



Climate policy must account for community-specific socio-economic, health, and biophysical conditions—evidence from coastal Alaska

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Abstract

Climate warming, sea level rise, and extreme weather events are creating intensifying and more frequent hazards for human populations inhabiting the coast. In Alaska's remote coastal communities, flooding and erosion are rapidly increasing due to the combined effect of sea level rise, more frequent storm surges, and increasingly powerful wave action from lack of sea ice. This paper presents survey results documenting socio-economic and psychological livelihood impacts and relocation preferences as reported by residents of a remote coastal Indigenous community. We quantified direct costs of lost or damaged private property, affected community infrastructure, and interruption of public services and found that the resulting financial hardship adds to existing economic challenges and climate stressors. Findings underline a community-level preoccupation with coastal climate threats that manifests primarily in intrusive and distressing thoughts of consequences from storms and other destructive climatic events. We highlight the need to monitor more broadly livelihood impacts to inform the design of innovative risk management tools to moderate financial hardship and strengthen community-driven action. We conclude that new policy responding to the needs of remote Indigenous communities affected by repetitive environmental disasters needs to account for a complex array of community and culture-specific socio-economic, health, and biophysical factors that require frequent co-produced assessments to capture rapidly changing conditions at the local scale.

Keywords Buyouts · Coastal flooding · Cost assessment · Climate change · Indigenous communities · Relocation

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Key summary points

- Elicited often hidden livelihood impacts related to extreme weather events in underserved Arctic communities using a brief household survey.
- Assessed significant and frequent financial hardship from loss and damage of private property given recurring and intensifying extreme weather events.
- Found evidence of mental distress due to rapidly changing environmental conditions.
- Contributes information essential for decision-making, policy design, and risk management such as buyouts.
- Concludes that climate policy and response need to account for community-specific socio-economic, health, and biophysical factors at the local level.

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Introduction

Exposure to coastal hazards such as flooding can lead to property damage, loss of life, and environmental degradation and are driven by climate change-related sea level rise and storm surges that are a growing threat across the world's coastal areas (Finkl 2013; Bongarts Lebbe et al. 2021; IPCC 2022a). Within the next 30 years, approximately one billion people living in the coastal zone will be threatened by coastal hazards, requiring complex multi-decadal response planning (Merkens et al. 2016; Haasnoot et al. 2021). Public policy aimed at the preemptive management of coastal hazards requires a better understanding of the social and economic impacts of these hazards and more research about

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the implications of and the public support for adaptation pathways specific to local conditions (Malette et al. 2021; Greer et al. 2022). Recent research revealed that public preferences most often support hard protection, also called a “gray infrastructure response” prevalent in Northeastern Europe, Asia, and very populated coastal cities allowing residents to remain in place (Bongarts Lebbe et al. 2021; Malette et al. 2021).

Aside from coastal hazards, the threat of sea level rise has accelerated calls to move entire communities away from coastal hazards through relocation, either pre-emptively before or after disaster. Relocation is widely viewed as an economically efficient climate change risk reduction strategy for society (Nelson and Ehrenfeucht 2016; Nelson and Camp 2020; Caron 2023). Relocation is incentivized through federal buyouts that finance permanent relocation for willing homeowners away from high-risk areas (Greer et al. 2022). It is a tool for governments to reduce the risk of climate change and mitigate hazards (Greer et al. 2022; Caron 2023). In the USA, buyouts are typically funded by the Federal Emergency Management Agency (FEMA) and the US Department of Housing and Urban Development (HUD). Most (89%) of FEMA’s Hazard Mitigation Grant Program (HMGP)¹ has funded post-disaster buyout programs in the contiguous US, leaving only a small portion for preemptive investments that limit future damages during disaster (Bukvic and Borate 2021). Since 1989, HMGP’s funding allocations for coastal rural areas declined whereas for coastal urban areas, it increased, with a continually widening gap (Bukvic and Borate 2021).

Despite the economic efficiencies of hazard reductions through home buyouts (Nelson and Camp 2020), research increasingly points towards the trade-offs and social costs associated with displacement causing worse recovery outcomes for those deciding to leave (Dannenberg et al. 2019; Binder et al. 2019; McGhee et al. 2020; Griego et al. 2020). Relocations also come with wide ranging implications for well being, justice, social capital, food security, water supply, sanitation, and public health (Ristorph 2017; Dannenberg et al. 2019; McGhee et al. 2020; Greer et al. 2022).

Human dimensions research on coastal hazards often focuses on urban areas due to increasing population densities along coasts (Monteiro et al. 2022). Here we present a case study from remote rural Alaska, documenting human experiences with extreme weather events and associated material loss, psychological impact, and adaptation preferences. Arctic climate change is occurring faster and is more severely affecting residents than elsewhere around the globe

(IPCC 2022b; Rantanen et al. 2022). Alaska’s remote coastal communities are most acutely exposed to impacts from increasing coastal hazards. Coastal flooding and erosion are rapidly intensifying due to the combined effect of sea level rise, more frequent storm surges, increasingly powerful wave action from lack of sea ice, and permafrost thaw (Basu and Walsh 2018; Jones et al. 2018; Walsh et al. 2020; Williams and Erikson 2021).

Below, we first review existing literature on coastal hazard assessments, the changing nature of coastal storms in the Bering Sea, and discuss previous studies on economic and health impacts related to climate change in Alaska. We then introduce background information on a case study, describing economic and health-related impacts of severe coastal storms in Hooper Bay, Alaska, a not road-connected community located on the Bering Sea coast. In the following “Methods” section, we outline our theoretical framework for inquiry and use the “Results” and “Discussion” sections to discuss policy implications from the research. The “Conclusion” section synthesizes the findings.

Literature review

The number of Alaska’s environmentally threatened coastal communities has been increasing over the past two decades (USACE 2009; UAF 2019; ANTHC 2023). In 2003, the US Government Accountability Office (GAO) evaluated 9 communities of which four were determined to be in imminent danger (GAO 2003). In 2009, an updated GAO analysis evaluated 31 communities of which 12 were considering relocation (GAO 2009), and another analysis by the US Army Corps of Engineers (USACE) looked at 178 communities affected by erosion determining 26 to be of highest priority for immediate action (USACE 2009). A 2019 study for the USACE assessed erosion, permafrost thaw, and flooding risk to infrastructure in 187 communities across Alaska. It found that risk of damaging or immediately threatening infrastructure was present in 29 communities due to erosion, 38 due to flooding, and 35 due to permafrost thaw (UAF 2019).

