popular belief, warmer temperatures damage trees in Alaska. We launched a program of tree ring analysis and looked at 600 + tree samples from East to West across the Yukon, where the soils are the same and we have good consistent baseline data. We found, counterintuitively, that higher temperature induced moisture stress, limited tree growth, and degraded the overall health of the tree. Trees have trouble reproducing in suboptimal warm temperatures in the Eastern interior, making it even worse, adding to tree stress. Geographically, my sense is that 90% or more of forests are in this stressed-out condition from global warming.

This is particularly true for Alaska tree species, with Barber et al. (2000) concluding that "temperature-induced drought stress has disproportionately affected the most rapidly growing white spruce, suggesting that, under recent climate warming, drought may have been an important factor limiting carbon uptake in a large portion of the North American boreal forest. If this limitation in growth due to drought stress is sustained, the future capacity of northern latitudes to sequester carbon may be less than currently expected." The U.S. Department of Agriculture, Forest Service (2023: p. xvi) warned that "the combination and interaction of socioeconomic change, climate change, and the associated shifts in disturbances will strain natural resources and lead to increasing management and resource allocation challenges." AK9 puts these findings into context and indicates just how warm it now gets inside Alaskan forests in the summer. As they clarified: "Here in the Tanana Valley Forest this summer we have had really hot weather, many days of 90 degrees plus Fahrenheit. It's unusual and extraordinary."

One particularly severe and important manifestation of heat stress is drought. The U.S. Department of Agriculture, Forest Service (2023) cautioned that by 2070, droughts within American forests are expected to occur more often, last longer, and be more intense. They noted that adaptation options such as water storage and groundwater mining have limited availability to address this threat, and that the diversion of water for agricultural uses and consumption in urban areas is already making water scarcer for forests. Drought is also creating shortages of nutrients within forests, is shortening growing seasons, and decreasing the vitality of many tree species. Vynne et al. (2021) confirmed this risk is present in Alaskan boreal forests, documenting "drought-induced declines in productivity throughout interior Alaska, indicating a biome shift is underway." AK14 also added that changing patterns of snowpack melt and rain are already creating less water available for the Tanana Valley Forest.

More severe storms and wind events were identified as another dimension of this natural risk to Alaskan forests. AK9 explained that: "Wind is another serious risk, wind events have increased like you would never believe, like we have never seen." AK11 added even more context to this risk, articulating that "wind events can be severe here in Alaskan forests, we can see 50 to 100 mph wind gusts now happening with the frequency and intensity of every season. It is literally like a hurricane or tornado in the forest in terms of its destruction, and the damage it causes to trees."

Furthermore, both natural and anthropogenic (human-caused) wildfires were identified as a considerable component of this risk. AK1 admitted that they were "shocked and sickened by the recent rate and scope of wildfires in Alaska," but added that "fires can erase any net gain you and by carbon management." AK2 expanded on this thought, noting:

> We have an active forest fire regime south of the Brooks Range and north of the Alaska Range, depending on the forest type, we have a 100-year fire return cycle. Moreover, fire seasons in Alaska tend to be very big, affecting multiple millions of acres, because we have lots of lightning strikes, which can lead to huge fires. Interior Alaska, in my opinion, is very fire prone, and worryingly, because much of the carbon in Alaska is in the soils and ground and not the trees compared to other areas, this means fires burn not just above ground biomass but burn vegetative mass and soils below ground. Some fires even cause permafrost to release carbon or methane.

AK10 expanded on fire risks, noting that they could occur at any moment (making them chronic), but also with severe consequences (making them catastrophic):

> To me, carbon removal in Alaskan forests is too risky. All it takes is one major fire event, and everything is gone. Managers can lose one million acres in a flash, some of the largest fires on record destroyed 5 to 6 million acres of forest in a matter of hours to days. Carbon storage in Alaskan forests is a high-risk strategy, all the more so because it would most likely occur in unprotected areas, far from fire containment. There exist lots of errors in predicting them and in previous estimations, which means we are still practically clueless when it comes to anticipating the next fire event.

AK11 affirmed this point and noted that once a fire starts, not even the United States military can stop it: "yes, it's true, a fire event can wipe out 6 million acres, something that large not even the US army can stop, and the causes can be impossible to prevent, given we can have up to 10,000 lightning strikes in Alaskan forests every day, making it a perennial and ever-present risk, and we cannot predict where the fire will go next, making it purely a matter of luck."

