The Impacts of Climate Change on Bowhead Whale Access and Adaptive Strategies in Kivalina, Alaska

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Abstract

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This study examines the effects of climate change on bowhead whale hunting and community responses in Kivalina, Alaska, an Iñupiaq community in Northwestern Alaska. Thinning shorefast ice and altered whale migration patterns have disrupted traditional hunting practices. Using access theory and collective continuance, the study explores how hunters navigate barriers to physical, financial, and informational access. Interviews reveal that thinning ice and unpredictable leads hinder physical access, while rising equipment costs necessitate communal resource-sharing to mitigate financial burdens. The need for real-time environmental data is critical for safe hunting. Adaptation strategies include shifting hunting locations north and leveraging inter-community networks. Key needs identified are larger boats with powerful motors, enhanced safety equipment, and improved sea ice lead forecasting and real-time data. Recommendations advocate integrating Kivalina into larger observing networks like the Alaska Arctic Observatory (AAOKH) and securing grants to support adaptations. This research highlights the importance of community-driven, localized strategies to sustain traditional practices and enhance resilience amid climate change

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Background

Kivalina, Alaska, is an Iñupiaq community located in Northwestern Alaska, where Kivalliñiġmiut have historically practiced a semi-nomadic lifestyle. Historically, this group adapted their movements and settlement patterns based on subsistence needs, weather conditions, and social networks. In 1905, mandated education policies initiated by the U.S. Bureau of Education marked the beginning of a decades-long effort that transitioned the semi-nomadic Kivalliñiġmiut from their expansive homeland of 2,180 square miles to a small 27-acre site, historically used as a seasonal hunting camp, which allowed access to an abundance of marine food sources (Burch 1998; Griffin 2019). This site has since evolved into the present-day community of Kivalina, located on a thin stretch of barrier island. The federal government's choice of a barrier island for permanent settlement has made Kivalina acutely vulnerable to climate impacts (Griffin 2023). Barrier islands are dynamic coastal structures that are particularly susceptible to sea-level rise, storm surges, and coastal erosion—challenges that are exacerbated by the changing climate. A connecting road and upland area were later developed, including the construction of a new school and school administration housing, marking the beginning of a phased movement upland for permanent structures (Alaska Department of Transportation and Public Facilities 2022).

Over the decades, these vulnerabilities have become more pronounced with the accelerated melting of Arctic shorefast ice, reducing the natural barrier that previously protected the island from storm surges. Since the 1990s, residents of Kivalina have been witnessing significant changes in their environment (Griffin 2019; Huntington & Quakenbush 2016). The shorefast sea ice, which traditionally protected the coastline during the harsh winter storms, is forming later in the season and at a thinner consistency than in the past. (Huntington &

Quakenbush 2016). This reduction in natural defense mechanisms has left the island exposed to erosion and flooding, particularly during fall storms which have been increasing in intensity and frequency (Huntington & Quakenbush 2016). The ongoing environmental changes pose a direct threat to the sustainability of the community's subsistence economy, highlighting the urgent need for adaptive strategies. This situation both underscores and complicates broader narratives of climate vulnerability faced by many Indigenous Arctic communities, making Kivalina a critical case study in understanding and addressing climate impacts in similar settings.

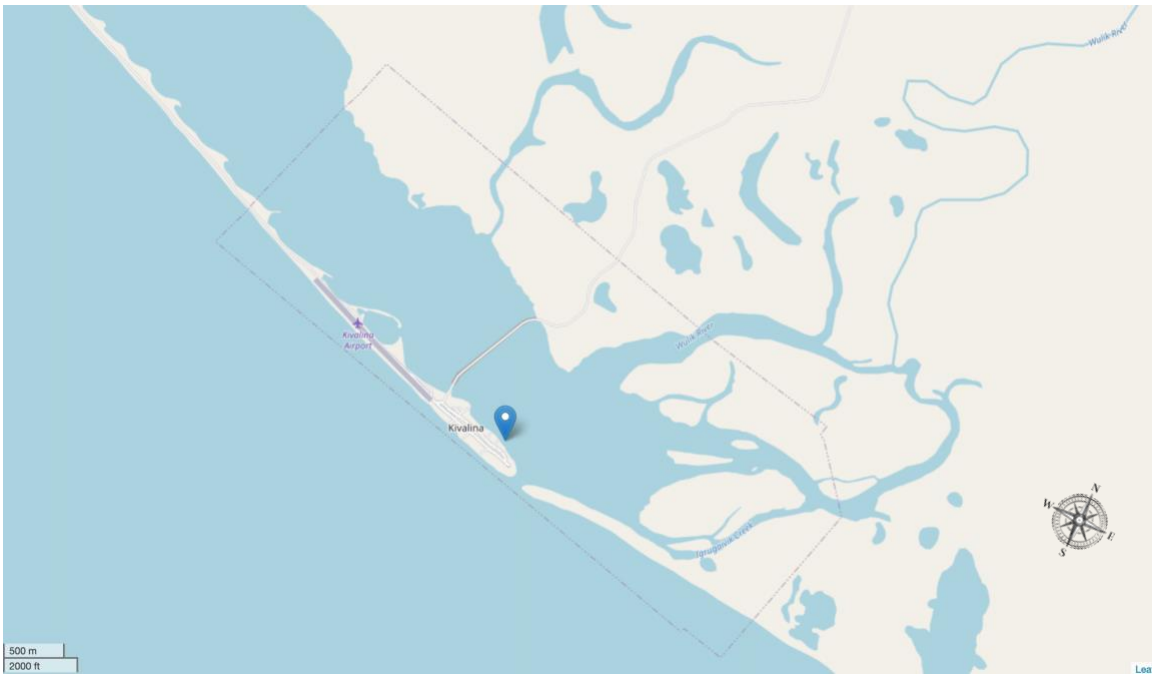

Figure 1. A map displaying Kivalina, AK in Northwestern Alaska.

Bowhead Whale Hunting in Iñupiaq Nunaat

Historically, the community of Kivalina has been deeply intertwined with bowhead whaling, a practice that transcends mere subsistence hunting to embody cultural, social, and economic significance (Huntington et al. 2021). Known regionally as *agviq*, the bowhead whale is regarded as a cultural keystone species within this Arctic community. Across Iñupiaq Alaska, whaling is not only about the harvest but also serves as a profound communal event, involving

extensive preparations that include the preparation of specialized tools, the sharing of intergenerational hunting tactics, and the distribution of the catch, which reinforces social bonds and affirms cultural identity (Sakakibara 2012). Collective engagement in bowhead whaling has historically fostered a strong sense of community and continuity among the Kivalliñiġmiut.