Response to intensifying coastal hazards needs to be considered within cultural expectations of living a traditional way of life that is intricately connected to the environments communities depend upon for survival and culture (Kofinas et al. 2010; Marino 2012; Fall 2016). Ecological integrity and societal well being are interconnected and need to be accounted for in relocation decision-making (Bronen and Chapin 2013; Marino 2018). Thus, relocation sites need to accomplish coastal hazard reduction (no permafrost thaw and unaffected by sea level rise, coastal flooding, and erosion) and cultural integrity (continued community cohesion and opportunities for wild food harvesting) (Bronen and Chapin 2013).

¹ FEMA’s Hazard Mitigation Grant Program (HMGP) is the largest US program funding relocation and was enacted in 1974 by the US Congress (42 U.S.C. 5170c).

Coastal storms are intensifying over increasingly warm ocean waters with more devastating power once they are landing inland (Reed et al. 2022). Impacts from extreme weather events are being realized most quickly in coastal Alaska, where historically sea storms were the most frequent extreme weather event (Kettle et al. 2020). Since the 1950s, the seasonal frequency of strong Arctic cyclones has increased by 20% in the summer and 35% in the winter (Zhang et al. 2022) where cyclones are also accelerating sea-ice loss (Blanchard-Wrigglesworth et al. 2022; Finocchio et al. 2022). Human perceived increase in storm intensity and frequency has already been documented by qualitative studies of western Alaska residents, conducted prior to the latest research mentioned earlier (Huntington 2000; Hinzman et al. 2005). These findings are also quantitatively supported by a recent statistical analysis that found an increase in high-wind events in northern and western Alaska between 1980 and 2014 (Redilla et al. 2019). High-wind events tend to occur in winter and can carry devastating consequences especially for remote coastal communities that largely rely on local infrastructure for communications, electricity, water, and waste water services with limited local capacity and redundancies to respond to disasters (Marino 2012; Hamza et al. 2021).

The latest federally declared disaster occurred on September 16–18, 2022, when remnants of Typhoon Merbok entered the Bering Sea and unleashed widespread devastation across western Alaska (Rosen 2022). The storm was one of the worst in 50 years and intensified existing coastal hazard and emergency response challenges that laid bare the vulnerability of Alaska's coastal regions (Thoman 2022; Rosen 2022). Besides extensive flooding, the storm interrupted electricity service for several days and led to food spoilage as freezers were not operating for extended periods. The effects of food spoilage can be especially severe when storms occur at the beginning of winter when freezers are full of wild foods collected and caught in the summer and fall harvest seasons (Thoman 2022). Combined with the storm-related loss of critical inputs to further wild food harvesting such as fishing boats or snowmobiles, food spoilage can lead to long-lasting repercussions and further financial hardship (Hughes et al. 2022; Thoman 2022).

As extreme weather events are increasing in frequency and intensity, there is a need for integrated cost assessment of natural hazards (climate costing) to inform and improve data-driven natural hazard risk management (Kreibich et al. 2014). For estimating disaster-related economic damages, the availability of data from disaster relief becomes an important input for damage assessments driven by direct costs related to damages that occur as a result of a hazard (Doktycz and Abkowitz 2019). Past research on disaster declarations in Alaska between 1977 and 2014 found that in general, disaster relief allocations are higher in more

vulnerable communities but remain disproportionately low for low lying coastal communities in unincorporated census-designated places with significant population, such as Hooper Bay in the Yukon Delta (Shen and Ristroph 2020). Related to this dichotomy is the fact that damages and loss of private property and equipment remain hidden as overly bureaucratic applications for federal or state disaster relief are less likely to be filed in communities that either lack the administrative resources or expertise to file for disaster relief (Shen and Ristroph 2020).

The literature on livelihood impacts related to climate change more broadly fails to address direct economic and health impacts from extreme weather events. For example, a broad-scale predictive study estimating the potential economic damages to public infrastructure from climate change found significant economic benefits in reducing risk through pre-emptive adaptation action (Melvin et al. 2017). Other economic studies looked at climate change costs and benefits to private households (Berman and Schmidt 2018), including impacts of changes in climate-related travel patterns and access to wild food harvesting (Berman and Kofinas 2004; Kofinas et al. 2010; Cold et al. 2020). Also, to our knowledge, broad household surveys across Arctic communities have not been conducted for almost 20 years such as the Survey of Living Conditions in the Arctic (SLiCA) (Poppel and Kruse 2009). Health-related studies looked into the health effects of air pollution from wildfire (Woo et al. 2020), threats to water and food security stemming from thawing permafrost (Berner et al. 2016), and injuries related to unpredictable weather, altered seasons, and poor water, snow, and ice conditions (Brubaker et al. 2011b), to name a few. Storms can also indirectly affect health by damaging and disrupting water and sanitation infrastructure, these impacts are more difficult to estimate using monetary terms (Brubaker et al. 2011b).

The impacts of severe weather on emotional and mental health are less well established, but there is an emerging evidence-base linking climate change impacts to worsening mental health outcomes for Indigenous peoples in the Circumpolar North (Middleton et al. 2021). Cunsolo Willox and colleagues proposed five main pathways by which climate change can influence mental health in Indigenous Arctic communities: through a change in sense of place and changes in traditional practices that promote well being; through effects on physical health; through deterioration of built infrastructure and resulting stress; through negative narratives of climate change (“disaster narratives”); and through compounding other stressors such as colonization, acculturation, and low economic status (Cunsolo Willox et al. 2015). Monitoring changes to mental health is also becoming more important internationally as more people experience the aftermath of extreme weather events (Brubaker et al. 2011a; Rasmus et al. 2014; Tschakert et al.

2017; Markon et al. 2018). The psychological trauma and distress related to environmental change is also known by the theoretical construct of solastalgia (Albrecht 2005). Land loss, livelihood changes, and disintegration of social networks and loss in social capital have been documented as psychological costs associated with displacement in coastal Louisiana, Texas, and other coastal regions of the contiguous US (McGhee et al. 2020; Griego et al. 2020; Simms 2021).

There is a growing body of literature documenting Arctic communities' challenges with climate change adaptation and hazard mitigation, focusing on human rights, inequities, and inadequate processes for climate adaptation and policy (Marino 2012, 2018; Bronen and Chapin 2013; Maldonado et al. 2014; Bronen 2015; Ristroph 2017, 2018). These studies are focused on analyzing existing mechanisms for climate adaptation governance, many of which document and reiterate livelihood impacts (Marino 2012; Maldonado et al. 2014; Bronen et al. 2020).