Two other aspects of wildfire risk deserve mentioning. One is that the natural fire cycle itself seems to be changing in ways that make forest carbon removal even riskier. AK16 explained that:

> The fire cycle is intensifying in the Alaskan Interior. The interval between fires is shorter, but we also started seeing reburns, where burns at a site within their dataset have been burned previously. This makes fires far more damaging. If a black spruce stand burns once, it can still reproduce prolifically afterwards, but if it burns hot and big and then reburns, before new black spruce reached maturity, it wipes them out. These sorts of re-burn fires basically de-coniferzed the landscape, then you get this shift to deciduous trees which changes the forest entirely to species of a shorter lifecycle, which do not store carbon same way spruce does, and which reduce the organic soil later to 4 cm or less, releasing huge amount of carbon. In other words, the new fire cycle breaks the legacy lock on Alaskan boreal forests being what they are, and it could lead to massive future changes.

Indeed, the U.S. Department of Agriculture, Forest Service (2023) has noted shifting fire cycles in North American forests towards more intense as well as longer and larger fires. As they documented, the average annual area burned by large wildfires in forests and rangelands from 2000 to 2017 was more than double the average from 1984 to 1999. The total area of high-severity fires, as well as the volume of trees killed annually by fire, is expected to increase further by 2070.

Second, the number of human causes to wildfires is growing, adding additional dimensions to this risk. AK21 noted that for the Mat-Su Valley Forest at least:

> The risk of human-caused fires are omnipresent, and can include a variety of causes, from idiots setting off fireworks to escape debris burns gone wrongly, to power lines causing fires, ATV engines grinding and sending sparks, chain saws, campfires, any one of these events can mean we are off to the races when it comes to a major fire, and that's in addition to the risk of lightning strikes or naturally caused fires. This is why the fire season is so long here, from April 1 to August 31, we are at an obnoxious risk of fire, especially when it is warm, dry, and we have no precipitation. Then, it's only a matter of time before a major fire occurs, before another big incident. It is also why we have only 2 people here in my division who do forest management, but 90 people across separate crews who do fire protection and management.

Our site visits to the Mat-Su Valley Forest still saw evidence of one major fire event from 2015, the Sockeye fire, which burned more than 7,220 acres, closed major roads, destroyed 55 homes, and required forced evacuations from the Willow, Alaska area. The cause was a honeymooning couple lighting off fireworks, which ignited nearby stacks of wood. Indeed, it is worth mentioning that unlike other regions of the world where the main drivers of tree cover loss or deforestation are logging (such as in Europe) or permanent agriculture (such as in the tropics), in North America the leading cause is wildfire (Sims et al., 2025).

The heat stress, drought, more severe storms and wildfires all contribute to a final nature-based risk of thawing permafrost, which accelerates climate change dramatically given it releases both stored carbon and methane (Jorgenson et al., 2001). AK10 stated that:

> Permafrost in this part of Alaska is definitively thawing, air temperature affects ground temperature in the long term, and we are losing permafrost at the entire forest landscape level. When it thaws and melts, everything on it collapses, trees, hills, roads, buildings, pipelines, and some alterations can be up to a ½ mile shifted, often with 200–300 feet of subsidence.

AK14 also indicated they had observed "swathes of forest area now without permafrost," AK19 that "sure, I have seen a slumping of tundra and permafrost in the area, I cannot tell you how many roads I have seen with ice wedges and lances in them, huge white areas of dried land that use to be lakes, all drained out." AK17 lastly noted their visceral encounter with permafrost, describing how it sounds: "Permafrost melting in our forests can be so severe, when you stand on top of where it is occurring, it sounds like toilets flushing. And you can see it, usually via moss dying or the displacement of the subsurface material, areas where carbon is leaking out, where the forest is losing its insulative layer, and literally pooping out carbon emissions."

4.2.2 Insect outbreaks and invasive species

As another risk, Alaskan forests are prone to sudden insect outbreaks that can fell millions of trees, and the spread of new invasive species. AK2 used the language of an "epidemic" to describe bark beetle outbreaks:

> Alaskan forests are susceptible to insects. We still struggle with a spruce bark beetle outbreak trying to wipe out every spruce tree over six inches, likely connected to climate change, and one which has managed to reach epidemic proportions … It is not easy to protect from such outbreaks, it's not like can protect a tree in your yard with chemical, as it is impossible to stop inspects on the landscape scale.