Regionally, bowhead whaling is regulated by the International Whaling Commission (IWC) and is safeguarded by the Alaska Eskimo Whaling Commission (AEWC). In 1977, the International Whaling Commission (IWC) implemented a ban on subsistence hunting of bowhead whales. This decision was driven by NOAA's whale census, which indicated that the Bering-Chukchi-Beaufort stock comprised fewer than 1,000 bowhead whales. As a result of the moratorium, the Alaska Eskimo Whaling Commission (AEWC) was established by local Iñupiaq leaders, with a quota system overseen by the U.S. government and the IWC. In 1981, the responsibility for the bowhead census project shifted from NOAA to the AEWC and then in 1982 to the North Slope Borough (NSB) Department of Wildlife Management (North Slope Borough 2024). Today, the AEWC is composed of representatives from each of the eleven whaling communities in Alaska, including Kivalina. The Kivalina Whaling Captain's Association works to ensure that bowhead whaling in Kivalina is safe and in compliance with regulations.

However, significant environmental changes over recent decades have severely impacted the traditional bowhead whale hunt in Kivalina (Huntington & Quakenbush 2016). The increasingly unpredictable ice conditions, characterized by thinner, less stable sea ice and altered ice extent, coupled with shifting migration patterns of the bowhead whales, have profoundly affected the community's ability to engage in this crucial practice. Since 1994, Kivalina has not recorded a successful bowhead whale harvest, an indication of the disruption caused by climatic

shifts (Suydam & George 2003; AEWC 2021). These changes are not isolated phenomena but are indicative of broader environmental dynamics that challenge the sustainability of traditional practices and necessitate adaptive strategies. As such, the decline in successful hunts is emblematic of the broader struggles facing Arctic communities as they confront the realities of climate change. In facing these challenges, the goals and priorities of communities themselves are essential to supporting locally defined adaptation strategies.

Changes in Sea Ice

For Iñupiaq communities of Northern Alaska, bowhead whale hunting is a practice deeply rooted in a seasonal rhythm dictated by the marine environment, particularly the sea ice conditions (Sakakibara 2020). Sea ice serves as a critical platform from which hunters can access the migratory paths of the bowhead whales during the spring hunting season (George 2004; Druckenmiller 2013). This practice involves the use of shorefast ice—ice that is attached to the coastline and extends out into the sea—as a stable base for launching *umiaqs* (traditional skin boats) and as a site for hunting camps (George 2004). The thickness and extent of this ice are crucial as they provide not only physical access to the whales but also a safe and solid foundation necessary for the operation of heavy equipment and the handling of large catches (George 2004). For Kivalina in particular, both break-up date and maximum sea ice extent has decreased rapidly over the past 30 years (Figures 2 and 3).

The process of bowhead whaling is intricately adapted to the characteristics of the sea ice, which facilitates proximity to the leads—open channels of water within the ice where bowhead whales are known to travel (Druckenmiller 2013). These leads are essential for the whales' passage and represent strategic hunting grounds for the Iñupiaq hunters (Huntington 2016; Druckenmiller 2013). The stability of the ice, along with specific wind and current

conditions, influences the formation and duration of these leads, dictating the timing and tactics of the hunt (George 2004). The Iñupiat have honed their ability to read these natural indicators over generations, integrating traditional ecological knowledge with the immediate sensory experience of the marine environment to optimize their hunting success (Huntington & Sakakibara 2020). This deep-seated relationship to sea ice underpins not only the logistical aspects of bowhead whaling but also its cultural resonance, embedding the practice within the seasonal and ecological cycles that define the Arctic maritime landscape.

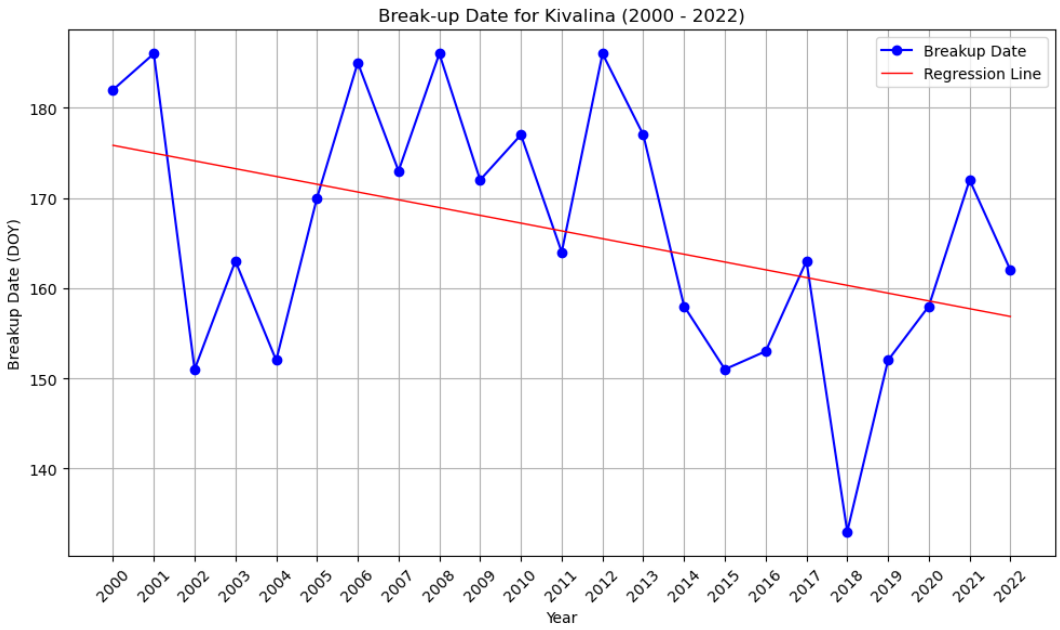

Figure 2: Break-up dates (Day of Year) for Kivalina from 2000 to 2022. The blue points and line represent the observed break-up dates. Break-up date refers to the approximate date when shorefast sea ice is no longer usable as a hunting platform. The y-axis ranges from approximately May 30th (Day of Year 150) at the bottom to July 1st (Day of Year 182) at the top. The red line indicates the linear regression trend, showing a general decrease in break-up dates over the period (Data: Cooley & Ryan 2024).

Figure 3: Maximum sea ice extent for Kivalina in the years 2000 and 2022, based on MODIS satellite imagery. The outermost line represents the maximum extent in 2000, while the innermost line indicates the reduced sea ice extent in 2022, showing a significant reduction over the 22-year period. To the right, maximum sea ice extent for 2022 is shown in real-color satellite imagery (Cooley & Ryan 2024; NASA Worldview 2024).