Buyout programs are part of a set of possible solutions for Alaska's coastal communities, yet, to our knowledge little research has investigated their acceptance or conditions under which buyout programs could be adjusted to fit local preferences for adaptation (Marino 2018). Critics point towards the cultural misfit of buyouts for Alaska's rural villages and the fact that most communities under current conditions do not qualify for such programs (Marino 2018). In welfare economics, willingness to accept (WTA) is the minimum monetary amount that a person is willing to accept for bearing a negative externality, here the demolition of homes in the hazard zone (Whittington et al. 2017). We assessed the propensity of residents to accept a federal buyout to inform future policy design. We used a case study of Hooper Bay, Alaska, to investigate the propensity for residents to accept buyouts, measure direct costs related to personal property loss and damage from coastal storm events, and explore mental health-related impacts of such events.

Insurance plays another important role in reducing and sharing risk related to increasing coastal hazards. Most of Alaska's 187 coastal communities that are frequently threatened by coastal flooding hazards are particularly challenged when participating in the US National Flood Insurance Program (NFIP) because of the federal law governing the NFIP and socio-economic conditions that result in lack of administrative resources needed to enforce and administer NFIP (UAF 2019). To qualify for the program, communities must have legal authority to adopt and enforce floodplain management ordinances for the area under jurisdiction. For tribes in Alaska, this authority was revoked under the Alaska Native Claims Settlement Act (ANCSA) (Landreth and Dougherty 2011). As a result, 64 federally recognized tribes that are situated in unincorporated Census areas and not co-located within cities are not eligible to participate in NFIP. In addition, participation in NFIP can be

administratively costly and not feasible for the small or non-existing tax base of many remote rural communities (GAO 2013). Finally, communities who have identified Special Flood Hazard Areas but choose to not participate in NFIP can be subject to financial penalties, suspensions of coverage, and ineligibility for disaster assistance. This creates additional disincentive for disadvantaged communities to join NFIP (GAO 2013).

Hooper Bay case study

Socio-economic conditions and housing disparities

Hooper Bay, Alaska (Fig. 1) is a Yup'ik Alaska Native coastal community that has 1375 residents, is 87% American Indian and Alaska Native, and has 146 households (U.S. Census Bureau 2020). It is not road-connected and located in the Yukon River Delta along western Alaska's Bering Sea coast (Fig. 1). Hooper Bay is part of the Kusilvak Census Area, an unincorporated area, not governed by a local municipal government (U.S. Census Bureau 2020). With a median age of 25 years, the Hooper Bay population is younger compared to Alaska with a median age of 35 (U.S. Census Bureau 2020). The median household income in 2020 was \$30,938, about 60% lower than the median income for Alaska. The poverty rate was 41%, four times the statewide average (U.S. Census Bureau 2020). The community is heavily reliant on wild foods largely comprised of fish (almost 2/3) and large mammals (1/3) including marine mammals, harvesting 160 kg per person in 2012. This harvest volume is more than five times the Alaska average per person harvest of 31 kg/year (Fall 2016).

Historically, the people inhabiting the general area of what's at present known as Hooper Bay were referred to as the Askinukmiut who lived in the wider Askinuk area. Historically, Yup'ik Alaska Natives lived a somewhat nomadic subsistence lifestyle until the 1900s when the US Bureau of Indian Affairs (BIA) forced families to enroll their children in school, consolidating the local population into stationary settlements (Berardi 1999; Maldonado et al. 2014). Many of the current housing units have been built decades ago without Arctic-specific building standards and were funded through federal programs (Ristroph 2021). Housing is built through HUD and BIA funding, where housing grants are managed by regional housing authorities which in Hooper Bay's case distribute limited funding across 48 communities. Newly constructed homes are generally sold to Alaska Native residents below construction value which can reach \$600,000 per single family home plumbed for water and sewer service (Ristroph 2021).



Fig. 1 Orthoimage of Hooper Bay, Alaska, showing the airport to the West, the main town center, and neighborhoods connected by roads of which one has the school towards the South, and another contains the fuel tank farm and sewage lagoon to the North. A spit of sand

dunes to the South of Hooper Bay separates the Bering Sea to the West from the bay that gave the town its name. The dunes serve as natural protection against storms and storm surge but are affected by coastal erosion

Many of the lands and housing lots in Hooper Bay are Indian/Alaska Native restricted deed titles. The buyer or occupant acquires the home through the regional housing authority, or inheritance. Due to its title, a lender would be unable to use the home as collateral for a residential loan, preventing foreclosure. For this reason, most homes do not have a mortgage and consequently no requirement for homeowner insurance. Only a very small portion of homes is held in unrestricted fee simple titles. In 2020, the median value of owner-occupied housing units in Hooper Bay was \$73,100, with the majority (60%) of housing units falling below \$100,000, 23% between \$100,000 and \$200,000, and 17% between \$200,000 and \$500,000 (U.S. Census Bureau 2020).

Most existing housing units are occupied by multiple families with average household size greater than five persons, twice the Alaska average (U.S. Census Bureau 2020). Some of the 1000 ft² single family homes that were originally built in the 1960s and 1970s are occupied by multiple families—parents with multiple adult members with their own children—forcing all available space to be used for sleeping, including in some cases entry ways. In addition to overcrowding, the community also experiences disparities in

sanitation. Until 2016, only about a quarter of Hooper Bay's housing units were connected to public utilities including water and sewer. The remaining 75% of homes are part of a multi-year project to bring running water to every household in the community (Alaska Dispatch News 2016).

Climate-induced coastal hazards

Hooper Bay is threatened by various coastal hazards including coastal erosion, permafrost thaw, and coastal flooding (UAF 2019). It ranks 16th among the 187 communities ranked for coastal hazards related to permafrost thaw, 26th for coastal erosion, and 46th for flooding (UAF 2019). Storm surges and coastal flooding are exacerbated by coastal erosion of protective dunes and low elevation combined with a significant tidal range (Miller and Ravens 2022). With expected sea level rise of 0.3 m by 2050, the community will see significant flood inundation during coastal storms that will turn the community into two islands and flood the recently elevated Airport Road (Fig. 1), threatening medical and evacuation access in an emergency (Miller and Ravens 2022). Hooper Bay has had informal discussions about

relocation yet is currently not actively planning to relocate. While sea level rise may eventually force the community to relocate, the planning process required to do so may take several decades as the case of Newtok, Alaska, exemplifies (Ristrop 2021).