AK9 used a similar metaphor of a "military front":

> Bark beetle infestations are a significant risk to Alaskan forests, marching and ravaging across the Interior driven by winds, terribly ravaging forests. It is like a military front, the beetles marching north, driven by hotter climate, over longer periods of time.

AK14 estimated that the current outbreak of bark beetles has already caused "widespread mortality of tree damage" so far, as much as 2 million acres of state forest lost, with Figure 6 showing both individual tree as well as landscape level mortality.

Confirming the severity of this risk, aerial detection surveys of Alaskan forests have noted at least 1.2 million acres of damage across only 15.7 million acres surveyed (see Figure 7). While the second single largest source of tree damage was spruce beetles (more than 193,000 acres), the report noted that western blackheaded budworms caused 520,000 acres of damage. Other significant sources were hemlock sawfly topkills (186,000 acres) and aspen leafminers (146,000 acres), underscoring the broad-based nature of this specific risk of insect outbreaks.

While the bark beetle and other insects are native to Alaskan forests, an added element of risk is that of new or invasive species and pests. AK8 confirmed that "boreal forests are extremely vulnerable now to new species, new invasive species, pests are coming in, that were not here before, they have gotten so severe some can even enter greenhouses and controlled environments." AK21 added that "the invasive species risk is real and growing, and these new species can spread new diseases, can bring in herbaceous vegetation which can alter the entire ecosystem, wreaking havoc on the forest, displacing native species."

Affirming these statements from our respondents, Schrader and Heron (2005) surveyed invasive species presence in Alaskan forests and noted more than 130 invasive plant species, rats, non-native slugs, fish, and four introduced insects—some of which were causing "substantial ecological harm" or "defoliation and tree mortality to spruce, birch, and larch." Snyder et al. (2007) also noted the presence of an invasive and destructive birch leaf mining sawfly in up to 20% of a surveyed area of south-central Alaska.

4.2.3 Concerns over additionality

The last risk facing Alaskan forest carbon removal is that of additionality, that any tons of carbon stored and sequestered would not have been emitted otherwise. Multiple respondents expressed

A B

FIGURE 6
Evidence of spruce bark beetle damage within the Mat-Su Valley Forest. Source: Authors. **(A)** Shows a single dead spruce with beetle holes, **(B)** a very large area of bark beetle damage near Houston, Alaska, within the Mat-Su Valley Forest territory.