Research Objectives

While primarily focused on the experiences and concerns of bowhead whalers in Kivalina, this research also has relevance for other Alaskan coastal communities that currently engage in bowhead subsistence hunting. Today, subsistence bowhead whaling supports the physical, cultural, and environmental wellbeing of tens of thousands of residents across the Arctic. As previously mentioned, in addition to Kivalina, there are 10 other whaling communities that participate in seasonal bowhead whale hunting. While sea ice remained relatively stable for whaling communities at higher latitudes, the impacts of climate-induced warming and decreased ice extent has heavily impacted Kivalina's bowhead whaling hunt. Because of this, Kivalina's response to climate impacts on bowhead whaling sets a precedent for other communities who are

This thesis project was designed with three main objectives. The first is to understand, generally, how climate change has impacted bowhead hunting opportunities in Kivalina, AK over the past 20 to 30 years. The second is to understand what other barriers impact access to bowhead whales in Kivalina, AK. Finally, this project seeks to identify adaptation strategies being undertaken by whaling crews in Kivalina, AK along with potential resources to support these strategies. This thesis aims to address these challenges by exploring the impact of climate change on bowhead whale hunting, investigating the barriers to accessing these vital resources, and identifying potential adaptation strategies to support the community's resilience

Theoretical Framework: Linking Access Theory and Collective Continuance

In this section, I will review the main theoretical frameworks applied in this thesis. They include access theory and collective continuance theory. Finally, I describe my own unique synthesis of these approaches, illustrating how they provide a comprehensive understanding of the climate challenges faced by Kivalina and the community-driven responses to these challenges.

Today, academic narratives surrounding the impacts of climate change as experienced by Indigenous communities regularly adopt deficit framing in their analysis, where climate-vulnerable communities are written about from a deficit standpoint. Eve Tuck's concept of "damage-centered research" criticizes this approach for portraying communities solely through the lens of their vulnerabilities and shortcomings, rather than their desires, strengths, or resilience (Tuck 2009). In her seminal work "Suspending Damage: A Letter to Communities," Tuck argues that such research reinforces a one-dimensional view of these communities as "depleted, ruined, and hopeless," calling for a shift towards research that highlights their capabilities and ongoing resilience (Tuck 2009). In this paper I use access theory as a more dynamic approach to understand physical, financial, and spatial barriers or facilitators of bowhead whaling in Kivalina.

Access theory is a body of literature developed by political ecologists to understand how communities interact with and utilize natural resources under changing environmental, social, and political conditions. This comprehensive theoretical framework is outlined by Ribot and Peluso in their seminal work, "A Theory of Access" (2003), which distinguishes between the ability to derive benefits from resources (access) and the legal entitlements to them (rights). In the context of Kivalina, access theory is crucial for understanding the multifaceted nature of bowhead whale hunting, a key subsistence activity deeply rooted in the community's cultural and economic fabric. The changing climatic conditions, particularly the thinning and reduced predictability of sea ice, have dramatically altered the physical access Kivalina's hunters have to bowhead whales. Traditionally, stable ice conditions facilitated their ability to reach the whales' migration paths. However, as Craig George et al. (2004) note, the decrease in Arctic sea ice thickness and extent has reshaped bowhead migration patterns and hunting grounds (George

2004; Stroeve 2012). This alteration requires a reevaluation of how physical access is facilitated or hindered by environmental changes. Lastly, spatial access, or physical distance from bowhead whales, forms a critical component of physical access, impacting the ability of hunters to reach viable hunting grounds safely and effectively.

Financial access pertains to the community's ability to afford the logistics involved in whale hunting. The financial aspects of maintaining equipment, fuel, and other necessary supplies are significant, especially as the distances to viable hunting grounds increase. According to Brinkman et al. (2016), the increasing costs of subsistence hunting due to changing ice conditions impose substantial economic strains on Indigenous communities, impacting their long-term access to subsistence foods (Brinkman 2016). This is highly relevant to bowhead whale hunting, which is labor intensive and costly. The cost of adapting whaling equipment to new conditions and responding to emergencies in the marine environment adds an additional barrier. Informational Access considers the traditional knowledge required to successfully hunt bowhead whales. Kivalina's hunters rely heavily on traditional knowledge passed down through generations, which informs them of safe ice conditions, whale behavior, and effective hunting techniques. Druckenmiller et al. (2013) highlight how such traditional ecological knowledge is critical in adapting to the rapid environmental changes observed in the Arctic (Druckenmiller 2013). By applying access theory**,** this thesis aims to delve deeper into how Kivalina's community navigates the complexities of maintaining access to bowhead whales under the duress of environmental shifts, exploring the interplay between these three access dimensions and the community's resilience strategies.

My second major framework comes from Indigenous environmental studies. Collective continuance, as articulated by the Potawatomi environmental philosopher Kyle Whyte, explores

how Indigenous communities maintain their cultural, environmental, and economic vitality amid challenges like climate change and colonial legacies (Whyte 2016). This concept posits that Indigenous resilience stems from both resisting external threats and actively fostering community well-being. This dual approach underscores the significance of self-determination and ecological stewardship within these communities, framing their enduring practices not merely as survival but as assertions of sovereignty and environmental justice (Whyte 2016). Whyte's concept of Indigenous ecologies enriches this framework by emphasizing the sets of relationships that Indigenous communities value and seek to sustain (Whyte 2018). These ecologies are not just about the physical environment but also include social and cultural dimensions that are crucial for the community's well-being (Whyte 2018). In the context of Kivalina, collective continuance and Indigenous ecologies are particularly relevant as they illustrate how the Iñupiaq hunters adapt to the changing Arctic environment. These two concepts highlight the community's efforts to maintain traditional ecological knowledge, implement innovative strategies, and foster resilience through cultural practices such as bowhead whale hunting. By situating the practice of whaling within the broader socio-cultural and environmental relationships that the community values, this theoretical application demonstrates how Kivalina's residents navigate the complexities of climate change. This approach provides a comprehensive understanding of their strategies for cultural survival and autonomy, emphasizing their agency and resilience in the face of systemic pressures.

In Kivalina, the practice of bowhead whale hunting is not just a means of subsistence but also a *critical component of cultural identity and intergenerational knowledge transfer.* Therefore, a more robust framework is needed to think about what people want access to, encompassing not only physical, financial, and informational dimensions but also cultural and

social dimensions. This new framework can be used to analyze how Iñupiaq hunters of Kivalina adapt to the changing Arctic environment, maintain their traditional ecological knowledge, and implement innovative strategies to continue their bowhead whale hunts under increasingly difficult conditions. The concept emphasizes the community's agency in shaping their responses to climate impacts, which is crucial for understanding their resilience and adaptive strategies. This approach will be applied to examine how traditional knowledge systems and community practices have evolved in response to the systemic pressures of climate change exacerbated by historical and ongoing colonial impacts. It allows for a deeper exploration of how these adaptations are not merely responses to immediate environmental changes but are embedded in a broader context of striving for cultural survival and autonomy. In the interviews and fieldwork conducted in Kivalina, this framework will help interpret the ways in which community members articulate their experiences and strategies for maintaining bowhead whale hunting. This includes understanding the community's internal dynamics, relationships with external entities, and the roles of leadership and knowledge transmission in fostering resilience.