Recent research showed that historically from the 1960s to 2016, Hooper Bay may have experienced at least 11 significant coastal flood events from storm surges including two minor, four moderate, and three major floods (Buzzard and Overbeck 2021). Minor flooding causes minimal or no property damage and may threaten property left on the beach (National Weather Service 2004). Moderate flooding results in some inundation of structures and roads with some possible evacuations of people and/or transfer of property to higher elevation. Moderate flooding can affect five low-lying residential homes and can prevent access to different parts of town connected by roads, interfering with emergency response (Fig. 2). Major flooding causes extensive inundation of structures and roads and significant evacuations may be necessary (National Weather Service 2004). Major flooding can inundate fuel tanks, drinking water sources, the wastewater facility, 31 buildings, and the airstrip preventing airplanes from landing for emergency response (Fig. 1) (Buzzard and Overbeck 2021). Coastal flooding also has the potential to warm and thaw permafrost, accelerating catastrophic destruction of permafrost with associated land collapse (Whitley et al. 2018; Jorgenson et al. 2018; Zhang et al. 2023).

Coastal change was not always this rapid. In the 1960s and 1970s, near shore ice would build up in late September and provide critical protection from fall storms. The absence of shore-fast ice until November and December results in increased flooding and erosion (Fang et al. 2018).



Fig. 2 Hooper Bay as seen from the air during the 2016 moderate flood that turned Hooper Bay into islands; the sewage lagoon is visible in the lower right; the road connecting the two islanded parts of town; protective dunes and the airport form the horizon near the top; the elevated airport road is slightly visible and remained accessible during the flood event

Health disparities

Due to the remoteness of the community, access to health care services in Hooper Bay is limited and mental health care services are mainly absent. Hooper Bay, as one of Alaska's 228 federally recognized Tribes (BIA 2023), has experienced rapid and imposed social changes over the past half century with colonization and enforced settlement of traditionally mobile hunting and gathering groups into permanently occupied villages (Rasmus et al. 2014). Changes in traditional ways of life have negatively impacted the health and mental health of Alaska Native people and contributed to the rise of health disparities and inequities (O'Keefe et al. 2021). Hooper Bay, and the Yukon Delta region more generally, experiences grave disparities in suicide among its younger residents (Alaska Native Epidemiology Center 2017).

For over a decade, Hooper Bay, along with other Alaska Native communities in this region, have been working together with university researchers to develop and implement solutions to eliminate these disparities and to promote the mental health and well being of young people in the communities (Rasmus et al. 2019a). These prevention strategies entail the engagement of young people in traditional activities that for the most part take place out on the land or waters (Rasmus et al. 2019b). Rapidly increasing climate change and attendant coastal threats in Hooper Bay have far reaching consequences and present additional challenges for health and mental health prevention efforts delivered locally.

Methods

The conceptual and theoretical framework for the study lies in social-ecological systems inquiry, specifically in building capacity to adapt to change (Berkes et al. 2008). Within this context, there is need for more consistent monitoring of the impacts of climate change not only assessing changes to the environment but also documenting the effects of changing environments (e.g., extreme weather events) on local livelihoods, including the effects on infrastructure, health, and wellbeing in underserved communities (Brubaker et al. 2011b; Bronen 2015; Bronen et al. 2020). Specifically, monitoring and identifying vulnerabilities and trends in socio-economic impacts that otherwise would not have been observed is important for adapting future governance and policy to changing local conditions (Kettle et al. 2020). Social-ecological resilience in part depends on equitable access to resources including federal aid, which is key for livelihood security and environmental justice (Berkes et al. 2008).

To establish a baseline for socio-economic impacts of extreme weather events, we used a household survey to

elicit historic experiences with extreme weather events, specifically coastal storms, explore potential psychological impact, assess adaptation preferences related to future coastal hazard mitigation including relocation and federal buyouts, and estimate direct monetary costs to households from these events. The survey was not intended to elicit other potential costs such as indirect costs induced by direct costs (e.g., the loss of a boat affecting wild food harvest/food security), business interruption costs, and intangible costs (e.g., loss of land), all of which are not as easily measured in monetary terms compared to direct costs (Kreibich et al. 2014).

The household survey was designed in close collaboration with local research partners from the Native Village of Hooper Bay, local health authorities, and Sea Lion Corporation, one of 200 village corporations established under ANCSA (Norström et al. 2020). Due to the COVID-19 pandemic, travel to rural Alaska communities was restricted and did not allow the non-local part of the research team to visit the community. Survey planning and design followed the tailored design method with open and closed ended questions (Dillman et al. 2014). Text entries to open ended questions were coded into categories that were then allocated to existing categories or recategorized, so that text entries became part of the statistical analysis. The survey was administered in-person by two local human-subjects trained researchers using a hand-held tablet device that connected to an online survey platform (Dillman et al. 2014; Qualtrics 2021). Since local researchers were involved in survey planning, no training was needed for them to assist respondents answering questions related to the survey. We attempted to survey all 146 households in the community, recruiting participants over radio and VHF radio announcements and door-to-door visits (Dillman et al. 2014; U.S. Census Bureau 2020). VHF radio remains one of the most common communication devices in rural Alaska villages. Contacts were also made through door-to-door in-person visits. Respondents received a \$20 incentive payment for taking the survey, conducted during summer and fall 2021.

The survey was divided into four sections (Online Resource 1). The first section documented concerns related to environmental changes that respondents witnessed. The questions asked about respondents perceived change in the intensity and frequency of coastal storms respondents had experienced over the past decade. The second section asked about what respondents remembered about the last significant storm event and whether respondents remembered the month and year of that event. The survey then asked about loss or damage to personal and community infrastructure, service interruptions, and financial burden associated with that last significant storm event respondents remembered.

The third section of the survey included questions about insurance coverage and mental health-related questions

(Online Resource 1). Specifically, we present answers to six questions associated with what is known as the Impact Event Scale (IES). IES is often used to analyze human experiences following exposure to traumatic events with the intent to explore whether storms are associated with trauma (Horowitz et al. 1979; Thoresen et al. 2009). The IES has three symptom clusters: intrusion, avoidance/numbing, and hyperarousal (American Psychiatric Association 2013). Respondents were anchored to the same coastal storm they remembered and stated earlier before responding to the following six statements (symptom cluster) with a 5-point scale including 0 = not at all, 1 = a little bit, 2 = moderately, 3 = quite a bit, and 4 = extremely:

I thought about the storm when I didn't mean to. (Intrusion)

I felt watchful and on-guard. (Hyperarousal)

Other things kept making me think about the storm. (Intrusion)

I was aware that I still had a lot of feelings about the storm, but I didn't deal with them. (Avoidance)

I tried not to think about the storm. (Avoidance)

I had trouble concentrating. (Hyperarousal).