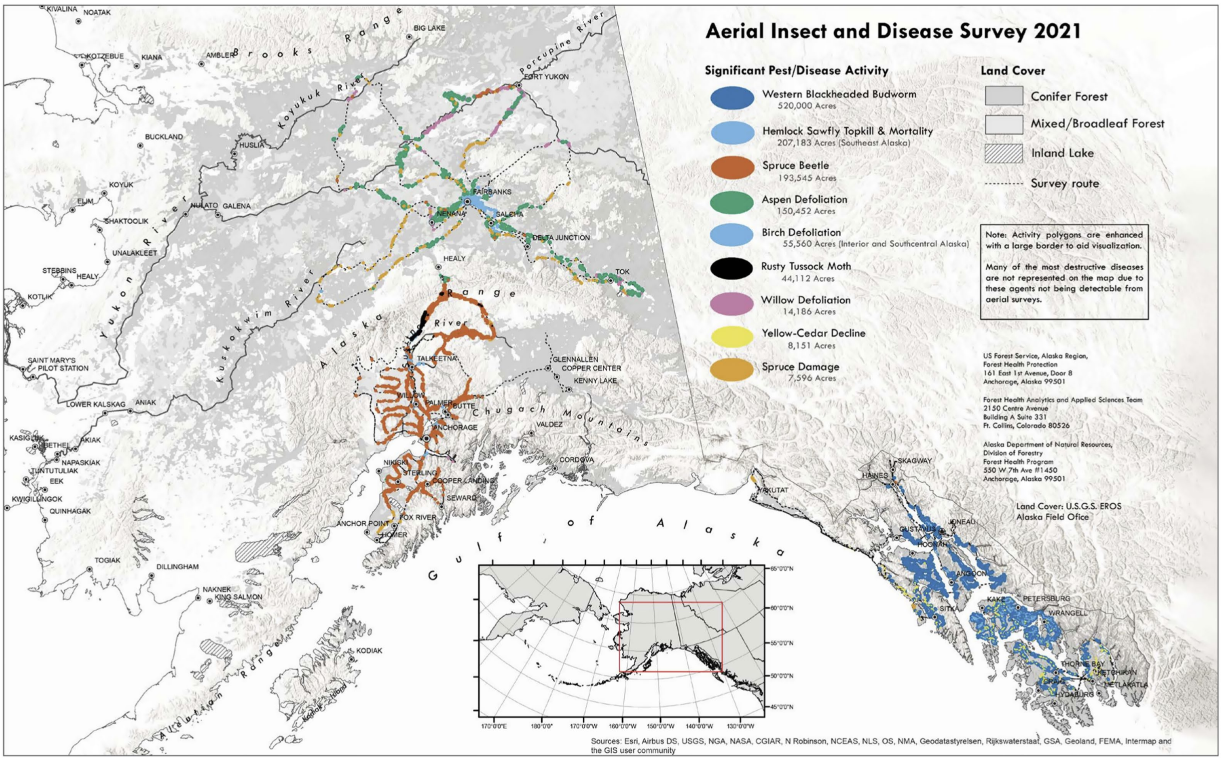

FIGURE 7
Confirmed insect outbreaks and diseases within Alaskan state forests. Source: FS-R10-FHP (2021).

concern that the carbon storage benefits of Alaskan boreal forests are non-additional because those trees would not be harvested or deforested otherwise. AK2 was skeptical of the permanence and additionality of SB48, noting that they believed it "will be a 'both and' approach, where we continue to harvest timber at the same or increasing rate as well as do carbon projects which protect land we would have protected anyway."

Substantial evidence already exists in the academic literature that many carbon forest projects, including those certified and even identified as best practice, are non-additional (Haya et al., 2023; Strapp et al., 2023; Randazzo et al., 2023; Coffield et al., 2022). Lezak (2024) and Elgin (2024) have levied this criticism specifically at SB48 and Alaska or at state managed/public forests in general, critiquing that the carbon offset program would only stipulate baselines that would make business-as-usual forest management practices appear as though they were creating new climate benefits. Chay and Badgley (2023) also express concern that the SB48 program would generate credits and revenues for not cutting down trees it probably would not cut down anyway—a non-additional outcome.

5 Discussion: differential risk dynamics, intersections, and uncertainty in risk estimation

Climate interventions that society may come to depend upon to protect Arctic communities, cultures and landscapes— enhancing adaptive capacity and resilience, or improving the natural capacity to store carbon dioxide thereby slowing climate change—seek to address the target risks shown in Table 1. But in addressing those target risks, they are also prone to, or fail to address, a series of equally daunting adverse and countervailing risks. Some of these risks are preexisting, such as permafrost thawing, whereas others are new, such as an increased risk of forest fires associated with afforestation or the changing of migration patterns associated with the completion of a seawall. Climate change policy therefore becomes an exercise in risk management, one only aggravated by three other aspects we will discuss in this section: differential risk dynamics related to speed, magnitude, reversibility, and the distribution of risks (Section 5.1), compounded again by intersections among risk types (Section 5.2) and scientific uncertainty in estimating and predicting them (Section 5.3).

5.1 Differential risk dynamics

Across Sections 3 and 4, we identified at least six target risks and nine adverse or countervailing risks, but the underlying dynamics of those risks differ in terms of their speed, their severity and magnitude, and their distribution.

For instance, some forms of risk can culminate very quickly. The storms ravaging the North Slope can occur within only a few hours' notice, and AK21 described spruce beetles as coming "hot and fast" into Alaskan forests. AK3 declared that "insects and disease can rapidly change the makeup of terrestrial ecosystem forests." Similarly, Grunzweig et al. (2004) caution that there is an almost immediate connection between the loss of a forest, deforestation, and release of carbon. Conversely, risks such as permafrost thawing and rising sea levels occur slowly, as does the amount of time it takes afforestation

TABLE 1 Summarizing risk–risk tradeoffs with Arctic coastal protection and forest carbon removal in Alaska.