In integrating access theory and collective continuance, this thesis undertakes a multi-dimensional analysis to more holistically understand the impacts of climate change on bowhead hunting in Kivalina. While access theory enables a structured investigation into the physical, social and economic barriers to resources, the concept of collective continuance enriches this analysis by embedding these challenges within the broader socio-cultural and historical contexts of colonial impacts and Indigenous resilience. This combined approach not only illuminates the practical aspects of resource access but also highlights how the community's cultural practices, such as bowhead whale hunting, serve as active forms of resistance and adaptation. By employing both theories, the study gains a nuanced perspective on how Kivalina's residents

navigate and counteract the multi-layered impacts of climate change, thereby providing a comprehensive view of their strategies for cultural survival and autonomy.

Despite extensive research on the Arctic and increasing global dialogues about circumpolar changes, community-driven studies on localized climatic impacts to marine hunting remain notably absent. This neglect has real consequences: it risks food security, wellbeing, and safety without proper analysis and examination of ongoing adaptation strategies. For my thesis, I am aiming to apply a holistic, multi-modal approach to the analysis of climate impacts in Kivalina. Climatic impacts on bowhead hunting go beyond changes in the physical environment. There are critical social, economic, and cultural factors that must also be examined. Because bowhead whaling as a practice is embedded in broader networks and systems, an approach that goes beyond an analysis of physical change in the region is required. Considering this, I believe a multi-modal approach is necessary for an honest examination of the impacts of climate change on bowhead whaling practices in Kivalina.

Methods

This section outlines the multi-modal techniques employed to understand the multi-faceted impacts of a changing climate on bowhead hunting safety and access in Kivalina, AK. By integrating qualitative and ethnographic methodologies, the study provides a comprehensive analysis of how environmental changes affect traditional subsistence practices and community resilience. This project was carried out as part of "Polar Science at a Human Scale," a three-year collaboration between Kivalina Volunteer Search and Rescue, the City of Kivalina, and University of Washington.

I utilized a structured interview methodology, designed to gather in-depth insights from local hunters about their experiences and observations regarding bowhead whale hunting in

Kivalina. This method was chosen to ensure a comprehensive understanding of the interplay between environmental changes and traditional subsistence practices, reflecting an ethnographically informed approach to data collection. Prior to visiting Kivalina in June 2023, I met virtually with two community members and key collaborators in Kivalina to refine and review the interview questions to ensure they were relevant to the community's experiences and challenges. This collaborative approach enhanced the relevance of the research questions, ensuring that they were in line with research interests and priorities within the community.

The interview guide was structured around four main themes: the historical significance of bowhead whaling, environmental impacts on whaling practices (sea ice and wind), safety considerations in current and historical hunting practices, and adaptive strategies developed in response to changing sea ice conditions. These themes were carefully chosen to elicit detailed responses that would provide insights into both the traditional importance and the contemporary challenges of bowhead whaling in Kivalina. I conducted one-on-one semi-structured interviews with seven hunters, whose ages and experiences spanned from young adults involved in the recent revitalization efforts to Elders who had participated in bowhead whaling when it was more prevalent. This demographic range allowed for a multi-generational perspective on the changes and continuities in whaling practices. In 2024, I conducted a follow-up visit, which included a non-hunting member of a whaling crew, to discuss preliminary findings and gather additional feedback. Each interview was audio-recorded with the consent of the participants who were also given the option to remain anonymous, or to have their contributions attributed by name. Verbatim transcriptions ensured that data analysis was grounded in the actual language used by the participants, preserving the authenticity of their narratives. This was crucial for capturing the nuanced understanding of local knowledge and practices.

Following transcription, I employed thematic analysis to identify, analyze, and report patterns within the data. This involved a process of coding the transcriptions to distill the data into themes that corresponded to the research questions. The coding process was iterative, involving initial codes being revisited and refined as more data were analyzed to ensure comprehensive and systematic coverage of all relevant themes, including themes that were not previously expected at the development stage of the interview methodology. To systematically approach the qualitative data, I applied a combination of phenomenological and ethnographic frameworks. This mixed-methodological approach enriched the analysis by allowing for a detailed exploration of individual experiences (phenomenological) while situating these experiences within the broader cultural and environmental context of Kivalina (ethnographic). This framework was instrumental in revealing how personal and collective experiences intersect with broader socio-environmental dynamics. By incorporating these methodological steps, the interview process was not only methodically rigorous but also deeply respectful of and responsive to the community's values and realities. This approach has provided a robust basis for understanding the complex dynamics at play in the subsistence practices of Kivalina, contributing valuable insights into community resilience and adaptation strategies in the face of climate change.

Results

Physical Access

Sea Ice Conditions

In the context of Kivalina, physical access to bowhead whales critically depends on the condition and characteristics of sea ice, particularly its thickness, which has decreased considerably over time. Whaling crews require a minimum ice thickness of approximately three

feet to establish a stable camp and support the significant weight of both the crew and their equipment. One whaling captain emphasized this saying, "*We're getting an average of, like 3-feet of ice a year. So that's enough to pull up a whale now. About 3-feet, 3-5 feet here*," indicating a shift from past conditions where ice was substantially thicker and more reliable. The historical data provided by experienced whalers like Reppi Swan, who recalls times when ice was "*8-10 feet thick*," starkly contrasts with current conditions, illustrating a significant reduction in ice stability. This thinning ice not only presents challenges in creating and maintaining a camp but also increases the risk of sudden ice breakages, which can jeopardize the safety of the crew. Enoch Adams, Jr. highlights the hazards of thinner ice, "*But now we have two - three feet. Three feet is thickest, normal is about two now and that's very dangerous. Leads develop quicker and unexpectedly due to the swells, and we have developed in the large open water."*

Additionally, features of sea ice beyond thickness also critically shape physical access to bowhead whales for Kivalina's whaling communities. Pressure ridges, elevated formations of ice that occur when separate sheets or floes of sea ice collide, are particularly significant. Flat areas near these ridges often provide more stable platforms for setting up camp due to their denser structure, as pressure ridges usually indicate sea ice being anchored to the seafloor. One whaling captain describes the strategic importance of selecting these features: "*The guides, the captains, and whoever is in charge would look for a good spot not only for the boat but also for the tent. Usually, they would choose a spot by ivuniq [pressure ridges].*" However, the increasing frequency of thinner and less stable ice complicates the identification and utilization of these ridges, presenting a notable barrier to safe and effective whaling.

The integrity of the ice is further compromised by the appearance of leads—long cracks or breaks in the ice that can quickly expand and change under varying conditions. These leads

are necessary for accessing whales but also represent significant risks if they expand unpredictably or if the ice surrounding them is too thin to support human activity safely. Enoch Adams, Jr. notes the growing challenge: “It used to be easy to find whales back in the day because the ice was thicker and the leads would not be that many. Right now, it's not unusual to find a lead that goes all the way to Point Hope. That's 70-80 miles long.” The shifting pattern and unpredictability of leads, exacerbated by warmer temperatures and less predictable weather patterns, thus form a critical barrier to accessing traditional whaling grounds and necessitate greater adaptability and caution from the community.