Note, we further refer to statements associated with avoidance and hyperarousal as *distressing thoughts*, while referring to statements associated with intrusion as *intrusive thoughts*.

We tested the distribution of scores for normality applying the Shapiro–Wilk normality test and identified skewness using the R-package *moments* (Royston 1982; R Core Team 2022; Komsta and Novomestky 2022) (Online Resource 2). It is important to note that we did not calculate IES scores by symptom cluster as a diagnostic measure and as such did not analyze psychological distress and did not imply presence of a mental health disorder or clinical PTSD.

In the final section of the survey, respondents were prompted with a hypothetical onetime federal buyout that would allow Hooper Bay residents to relocate due to rising sea levels within the next 10 years, stressing the pre-disaster application of this type of buyout. The relocation question was framed in the context of the most recent analysis of storm surge impact given sea level rise that predicted significant flood inundation by 2050 (Miller and Ravens 2022). Participants were asked two buyout questions. The first one was about a community buyout for a lumpsum received by the community as a whole, and the second was aimed at an individual buyout, commonly used by FEMA (Bukvic and Borate 2021).

The community buyout asked whether they would vote to accept a federal buyout of \$500 million received by the community. This amount is the most recent and only available estimate to cover relocation costs for the

community (ANTHC 2023). The survey then asked how the amount should be allocated once received by the community. Specifically, we asked if the buyout should be equally distributed to households, kept in a single community fund to move together, used to temporarily shelter the community in place with the remainder distributed to the community, or used to harden the community in place with the remainder kept in a community fund for future relocation. If participants declined, they were asked about the minimum one-time payout that would be acceptable.

The second buyout question focused on individual households. We asked respondents about the acceptability of randomly generated hypothetical payouts directed to individual households. Specifically, it asked whether participants would accept a one-time buyout that would disqualify them from future aid but could be used to relocate their home. The hypothetical scenario primed participants that if they accepted the buyout, their existing home would be removed, and they would have to leave their current location. The task was designed as a double-bounded dichotomous choice contingent valuation question (Hanemann et al. 1991). Randomly generated initial offers ranged between \$10,000 and \$100,000 in accordance with home values found in remote rural Alaska housing stock and within the caps of the NFIP (Alaska MLS 2022; Stern 2022). Also, the US Federal Emergency Management Agency (FEMA) and the US Department of Housing and Urban Development (HUD) consider local acquisition costs in setting buyout funds (Stern 2022).

After accepting (rejecting) the initial buyout offer, respondents were prompted with the same question and a randomly generated lower (higher) amount, and finally prompted for the minimum amount that they would still accept. The random adjustment amount decreased (increased) the initial offer by an amount that ranged between \$5000 and \$10,000. If that offer was still declined, respondents were asked to state the minimum amount they would accept. Demographic variables were not included due to length of survey and concerns about privacy. Due to a technical glitch that did not properly record responses to the individual buyout question, a follow-up survey occurred in spring 2022 that repeated the buyout question and framing and attempted to recruit previous respondents but was open to new participants. Respondents received a \$10 incentive payment for completing the follow-up survey.

Results

A total of 90 heads of household participated in the initial survey and 84 took the follow-up survey with 48 respondents taking both surveys, resulting in 126 (85%) of Hooper Bay households taking at least one of the two surveys. Below we present results from each of the four sections of the initial

survey followed by individual buyout preferences elicited in the follow-up survey.

Local concerns and observations

Survey respondents reported a wide range of environmental changes and related concerns ($n=82$). Coastal and riverine erosion was the single most stated concern with 61% of respondents mentioning it followed by flooding (23%), concerns related to the health of wild food resources (18%), sea level rise (16%), seasonal changes (15%), the degradation of land using all-terrain vehicles (ATVs) (13%), and concerns over local preparedness for relocating the community (11%). Other less frequently reported concerns were warmer winters, high winds, permafrost thaw, local pollution from landfills and sewage treatment, freshwater scarcity, colder summers, sea ice loss, summer heat, and impacts to infrastructure. Asked about the single most concerning environmental changes among the ones listed ($n=83$), coastal hazards were mentioned by 67% of respondents and included sea level rise, erosion of protective dunes, coastal flooding, lack of critical sea ice, and permafrost thaw. The remainder ($n=26$, 31%) frequently mentioned concerns related to subsistence and food security as the single most concerning.

There is widespread belief that storminess has increased over the past decade. Almost all the 90 respondents ($n=86$) answered questions about perceived changes in storm intensity and frequency over the past decade, with none indicating that they “don’t know” (Table 1). Most respondents (64%) believe that both storm intensity and frequency have increased in the past decade with 30% saying that both have *definitely increased*. Only two respondents (2%) stated that both have *definitely decreased*. Only 9% believe that intensity and frequency both have decreased over this time with 2% believing that both have *definitely decreased* (Table 1).

Table 1 Perceived changes in storm intensity and frequency in the last decade, $n=86$

Storm intensity	Storm frequency	Count	%
Increased	Increased	58	64%
Increased	Decreased	5	5%
Increased	No change	6	7%
Decreased	Increased	2	2%
Decreased	Decreased	8	9%
Decreased	No change	2	2%
No change	No change	2	2%
No change	Increased	2	2%
No change	Decreased	1	1%

Survey question: In your opinion, has the intensity of storms (how damaging they are)/frequency of storms (how often they occur) changed in the last decade?

Interesting to note are respondents who had opposing opinions about the direction of storm intensity and frequency, but these opinions are only held by few respondents (Table 1).

Storm damages and impacts

Community-wide impacts of significant storm events were reported over the past five decades. More than half of respondents ($n=48$) reported the year they experienced the last significant storm they could remember with 18 respondents also reporting the month. These responses captured 16 individual years since 1974/75, where every year since 2016 was mentioned as a significant storm event year (Tables 2 and 3). Except for 1997 and 2017, when significant storms were reported in the spring and in 2020, when a significant winter storm was reported, all other reported storms occurred in the fall with September being the most frequently reported month. 2018 was the most frequently mentioned storm event by a total of 15 households. Home or

property-related damages were most frequent and reported by 35% of respondents answering this question, followed by service interruptions (33%), lost property (27%), and damages to the inside of homes (17%). Six respondents (13%) indicated that they had health-related impacts from storm events (Table 2). For example, some households had to leave their home because living space became flooded or unhealthy to inhabit. Ten respondents (21%) reported to have had no damages (Table 2).