Case study	Cost/revenues involved	Target risks	Countervailing and adverse risks	Existential risk	Systemic risks	Discrete risk events
Barrow Coastal Storm Damage Reduction Project	~330–360 million	• Storms, flooding and coastal erosion. • Trauma prevention and the protection of cultural heritage. • Community survivability and vitality.	• Sea-level rise and infrastructural risks. • Thawing permafrost. • Inward migration and loss of social cohesion.	Climate change and global warming	Sea-level rise, changing precipitation patterns, permafrost thaw, severe storms	Flooding, coastal erosion, retreating ice
Alaskan Carbon Forestry	~$50 million	• Carbon storage and climatic stability. • Wildlife conservation and habitat protection. • Preservation of rural economic, recreational, and cultural activity.	• Heat stress and drought. • More severe storms and wind events. • Wildfires. • Thawing permafrost. • Insect outbreaks and invasive species. • Concerns over additionality.	Climate change and global warming	Changing fire cycles, drought, permafrost thaw, severe storms	Wildfires, wind events, tree stress, insect outbreaks

Source: Authors, based on Sections 3 and 4.

and reforestation to recover from severe storms or wildfires. Even when accounting for possibly equal probability, the risks across our two cases have inherently different temporalities.

One added complexity to these risks is their reversibility. Some risks such as infrastructural damage to a seawall, a road, a revetment, or a property can be reversed through maintenance or repairs. Even massive damage to a forest in the form of a wildfire or insect outbreak can be "reversed" as the forest recovers, albeit more slowly than one can repair a house. Other risks, however, most notably permafrost thaw, sea-level rise, or fundamental changes in things like fire cycles or precipitation patterns, may be patently irreversible.

Second, very distinct risk magnitude or severity is involved across the cases. The Barrow Coastal Storm Damage Reduction Project could cost at least $360 million but, if successful, would protect more than $1 billion in assets (when the value of the Utilidor is taken into consideration). It could also help protect and preserve a Native Alaskan community whose cultural heritage could have priceless value. Carbon forestry in Alaska could also generate up to about $50 million in revenues that could be utilized to enhance the resilience of forests, or at least expand their capacity to sink and store carbon through additional afforestation and reforestation efforts. But some of the adverse countervailing risks could totally overwhelm these gains, especially if a single severe storm breaches or destroys the Barrow Coastal Storm Damage Reduction Project, or a new invasive species wipes out an exceptionally large percentage of Alaskan state forests. Consider the possibility of crossing a "tipping point" such as methane flux or permafrost thaw that could see one risk trump or magnify all other risks. AK3 put it this way:

> In our region, one of the huge questions is methane flux. We have peatlands and deep wetlands, which hold a huge amount of methane, and if these are disturbed, it can completely upend any ecological carbon cycle balance that we have. It can be a huge tipping point that is impossible to recover from. Same with permafrost thaw, another big buffer against ice in the Arctic and subarctic, which can lead to massive amounts of carbon release and gaseous and dissolved export of methane. Troublingly, the big disturbance you see may not be the one that matters most or is the most readily apparent.

Tellingly, Oswalt et al. (2019) already argue that risks such as fire or disease now remove or damage more forest than timber and harvesting: tree cutting and removal occurs on less than 2 percent of forest land per year, but 3 is percent disturbed annually by natural events like insects, disease, and fire. This may suggest that carbon forestry in Alaska is on balance more prone to adverse risks than achieving target risks.

Third, how risks and benefits are distributed is an apt issue. The Barrow Coastal Storm Damage Reduction Project would see its benefits almost exclusively concentrated on the North Slope, but the bulk (90%) of its costs are coming from federal and state budgets outside of that community. The benefits to Alaskan carbon forests would accrue to a mix of state foresters and planners and those purchasing carbon offsets—private firms as well as possibly carbon credit programs in states like California—but the aggravated risks of wildfires or insect outbreaks would affect other actors or sectors such as the logging industry, those owning property in the forest, or Alaskan taxpayers.

5.2 Intersecting and compounding risks

Risks not only differ in their speed, magnitude, reversibility, and distribution, but in their interconnections. Figure 8 attempts to visualize these complexities within a nested hierarchy of risk–risk tradeoffs. At one level, as Figure 8 shows, there is the general paradox that climate interventions intended to fight or address climate change are also highly susceptible to climate change. For lack of a better term, this can be envisioned as an "existential risk" as it sits at the bottom of the diagram because it is a foundational form of risk (Salmon et al., 2022). Bostrom (2002) defines an existential risk as being global, catastrophic, and associated with potentially terminal events, bringing humanity to extinction or irreversibly impeding its potential. Our interpretation of existential risk is less severe and meant to capture a risk that is external and intangible such as the loss of place or loss of identity, or a risk that is permanent and durable over long periods of time, rather than intermittent or temporary. AK1 captured this well, when they stated that "to me, the most dire and direct risk facing all climate interventions in Alaska is climate change, that is the greatest threat to American forests, and it is the most significant threat to our nation's coasts." AK9 added that "climate change is the most serious risk all interventions face, previously worst-case scenarios are here now as the new normal in Alaska."