Wind Speeds and Currents

Wind speeds and currents are also critical factors in determining the physical access to bowhead whales around Kivalina, impacting not only the practicality of mobilizing one’s crew, but also the safety of those on the ice. For bowhead whaling, wind speeds that facilitate safe conditions are typically moderate and predictable. Lower wind speeds, particularly from the north, are favored as they tend to stabilize sea ice and maintain the integrity of the ice pack, crucial for the establishment of hunting camps. Enoch Adams, Jr. explains the optimal conditions, stating, "*If the winds are from the west, that can create swells*,” which underscores the challenges posed by less predictable wind directions. Conversely, high wind speeds, especially those exceeding 30 miles per hour, are considered unsafe as they can rapidly shift ice conditions, causing leads to open unpredictably and ice to break apart. Stephen Koenig reflects on the need for cautious approach during such conditions: “[I]f it stays 30 miles an hour and below, we can be okay. Anything higher than 30 miles an hour would become a concern for safety.” Additionally, the increasing open water has led to more frequent windstorms,

complicating these dynamics further. One captain noted, “We’re getting more and more windstorms it seems like,” highlighting the escalating challenges posed by changing weather patterns. This is corroborated by research which shows that the reduction in sea ice affects atmospheric circulation patterns, leading to increased storm frequency and intensity in the Arctic (Huntington & Hauser, 2016).

Moreover, currents play an equally pivotal role in shaping the physical access to bowhead whaling territories. Favorable currents are those that are stable and predictable, allowing hunters to anticipate the movement of sea ice and the location of open water leads through which bowheads travel. Ideal currents assist in maintaining solid ice conditions and prevent the rapid disintegration of ice formations critical for setting up hunting stations. One hunter describes how changing currents have altered traditional hunting strategies: *"We used to rely on the currents to keep the leads stable, but now with the unpredictable currents, we find ourselves constantly adjusting our strategies."* Unfavorable currents, which may swiftly change direction or speed, complicate the whalers' ability to maintain stable platforms for hunting and can isolate or shift large sections of ice, dramatically impacting the ability to access usual hunting grounds and potentially endangering the lives of the crew. This dynamic illustrates the complex interplay between environmental elements and the traditional practices of Kivalina’s whaling crews, highlighting the necessity of deep local knowledge and its adaptability in the face of ongoing climatic shifts.

Changing Bowhead Migration

The shifts in bowhead whale migration patterns near Kivalina present a profound challenge to physical access for local whalers, underscoring a dynamic interplay between

environmental variability and whaling practices. Historically, bowhead whales followed predictable migration routes that aligned closely with the community's geographical and seasonal hunting strategies. Traditionally, the spring migration of these whales through the leads in the ice near Kivalina has been a cornerstone of local subsistence hunting. However, as climate change leads to more open water, these marine mammals increasingly opt for a more direct migration route from Wales to Point Hope, effectively bypassing the Kivalina area. This shift is particularly pronounced when offshore ice is thick, as bowheads and belugas are more likely to travel along the shore-associated leads, closer to Kivalina. Yet, today's conditions often push these routes further offshore, up to 20 miles away, where the diminishing shorefast ice makes traditional hunting practices—such as camping at the ice edge to hunt—increasingly perilous and less feasible. However, recent decades have seen a significant shift in these patterns, largely attributed to changes in oceanic chemistry and sea ice conditions due to climate warming. Stephen Koenig notes the impact of this shift, stating, "I haven't seen many whales come out here towards Kivalina. The only time I've seen them come out here was this year and last year." This irregularity not only affects the success rates of hunts but also the transmission of traditional ecological knowledge (TEK), which benefits from regular encounters with bowhead whales for experiential learning opportunities.

The re-routing of whale migrations has necessitated adaptations in hunting locations and strategies, pushing the community to seek whales further from traditional hunting grounds. This adaptation reflects a broader narrative of access whereby physical entry to resource zones is modulated by environmental changes. A hunter reflected on the increased effort required to track whales due to these dispersed routes: "When they're there on that side, by Gambell area, Savoonga, when it opens up that's where they travel to. There's now more open water for them

to travel through, so it’s not only one set route anymore like it used to be." Here, the concept of access is expanded to include the ability to reach, engage with, and ultimately harvest whales under shifting environmental conditions. These shifts exemplify how access to traditional hunting grounds is being transformed, requiring a recalibration of what physical access means in the face of climate-induced changes. Such adaptations are not just responses but are proactive engagements that redefine the interaction between the community and their changing environment.

Physical Characteristic	Access	Barrier
Sea Ice Thickness	Thickness is greater than ~3 feet.	Thickness is less than ~3 feet.
Sea Ice Features (Pressure Ridges)	Pressure ridges indicate stable, anchored sea ice.	A lack of pressure ridges is risky and indicates potential breakages in ice.
Stable leads	A primary, stable lead increases the chances that hunters will find a whale.	Multiple, unstable leads make whale migration unpredictable.
Wind Speeds	Wind speeds <30 mph are favorable.	Wind speeds >30 mph are generally considered unsafe.
Bowhead whale presence	Bowhead whales migrating closer to Kivalina.	Bowhead whales migrating further away from shore, coupled with unstable ice, makes them unreachable.

Table 1. Physical characteristics influencing access to bowhead whale hunting in Kivalina, highlighting favorable conditions and associated barriers

Financial Access

In Kivalina, financial access to bowhead whales is deeply influenced by high and escalating costs of living and community-based financing models that have evolved in response to both environmental and economic pressures. The necessity to pool resources is a critical strategy employed by whaling crews to ensure that each team is adequately equipped for the

conditions of the sea ice-based hunt. This collective resource sharing extends to the meticulous and expert maintenance of boats during the summer, preparing them for the rigors of the whaling season. Boat maintenance is not only a logistical necessity but also an arduous task that underscores the indispensability of well-functioning vessels for successful hunting expeditions. Without properly maintained boats, whaling activities would be severely hampered, rendering the hunt impossible.

In addition, as Papa Joe, a respected Elder in Kivalina, highlights, "*We started the whaling, and Oscar [went] training at the rural camp in Anchorage. They wanted Kivalina to start whaling again. So, they trained him, they gave him everything he would need – harpoons, whaling equipment, everything*." This underscores the value of both internal and external support systems to sustain traditional practices. Another instance of external support is that of the Alaska Eskimo Whaling Commission (AEWC). The AEWC's Weapons Improvement Committee (WIC) supports whalers by ensuring that the bowhead whale hunt is conducted efficiently and humanely, complying with International Whaling Commission (IWC) requirements. The WIC provides technical assistance, modernizes equipment, and offers training to whalers, thereby enhancing the safety of modern bowhead whaling practices. Moreover, the financial constraints and limited equipment in town often necessitates a highly cooperative approach among the whalers, fostering a collective resilience that is crucial for survival. Typically, whalers recounted the practice of equipment sharing with other crews, a collaborative effort ensuring that each team is fully prepared for bowhead whaling, which is instrumental in safeguarding collective safety.