Of those 13 respondents who reported lost property, the most frequently reported lost property were boats with 84%. Even minor flooding can threaten boats left on the beach. Damages to furniture and appliances from indoor flooding were reported by 46% of those reporting lost property, followed by 38% stating damage to exterior structures like sheds. These structures can either be in town or in fish camps outside of town. About a third of those reporting lost property stated that they lost ATVs or snowmobiles, and 15% stated that they lost a car or truck (Table 2). Mean annual

Table 2 Stated private property damage and/or loss, impacts, and injuries/loss of life related to historic storm events, $n=48$

Reported event year	Flood ^a category	<i>n</i>	Type of damage or impact ^b					Injuries/loss of life	Type of property lost or damaged ^c					Mean stated property damage per household ^d
			Outside home	Inside home	Lost property	Service interruption	No damage		Furniture/appliance	Shed/exterior structure	Snowmobile	Boat	Car/truck	
1974/75	Moderate	5	2	2	4			1	1	2		3	1	\$9700
1978	Moderate	1	1											\$1000
1979	Major	2		1	2	1				1	2	2	1	\$9375
1983	n/a	1			1							1		\$1000
1987/88	Minor	1												\$1750
1997	n/a	1												\$0
2003/04	Major	1												\$3750
2008	n/a	1	1			1								\$1000
2009	n/a	2										1		\$10,625
2014	n/a	2			2	1		2	2			1	1	\$2750
2016	Moderate	1	1											\$12,500
2017	n/a	4		1	1							1		\$5062
2018	n/a	15	9	3	2	8	3	2	2	1	2	2	1	\$7667
2019	n/a	3	1											\$1250
2020	n/a	5			1	4		1	1	1		1	1	\$7200
2021	n/a	3	2	1		1								\$3833
Total		48	17	8	13	16	10	6	6	5	4	11	2	\$6259 ^e

^aSource: Buzzard and Overbeck (2021) who categorized floods based on historical imagery until 2016, marked by the dashed line. Buzzard and Overbeck (2021) also documented an uncategorized flood in 1991, a major flood in 2005, a minor flood in 2006, and a moderate flood in 2011 that respondents did not report

^bSurvey question: What happened to you and your household during the storm? Select all that applies

^cSurvey question: what property did you lose or got damaged during the storm? Select all the applies. Note, this question contained an open-ended text entry which received no responses

^dSurvey question: How much do you estimate it cost you to repair or replace what you lost or what was damaged? Note, US dollar values are nominal and were not adjusted for inflation. For estimation, the mid-point of ranges shown in the questionnaire was used (Online Resource 1)

^eMedian: \$8750

damages per household amounted to between \$1000 and \$12,500 for replacement and repair of the lost or damaged private property with a mean of \$6259 (median \$8750) (Table 2). Most respondents (89%) indicated they do not carry homeowners' insurance ($n=56$). Three of the 56 respondents reported to have coverage for flooding and two had coverage against fire.

When asked about what damages to community infrastructure respondents remembered from the historic storm event, 66% of those reporting storm impacts ($n=48$) mentioned damages or impacts related to the airport, followed by the school (60%), roads (40%), fuel tank farm (33%), sewage lagoon (27%), power lines (17%), water and sewer lines (17%), dump site (12%), boat launches (8%), and homes (6%) (Table 3). Storm impacts to the airport were mentioned in almost all reported storm years since 1975, like impacts on the school (Table 3).

More than a third of respondents (37%) indicated that the intensity of the significant storm event they reported on was similar to storms they experienced on several occasions every year, 43% believed that recurrence intervals were annually, and 17% stated that the intensity was similar to storms that occurred once every 5 years or even less frequent (Table 3).

Most storm-related interruptions in service were for electricity with the majority lasting at least a day but less than a week (65%) and none lasting a week or longer (Table 4). About three-quarters of water and wastewater utility interruptions were reported to last a day or less but a significant proportion (9%) lasted longer than a week, like telephone and internet interruptions. More than half of the interruptions to air transportation were reported to last a day or less, with more than a third lasting a day to up to a week, and 9% lasting a week or longer.

The ways in which households reported to be affected by service interruptions varied. Storm surges can flood freshwater sources with either seawater and/or wastewater, affecting the availability of potable water with associated health consequences. The interruption of air transportation during storm events can prevent medical transport in case of illness, accidents, or other medical emergencies. Lack of air transportation also resulted in missed or delayed medical treatment and medical appointments. Some respondents considered the combined interruption of telephone and electricity services particularly threatening as communication services are essential for asking for help in emergency situations. Respondents also mentioned communications as

Table 3 Community infrastructure reported to have been affected by historic storm events; documented storm impacts in Buzzard and Overbeck (2021) for comparison and scale; and stated perceived storm recurrence intervals, $n=48$

Reported event year	Flood ^a category	n	Respondent count, n and *documented by Buzzard and Overbeck (2021)							Only respondent reported, n			Perceived recurrence interval ^b , n		
			Air-port	Homes	Roads	Tank farm	Boat launch	Sewage lagoon	Dumpsite	School	Water/sewer	Power lines	> 1/yr	1/yr	> 1/5yrs
1974/75	Moderate	5	3*	*	1*	*	1	1	1	2	1		4	1	
1978	Moderate	1	1*			1		1		1			1		
1979	Major	2	1*		*	1*	*	1*		1	1		1	1	
1983	n/a	1								1				1	
1987/88	Minor	1	1*					1		1	1		1		
1997	n/a	1	1											1	
2003/04	Major	1	1*										1		
2008	n/a	1	1		1			1		1				1	
2009	n/a	2	2	1	1					1			1	1	
2014	n/a	2	2		1			1	2	1	1		1	1	
2016	Moderate	1	1*		*								1		
2017	n/a	4	2		1	1	1	1		2			1	3	
2018	n/a	15	10		9	8	2	4	2	11	2	4	3	9	2
2019	n/a	3	2	1	1	2		2			2	1	2	1	
2020	n/a	5	4	1	2	2			1	4	1		4	1	
2021	n/a	3			2	1				3		2	3		
Total n		48	32	3	19	16	4	13	6	29	8	8	18	21	8