However, Figure 8 also visualizes what we call "systemic risks," chronic or more structural risks that will never truly go away, they only grow, or change, in their magnitude and severity. These systemic risks, such as sea-level rise or more severe storms, also help justify the rationale for carbon interventions in the first place, but also, like climate change, place them at greater risk of damage, harm, and failure.

Lastly, the top of the diagram illustrates specific and intersecting risk outcomes or individualized events. These often occur because of the confluence of existential and systemic risks (in this case, climate change exacerbating permafrost thawing, an adverse risk for both case studies, or changing patterns of rainfall, drought, or fire cycles). But they can compellingly also affect each other: coastal erosion can increase the severity and scope of flooding, which in turn can accelerate further erosion; or wind events can further spread bark beetles and wildfires, which in turn increase tree stress and make forests more vulnerable to future insect outbreaks or more damaging "re-burning" wildfires. Multiple respondents picked up on these salient interconnections. AK4 noted that "retreating ice in the Beaufort Sea increases more wave action and more erosion, creating stronger winds and waves, which break apart more ice and cause further erosion, leading to a dangerous feedback loop." In the case of carbon forestry, spruce beetles can make trees less resistant to fire and more prone to drought (AK1). Changing rainfall and precipitation patterns make trees more vulnerable to invasive species and insects (AK8). Wind events can carry beetles farther and faster, amplifying insect outbreaks, and also spread wildfires further (AK7). When trees are stressed, they do not make enough sap or have strong immunity, making them more prone to wind events, to mortality during heatwaves, or having lack of protection against spruce bark beetles (AK9 and AK15). Heatwaves and hotter temperatures also worsen the spread of wildfires and the reach of invasive species and pests (AK9).

5.3 Uncertainty in knowledge and future predictions

One important caveat to all findings and analysis presented so far is that of uncertainty when it comes to understanding environmental change, and the impact of climate interventions in Alaska, along with future predictions and scenarios. AK3 staunchly stated that:

> Alaska is the place where models come to die, because of the complex topography, we find we invalidate several remote sensing findings. Our forests have slopes, we have large stature trees, and