Despite barriers in economic access, hunters in Kivalina remain incredibly adaptive. Stephen Koenig's account illustrates the practical adjustments made due to resource limitations: "Going straight out from town, compared to up north, was safe for us, because we didn't have

enough gas to go that far... Further up north was safe because of the cooler air and thicker ice, but straight out from town was also safe because we didn't have enough gas." This statement not only emphasizes the strategic adaptations to geographic and environmental realities but also highlights how financial limitations directly impact the safety and operational decisions of the crews. This model of shared responsibility and mutual aid is emblematic of the broader socio-economic fabric of Arctic Indigenous communities, where collaborative approaches to resource management and utilization are not just beneficial but essential for the sustainability of cultural practices like whaling. The interplay between these community financing strategies and the escalating costs associated with changing climatic conditions presents both challenges and opportunities for innovation in preserving the cultural heritage and economic viability of bowhead whaling in Kivalina.

Financial Characteristic	Access	Barrier
Costs of Equipment and Supplies	Adequate funding allows for the purchase of necessary equipment and supplies.	Rising costs of equipment and supplies increase the financial burden on whalers.
Maintenance and Repair Costs	Sufficient resources for regular maintenance and repairs ensure equipment reliability.	High maintenance and repair costs reduce available resources for other necessities.
External Funding	Access to external funding supports community whaling	Limited external funding necessitates communal

	activities.	resource sharing.

Table 2. Financial characteristics influencing access to bowhead whale hunting in Kivalina, highlighting favorable conditions and associated barriers.

Informational Access

The acquisition and application of knowledge critical to bowhead whaling reflect the intersection of cultural resilience and environmental challenges. Traditional Ecological Knowledge (TEK) plays a crucial role in shaping community engagement with the environment, particularly under the escalating pressures of climate change. Access theory emphasizes the importance of not only accessing information but also possessing the means to effectively utilize it. During our interviews, a whaling crew member expressed, *"I try with most of the young ones here, I try to teach my boys how to watch the weather and the current and watch the cracks. Mainly the wind and the current are what we really watch for*," highlighting the dynamic process through which experienced whalers transmit essential survival knowledge to younger generations. This practice is indispensable for maintaining safety and efficacy in whaling activities, as these younger individuals learn to navigate increasingly unpredictable ice conditions and evolving marine ecosystems.

Continuous monitoring of ice conditions and meteorological patterns by the whalers, as exemplified by Enoch Adams Jr.'s statement, "Y*ou always make sure you can ulaq, that you have a way out of danger*," exemplifies a critical form of informational access that directly influences their capability to conduct safe and successful whaling operations. This facet of informational access merges traditional knowledge with contemporary technologies such as GPS and communication devices, facilitating the dissemination of instantaneous changes in weather and ice conditions. The integration of these technological tools with traditional practices

represents an adaptive strategy that strengthens community resilience in the face of environmental unpredictability.

However, significant barriers to informational access persist, notably impacting the transmission of crucial TEK to younger generations. The fact that no successful bowhead whale harvest has occurred in Kivalina since 1994, coupled with there being several whaling captains who have yet to catch a whale, starkly highlights these challenges. For example, one whaler noted, "*And so, I've been a captain myself for almost 20 years and I have not struck a whale*." The gap between successful whaling hunts at Kivalina has reduced opportunities for young whalers to learn critical skills necessary to adapt to changing sea conditions and altered whale behaviors—skills traditionally transmitted through generational knowledge. These barriers necessitate innovative approaches to ensure that younger community members can acquire and refine essential whaling skills. In addition, traditional ecological knowledge in Kivalina is adaptive and is reacting in real-time to uncertain conditions in the local environment. A young hunter made a point of this saying, *"I looked at what I thought was good ice and stepped near it. My pick fell right through. It seems like you can't trust the ice anymore"*. Hunters that continue to practice bowhead subsistence hunting on the sea ice platform are adapting their TEK to respond to uncertain and rapidly changing ice conditions.

Most importantly, the unique geographic and administrative positioning of Kivalina presents significant challenges to its ability to engage in and benefit from long-term wildlife and subsistence research projects. Unlike communities within the North Slope Borough (NSB), Kivalina falls outside this municipality, limiting its access to the resources and infrastructure available through the NSB's Department of Wildlife Management (NSB-DWM) and the Barrow Arctic Research Center (BARC), which houses visiting research scientists and provides

laboratory and technological assistance. These institutions facilitate and fund extensive, long-term wildlife and subsistence research projects for North Slope communities, providing critical data and insights that support sustainable management practices. Kivalina's geographic location outside of the NSB's jurisdiction means it lacks the institutional support necessary to develop and sustain similar long-term research initiatives independently. This poses a significant barrier to the community's ability to systematically study and respond to environmental changes affecting their subsistence practices. The absence of a robust research infrastructure challenges the capacity to monitor critical factors such as sea ice dynamics, bowhead whale migration patterns, and the impacts of industrial activities. Though they participate in annual meetings of the Alaska Eskimo Whaling Commission (AEWC), where certain studies and data are shared, the lack of direct access to NSB resources limits their ability to implement comprehensive research projects that can inform local practices and policy decisions effectively.

Several hunters in Kivalina have articulated a keen interest in establishing localized research projects that address specific migratory and sea ice phenomena directly impacting their subsistence activities. These proposed research initiatives include enhanced bowhead whale tracking studies to monitor the whales' proximity and movement patterns near Kivalina and investigations into the effects of noise pollution from industrial activities such as the nearby Red Dog port site on bowhead migration. Such studies are essential for developing a nuanced understanding of how these factors influence the availability and behavior of bowhead whales, which are important to the community's subsistence wellbeing. However, the implementation of these research projects is complex and resource-intensive. They require substantial funding, sophisticated tracking technology, and expertise in wildlife biology and ecological monitoring. The Alaska Department of Fish and Game (ADF&G) and NSB-DWM currently conducts

bowhead tracking research, but expanding these efforts to include focused studies around Kivalina necessitates increased financial investment and collaborative efforts between state agencies and local hunters.

Informational Characteristic	Access	Barrier
Real-time Environmental Data	Availability of real-time data (via a weather app or other online sources) improves decision-making for safe and effective whaling.	Lack of real-time environmental data makes whaling operations risky and less effective.
Traditional Ecological Knowledge	Adaptation of traditional knowledge to current conditions enhances hunting success.	Evolving environmental conditions necessitate new learning strategies and the adaptation of TEK.

Table 3. Informational characteristics influencing access to bowhead whale hunting in Kivalina, highlighting favorable conditions and associated barriers.