^aSource: Buzzard and Overbeck (2021) who categorized floods based on historical imagery until 2016. Buzzard and Overbeck (2021) also documented an uncategorized flood in 1991, a major flood in 2005, a minor flood in 2006, and a moderate flood in 2011 that respondents did not report. Survey question: What community infrastructure do you remember, was damaged during the storm? Select all that applies

^bSurvey question: How often do you experience a storm of comparable severity? Note, in the survey flow, these questions pertained to the last significant storm event the respondent remembered and the reported year of that event

Table 4 Service interruptions during storm events respondents reported as the last significant storm, $n = 17$

Type of service	n	Length of service interruption		
		1 day or less	A day to less than a week	1 week or longer
Electricity	17	35%	65%	0%
Water and/or sewer	11	73%	18%	9%
Air transportation	11	54%	37%	9%
Telephone/Internet	11	63%	28%	9%

Survey question: Did you lose any services during that storm? For how long? Note, in the survey flow, this question pertained to the last significant storm event the respondent remembered, $n = 48$

essential for coordinating emergency response within the community and between the community and state emergency coordinators.

Psychological impact

Findings underline a community-level preoccupation with coastal climate threats that manifests primarily in intrusive and distressing thoughts of consequences from storms and other destructive climatic events. Over half of respondents ($n = 51$) answered the six questions pertaining to psychological effects related to the last significant storm event they recalled (Fig. 3) (Thoresen et al. 2009). The extent of stated preoccupation with thoughts about severe storm events varied. For example, most respondents seem to have been occupied by thoughts and other things that made them think about the storm but very few respondents tried hard not to think about the storm or had quite a bit of trouble concentrating (Fig. 3).

All symptom clusters were not normally distributed (Fig. 3). Intrusion and hyperarousal were skewed to the left, meaning a larger proportion of respondents rated these statements higher: *thought about storm when didn't mean to* (skewness = -0.27), *felt watchful or on-guard* (skewness = -0.46), and *other things made me think about storm* (skewness = -0.16). Thus, feeling watchful and on-guard had the strongest response from respondents. On the other hand, statements of avoidance were less important to respondents as shown by the distributions being skewed to the right and indicated by the positive skewness: *aware of feelings but didn't deal with them* (skewness = 0.13), *tried not to think about the storm* (skewness = 0.28), and *trouble concentrating* (skewness = 0.45), with the latter being the least important across respondents.

Relocation and buyout preferences

Faced with the option to relocate in response to sea level rise and storm surges, 93% of participants ($n = 85$) would vote to relocate, primarily in response to erosion, floods, and

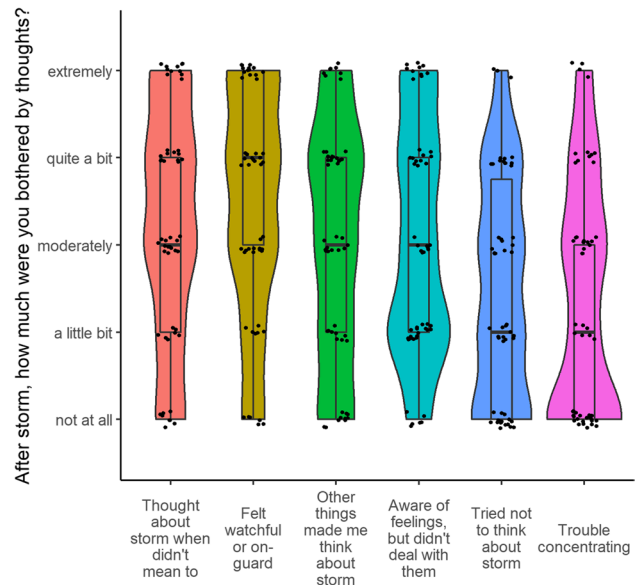


Fig. 3 Distribution of scaled answers for how much respondents were bothered by thoughts about the last significant storm event, where most frequently (box plot showing median rating and 25th and 75th percentile), respondents felt “quite a bit” watchful and on-guard, “moderately” bothered by thoughts about the storm when they didn’t mean to, “moderately” bothered by things that made them think about the storm, and “moderately” made them aware of feelings about the storm but didn’t deal with them, and “a little bit” made them try not to think about the storm or had trouble concentrating, $n = 51$

rising sea-level. Of those respondents in favor of relocation, half mentioned rising sea level and coastal flooding as the primary reason for their support followed by 27% who stated that coastal erosion was diminishing the protective nature of sand dunes: “I predict that by 2050, Hooper Bay will be under water. Water is rising and the dunes are diminishing with erosion” and “by 2050 the dunes may not be here to protect the town from floods.” Seventeen percent indicated that relocation was essential for safety and survival, the continued existence of the community and future generations, and that there was no choice but to relocate. Ten percent mentioned the need to relocate further inland, 5% indicated that relocation in 2050 would be too late and that the community should relocate as soon as possible. Three percent mentioned that environmental changes were speeding up.

Reasons for not supporting relocation were related to the vicinity of the current townsite to subsistence resources and concern over the loss of owned property and land and potential land ownership conflicts related to relocation. One resident mentioned that “it never floods in Hooper Bay,” perhaps hinting towards resilience and perseverance in the face of environmental threats. Four respondents (5%) gave reasons inconsistent with their votes.

Of the 84 respondents who answered the community buyout question, the majority (58%) supported the community

buyout with a vote to accept a \$500 million federal community buyout which hypothetically would require the community and all residents to forgo future aid related to coastal hazards. Respondents who did not accept the community buyout specified a different amount between \$0.8 million (25th percentile) and \$1 billion (75th percentile). Eleven respondents indicated community buyout amounts of less than \$1 million. Forty-seven respondents stated opinions about what the community should do with the buyout amount, of which 38% wanted to keep all of the money in a community fund to rebuild the community elsewhere, 28% wanted it distributed in equal shares among all households, 28% wanted to keep some of it in a community fund to raise buildings (prevent flooding for 20 years) and distribute the rest in equal shares to all households, and 6% wanted to keep some of it in a community fund to raise buildings and save the rest.

Results from the individual buyout question showed a wide distribution of accepted buyout amounts ranging from \$0 to \$800,000 within the 95th percentile of the data ($n=84$) (Fig. 4). The mean for the accepted buyout amount was \$68,468, with a median of \$66,000, first quartile \$28,000, and third quartile \$92,000 (Fig. 4). Four respondents indicated a willingness to accept a buyout of \$0, two respondents \$60 and \$80, and three respondents stated a WTA of between \$4000 and \$9000. The WTA for 13 respondents fell between \$200,000 and \$800,000 with four respondents indicating WTA above \$800,000 ($n=88$).