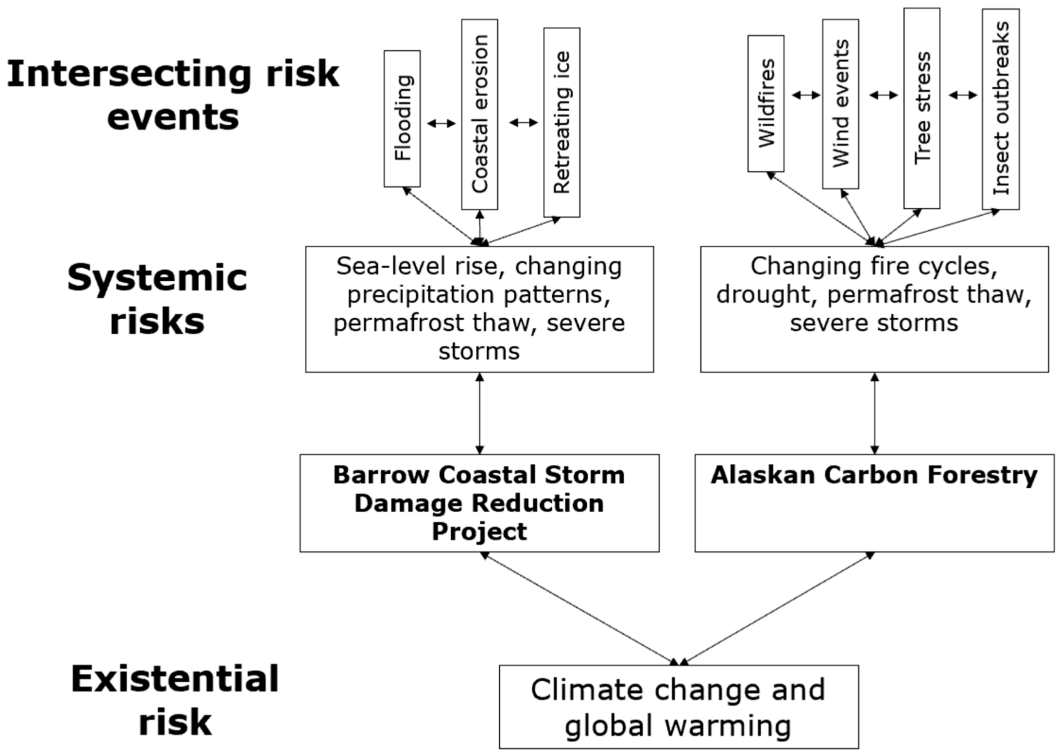

FIGURE 8
A nested hierarchy of risk–risk tradeoffs relating to climate interventions in Alaska. Source: Authors.

> we have water which distorts remote sensing products, like USGS IPSAR, our environment distorts that signal, providing no good ground return. A surface model is not a terrain model, our instruments are not getting through the tree canopy. We even get climatological and ecological drought within the rainforest.

Soils and permafrost are just as complex, with AK3 calling them "mind-boggling" and our knowledge about how they work and store carbon as "infantile." AK3 adds that another challenge is knowing baseline conditions by which we can calculate credits. As they warned: "We've learned that we are not always going to sequester carbon with management action, a key question is what the background is, we call them natural climate solutions, but we do not know the natural background sequestration rate for this vast forest, that's a key question we do not know." Even simplified models seeking to analyze trees, soils, and carbon stocks in Alaska have 40 factors contributing to complexity (Leighty et al., 2006). A further layer of complication is that Alaskan forests straddle no less than six climatic zones and ecotones (Yarie and Billings, 2002), meaning a model for one hectare of southeastern forest will not effectively work even a few kilometers away.

6 Conclusion

Based on two qualitative cases—coastal protection on the North Slope of Alaska, and carbon storage in interior boreal forests—undergirded by research interviews, site visits, and photographs, this study has shown how climate interventions address target risks such as coastal erosion or wildlife conservation, but only by unwittingly exacerbating, or ignoring, adverse risks such as sea level rise or heat stress. Climate interventions have a dualistic tension, or double-sided nature, succeeding and failing in equal measure: achieving climate resilience or adaptation but only at the expense of social cohesion or the risk of failure via future environmental stressors.

The implications of the study for policymaking are as clear as they are daunting. They suggest that climate, energy, forestry, and land-use planners collectively embrace more complex decision-making systems such as multi-criteria risk assessment (Stirling, 2006, 2010), to enable them to better understand the distribution of target and adverse countervailing risks. Moreover, city, state, and federal planners and regulators could benefit from risk register training. Lastly, policymaking efforts could be better informed by other research designs (different than those of interviews and site visits utilized in this study) such as systematic document analysis, foresight exercises, game theory, simulations, exercises, and deliberative focus groups or structured discussions. Given that risks are not fixed but instead relational and dynamic, the policymaking community could also explore the degree that self-governing arrangements exist that minimize the persistent presence of risk, especially in the absence of policy or in wilderness areas prone to weaker forms of governance.

The study also points the way towards more evolved risk management approaches. Multiple research gaps exist. This study has mapped risk–risk tradeoffs for Alaskan climate interventions in isolation from each other, but it's equally plausible that coastal protection measures and forestry protection measures could be utilized together as part of some complex portfolio, meaning they are integrated, not isolated. Moreover, the study has not sought to weight or quantify the severity or magnitude of the risk–risk tradeoffs involved, nor made any sort of judgment about whether the target risks outweigh the adverse risks, or vice versa. Future work would do well to consider the *net* social gain or reduction in societal risk to make a definitive judgment whether the two case studies are "worth it," whether they eliminate more risks than they create. Lastly, there are dozens of other climate interventions, from hydrogen fuel cells to carbon capture and storage systems to wind farms and nuclear power plants, that also are deserving of risk–risk analysis alongside our two cases of coastal protection and boreal forestry. Such shortcomings suggest the necessity for more comprehensive, intersectional, and holistic applications of risk management.

Data availability statement

The datasets presented in this article are not readily available because the data used is confidential. Requests to access the datasets should be directed to sovacool@bu.edu.

Ethics statement

This project was approved by the Institutional Review Board at Aarhus University 2021-13 as well as by the Ethics Committee at the European Research Council. Written formal consent was obtained from all expert interview respondents.

Author contributions

BS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declared that Generative AI was not used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpos.2026.1695743/full#supplementary-material

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