Ongoing Adaptations

Hunting Further North

One critical adaptation for Kivalina's bowhead whale hunting involves shifting activities to locations further north, about 10-20 miles north, where sea ice conditions remain more stable due to a mixture of geography and climate. This strategy includes hunting a few miles north from town, where the air is colder, and the ice is thicker, providing safer and more reliable conditions for whaling. Additionally, people in Kivalina are increasingly relying on their familial and community networks in Northern Alaskan communities, particularly in the nearby Point Hope (Tikiġaq)—a larger Iñupiaq community 70 miles north of Kivalina—where bowhead whale hunting remains steady year to year. In recent years, Point Hope has successfully harvested around 5 - 7 bowhead whales per season (Suydam et. al 2019). Kivalina and Point Hope have maintained strong community and familial ties for centuries, and today, these ties facilitate the

bartering and sharing of bowhead whale shares. For residents of Kivalina, bartering foods such as fish and berries—known for their abundance in Kivalina—for shares of bowhead meat from other Northern communities has become a common practice. These items are exchanged with families from communities who have successfully hunted bowhead whales.

Moreover, it is a longstanding tradition for some Kivalina hunters to travel to Point Hope to hunt bowheads with their familial crews, hunting by invitation of Point Hope whaling crews, and taking shares of the catch back to their families in Kivalina. Furthermore, Kivalina collaborates with other communities regarding their bowhead whale quotas, governed by the IWC and AEWC. During increasingly uncertain ice conditions and changing bowhead migration patterns, Kivalina often shares its quota with other communities who can hunt on their behalf, ensuring a continued supply of bowhead meat. These collaborative efforts are crucial as they enable Kivalina to maintain their cultural practices, intergenerational knowledge, and subsistence needs despite the challenging environmental changes. The adaptation of hunting further north and leveraging these inter-community networks showcases the resilience and ingenuity of Kivalina's hunters. These strategies ensure that bowhead whale hunting continues to be a vital part of their subsistence lifestyle, even as they navigate the complexities introduced by climate change.

Increasingly Strategic Decision-Making

A critical adaptation strategy for Kivalina's bowhead whale hunters involves making decisions based on a combination of factors such as equipment condition, crew expertise, and real-time environmental conditions, rather than relying solely on optimal physical conditions. This integrated approach allows for flexibility and responsiveness to changing conditions, enhancing safety and success in unpredictable environments. Historically, the primary

determinant for selecting hunting locations was the physical condition of the sea ice. However, contemporary hunters now incorporate the availability and condition of their equipment, the experience levels of crew members, and immediate environmental indicators into their decision-making processes. This shift is driven by the compounded impacts of climate change and associated physical and financial stressors, necessitating rapid adaptation. An illustrative example of this strategy is highlighted by Stephen Koenig's reflection: "*Going straight out from town, compared to up north, was safe for us, because we didn't have enough gas to go that far... Further up north was safe because of the cooler air and thicker ice, but straight out from town was also safe because we didn't have enough gas*." This quote underscores the practical considerations that hunters must balance, including financial constraints that limit their range and require careful evaluation of both environmental and logistical factors. By adopting this multi-layered decision-making framework, Kivalina's hunters demonstrate resilience and adaptability. This approach not only increases the likelihood of a successful hunt but also mitigates risks in a volatile Arctic environment, ensuring the sustainability of bowhead whale hunting practices.

Resource Sharing and Innovation

Kivalina's community has long practiced resource-sharing models, a traditional approach that has become even more critical in the face of increasing challenges posed by climate change and other stressors. The practice of pooling equipment and supplies among different whaling crews ensures that each team is adequately prepared for the hunt, distributing the financial burden and enhancing overall community resilience. One whaling captain noted, "*We stayed out the longest on the ice last year, and we're the youngest crew. We're learning to adapt faster than before*." This quote illustrates the proactive and innovative spirit of the younger generation in Kivalina, who are finding new ways to sustain their cultural practices despite environmental

adversities. The practice of equipment pooling exemplifies this collective approach. Sharing resources not only reduces the financial strain on individual crews but also ensures that all teams have access to necessary tools and supplies, thereby increasing the likelihood of successful hunts. Another captain emphasized the importance of this communal support system: *"We always make sure each crew has what they need to go whaling. If a crew doesn't have enough equipment, we'll share. That's how it's done.*" Another hunter connected these resource-sharing practices to the Iñupiaq value of sharing (siġñataiññiq), a foundational Iñupiaq value that builds social cohesion and increases access to resources in Iñupiaq communities like Kivalina. This cooperative model fosters a sense of connection, which is crucial in the face of unpredictable and challenging conditions. By leveraging shared resources and innovative strategies, Kivalina's whaling crews demonstrate resilience and adaptability, maintaining their cultural traditions and strengthening social networks, all while effectively responding to environmental changes.

Desired Resources for Adaptation

Bigger Boats for Open Water

All seven hunters interviewed identified the need for bigger boats as a critical resource for bowhead whale hunting in changing marine conditions. Larger boats are necessary to navigate the open water conditions and cover larger distances safely, especially in increasingly open water conditions as maximum sea ice extent continues to decline near Kivalina. Most crews in Kivalina have boats that are too small to handle the rough ice and open water, limiting hunting opportunities and increasing risks. As one hunter noted, "Bigger boats would allow us to hunt further and stay out longer", indicating that larger boats could provide a longer hunting window for whalers in Kivalina. This has been the case for other whaling communities further north,

such as Utqiagvik (Barrow), where increased purchasing power, coupled with environmental changes, facilitated the widespread purchase of larger boats (Huntington et. al 2017). However, bigger boats that can traverse larger distances are incredibly costly and present logistical challenges, such as difficulty in transporting them on ice trails to reach the physical leads. Determining a feasible way to transport these larger boats to the ice edge is also essential. Another hunter added onto this saying, "A 30-footer *and* a way to get them to the lead", pointing towards the additional resources needed to support the transportation of larger boats in Kivalina, such as larger sleds, to make hunting successful. The necessity for larger boats reflects the changing conditions and the need for more robust equipment to adapt to these challenges.

Safety Equipment for Whaling Crews

Four hunters emphasized the need for enhanced safety equipment to cope with the increasingly uncertain conditions during bowhead whale hunting. Safety gear such as life jackets, insulated heat wraps, and emergency supplies can be crucial for ensuring the well-being of the whaling crews. These items can make a significant difference in survival and comfort when facing the unpredictable and rapidly changing conditions around Kivalina, and especially in the case of an unexpected accident on the ice. In all of the interviews I conducted, hunters emphasized the necessity of being highly aware of physical conditions and to be alert of any sudden changes, which points towards the traditional and familiar practice of having safety measures and protocols in place while hunting. However, with thinner ice and more frequent storms, having additional safety equipment is now not just a precaution but a necessity. Life jackets and dry suits can prevent drowning in case of unexpected ice breakage, while insulated heat wraps can protect against hypothermia in freezing conditions, in case of an accident.

Emergency supplies, such as first aid kits and survival gear, are also essential for addressing injuries and other emergencies that can arise far from immediate help, which is especially important in remote environments like Kivalina. Ensuring that all crew members are equipped with the latest safety gear can help mitigate the risks associated with the dangerous hunting expeditions, providing peace of mind and additional security. As hunting conditions become more unpredictable, investing in comprehensive safety equipment for all whaling crews is critical to the sustainability of bowhead whale hunting in Kivalina.

Better Sea Ice Lead Forecasting and Real-Time Data

Whaling crews utilize a variety of digital tools, from weather apps to publicly available satellite photos, to support their efforts. However, three whaling captains identified better sea ice lead forecasting and real-time satellite data as an essential informational resource. Accurate forecasting of sea ice leads, wind speeds, and other relevant environmental conditions can help whaling captains plan safer and more efficient hunting expeditions. Improved forecasting tools would allow captains to make informed decisions about the best times and locations for setting up camps, thus optimizing their chances of a successful hunt while minimizing risks. One whaling captain highlighted the importance of this information, stating, "*To do that, we have to pay attention to wind, ice thickness, the migration route, wind speed... it's not unusual to find swells in the calm water so we have to pay attention to that now, too*." Enhanced forecasting capabilities would support the captains in navigating the increasingly unpredictable Arctic environment. With better real-time and predictive data, hunters can avoid dangerous conditions and make more cost-effective decisions, such as determining the optimal times to go out and when to take the crew. This would not only improve safety but also reduce the financial burden

associated with failed or aborted trips due to unexpected changes in sea ice conditions. Accurate and timely information could significantly enhance the overall efficiency and success rate of bowhead whale hunting in Kivalina.

Future Efforts

Future research and funding efforts for bowhead whalers in Kivalina, Alaska should be community-led. Allied collaborations should be sustainable, long-term, and align with the priorities of Kivalina's whaling captains and crews.

Integration into Larger Observing and Knowledge-Sharing Networks

The lack of access to community-driven, long-term research projects tailored to the immediate needs of Kivalina's subsistence hunters underscores a critical gap in the region's scientific and environmental management framework. Addressing this gap requires strategic funding sources to build research capacity within Kivalina, empowering the community to generate relevant data, actively participate in regional wildlife management, and develop adaptive strategies to mitigate the impacts of climate change and industrial activities on their traditional hunting practices. Enhancing local research capabilities through relationships with science institutions, such as larger observing and knowledge-sharing networks can provide Kivalina additional tools and resources to sustain their whaling practices and Iñupiaq lifestyle. For example, the Backyard Buoys project offers a viable solution by providing low-cost, community-deployed buoy systems that can deliver real-time data on marine conditions, water temperatures, and other critical environmental parameters (Backyard Buoys 2024). Integrating such technologies into Kivalina's research framework would enhance local observational

capacities and support data-driven decision-making for subsistence hunting practices, thereby fostering resilience and adaptive capacity within the community. Additionally, this participation can create new sources of income for Kivalina residents by employing them as observers and collaborators in broader environmental monitoring efforts. Furthermore, the Alaska Arctic Observatory and Knowledge Hub (AAOKH) represents a potential resource for Kivalina. This community-based monitoring program engages Indigenous observers in collecting environmental data, facilitating a collaborative approach to understanding and addressing climate impacts (Hauser 2021). By becoming part of the AAOKH network, Kivalina can both contribute to and benefit from a broader database of Arctic environmental observations, enabling knowledge-sharing and cooperation with other Arctic communities. This integration would not only bolster Kivalina's research capabilities but also ensure that their unique insights and experiences are included in regional and global discussions and efforts on climate adaptation.

Establishing collaborative research partnerships with academic institutions, government agencies, and nonprofits focused on Arctic research can provide Kivalina with the technical expertise and resources needed to conduct long-term studies. These partnerships can help design, fund, and implement research projects that address specific local needs, such as tracking bowhead whale migrations and studying the impacts of industrial activities. Additionally, hiring local observers to participate in the AAOKH or Backyards Buoy projects can provide additional income streams for hunters in Kivalina. By embedding Kivalina within these larger networks, the community can enhance its resilience amid climate change, reduce the strain felt by its hunters, and ensure that subsistence hunting practices can continue to thrive despite the environmental challenges they face.

Securing Additional Funding for Adaptation Efforts

Identifying and securing new financial resources may be essential to support the adaptation of whaling crews in Kivalina, given the significant financial stressors involved in acquiring larger boats, advanced safety equipment, and improved forecasting tools. New or existing partnerships can support local efforts in securing grants or other sources of funding for desired adaptations. Implementing a centralized, automated grant management tool has the potential to enhance the efficiency and reach of grant efforts, allowing a single grant worker in Kivalina to identify new funding opportunities, draft proposals, and manage applications more effectively. This tool might continuously scan databases for relevant grants, provide writing assistance, and integrate with existing financial and project management systems to streamline workflows and expedite the grant application process. By efficiently applying for and managing grants, Kivalina can alleviate financial burdens and support robust adaptation strategies for their whaling crews. Potential grant sources include the U.S. Environmental Protection Agency (EPA) Environmental Justice Grants, Alaska Conservation Foundation (ACF) grants, NOAA Fisheries' Alaska Indigenous Engagement Program Grants, the Northwest Arctic Borough Village Improvement Fund (VIF), the Alaska Climate Change Impact Mitigation Program (ACCIMP), and the Alaska Sea Grant's Coastal Community Resilience initiatives. By securing these grants and integrating into larger observational networks, Kivalina can achieve the desired resources for adaptation without straining community members, thereby enhancing their resilience and ensuring the continuity of their traditional practices in the face of climate change.

Conclusion

This study investigated the impacts of climate change on bowhead whale hunting in Kivalina, Alaska, over the past 20 to 30 years, identified the barriers that hunters face in

accessing bowhead whales, highlighted the adaptation strategies being implemented by whaling crews, and identified desired resources for adaptation. The findings revealed significant environmental changes, such as thinner, less stable sea ice and shifting whale migration patterns, which have necessitated various adaptation strategies. Kivalina's whaling crews are implementing many creative strategies such as: shifting hunting locations further north, increasingly strategic decision-making, and relying heavily on resource-sharing models rooted in the Iñupiaq value of sharing. These strategies demonstrate the community's collective continuance amid challenges to bowhead whaling and other land-based practices from the disruptions of climate change and sea ice loss.

This study underscores the critical need for supporting localized, community-driven adaptation strategies to sustain traditional bowhead whale hunting practices in Kivalina amid the challenges posed by climate change. Many of these adaptive strategies are rooted in Iñupiaq cultural values and will continue to build resilience for Kivalina in the decades to come. By integrating into larger observing and knowledge-sharing networks and increasing supportive funding sources, Kivalina can secure additional resources and support to enhance their adaptive capacity and reduce the overall strain felt by hunters. Recognizing and addressing the invisible labor of climate adaptation, such as the unpaid efforts involved in strategizing and sharing resources, can further alleviate the burden on the community, ensuring their efforts are adequately supported and valued (Johnson et al. 2023). These efforts are vital for preserving cultural heritage, ensuring food sovereignty, and maintaining the well-being of the Kivalina and its future generations in an increasingly unpredictable world.

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