Discussion

Local residents' perceptions about their observations related to coastal change, specifically changes to coastal storms over the past decade, are consistent with recent western science findings that showed an increase in storm intensity (Reed et al. 2022) and increasing frequency of Arctic cyclones (Zhang et al. 2022). This result and the full response to questions about changes in storm intensity and frequency ($n=90$) underlines that local residents are highly in tune with their surroundings and have a sophisticated understanding of their environment, a finding widely supported in the literature (Roderick 2008; Huntington et al. 2017; Hueffer et al. 2019). The perceived increase in storm intensity and frequency has also been documented by earlier qualitative studies of local perceptions related to increased storminess and windiness in western Alaska (Huntington 2000; Hinzman et al. 2005) and are quantitatively supported by a recent statistical analysis (Redilla et al. 2019). High-wind events tend to occur in winter and can carry devastating consequences especially for remote coastal communities that largely rely on local infrastructure and have limited local capacity to respond to disasters (Marino 2012; Hamza et al. 2021).

The increase in storminess over past decades may also translate to an increase in social and economic impacts for

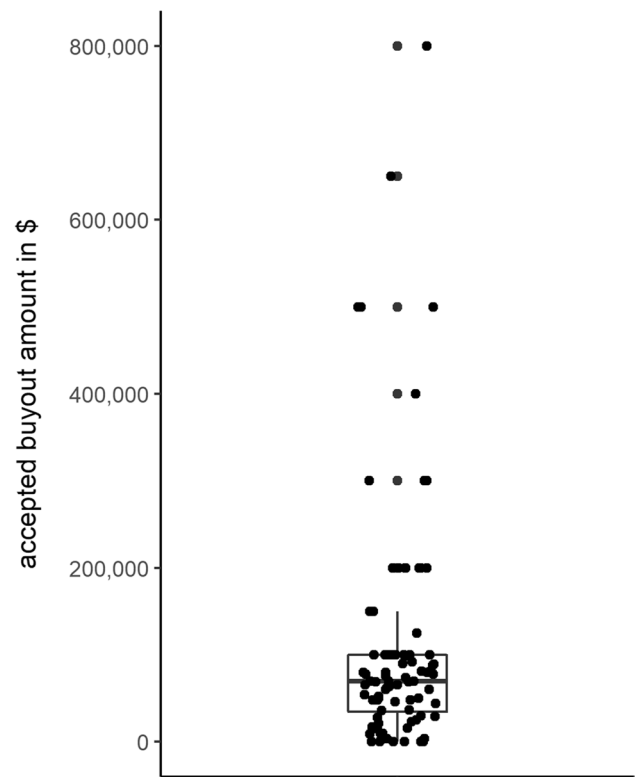


Fig. 4 Distribution of the accepted individual buyout amounts for a hypothetical buyout scenario after removing four outliers that were beyond the 95th percentile ($n=84$); the median shown by the bold horizontal line was equal to \$66,000; the box shows the 25th and 75th percentile

local livelihoods (Table 2). Most respondents (62%) reported storm events that they determined as significant within the past 5 years. Part of this result may be due to recall bias, favoring the reporting of more recent experiences that remain in people's mind (Coughlin 1990), yet the severity of the experience itself, as indicated by mental health results, may suggest that recall inaccuracy may be more of a factor than recall bias (Coughlin 1990). Also, given varying perceptions, exposure, and individual response to hazards, impacts greatly varied with each historic storm. For example, a respondent may have been affected more severely by a storm decades ago compared to any other more recent storm event. Also, a respondent may have responded to hazard exposure by moving to a less hazardous location within the community, therefore being less severely impacted by more recent stronger storms. Similarly, a respondent may not have been alive to remember a storm that occurred almost 50 years ago, likely the case for many respondents among the relatively young local population (U.S. Census Bureau 2020). More systematic monitoring of livelihood impacts, using similar approaches through broad surveying, could measure more accurately commonly hidden livelihood impacts of severe weather events on coastal residents.

The presented impacts in Table 2 are likely underestimating the true impact of coastal storms on the local population, for several reasons. First, the question format only asked about the experiences associated with one significant storm event respondents could remember yet fails to capture other storm events that could have likely resulted in similar damages. This argument is supported by 81% of respondents who reported on storm impacts believing that similar storms occur on an annual basis or even more frequently. Second, our approach mainly focused on direct impacts and costs and did not elicit indirect effects of lost property and other intangible costs (Kreibich et al. 2014). For example, exterior buildings such as sheds and fish camps as well as transportation equipment such as ATVs, boats, and snowmobiles are critical inputs to wild food harvesting and integral to food security within Arctic mixed cash-subsistence economies (Langdon 1991; Schwoerer et al. 2020). While our approach documents the storm-related loss of these assets, including its replacement value, the trickle-down effects of lost equipment are not captured and are likely much larger than the direct effects shown in Table 2.

Third, additional trickle-down effects related to lost equipment are associated with the significant financial burden that replacing the lost equipment presents to affected households. The reported mean financial burden for lost property and damages per household ranged from \$1000 to \$12,000 (Table 2). Compared to the median household income, this damage amount is significant, given that 41% of households earn income below the level considered poverty (U.S. Census Bureau 2020). For example, in 2020, the reported mean storm damages per household amounted to \$7200, about a quarter (23%) of the median household income of \$30,938 (U.S. Census Bureau 2020). Fourth, the lack of insurability through the NFIP and absence of homeowners insurance leave households without backups for financial hardship. The economic impacts from severe storm events are being realized by households directly, affecting disposable income and most likely having trickle down effects into health, well being, and food security.

The reported impacts on community infrastructure in Table 3 showed that the airport and the school are two of the most frequently affected infrastructure during severe storms. Both are critical for emergency response and evacuation. In many rural Alaska communities, schools serve as emergency shelters, yet if frequently affected by coastal hazards, cannot serve this essential role (DHS&EM 2011). This result underlines the vulnerability of Hooper Bay not having proper emergency shelter for its population and a robust transportation link to the outside world. Lengthy interruptions in air transportation can significantly hamper emergency response and medical evacuations.

Table 3 also illustrates potential differences between officially documented storm impacts and what people recall.

Infrastructure that was documented to have been affected by historic storm surges and consequential coastal flooding until 2016 is marked by the asterisk in Table 3 (Buzzard and Overbeck 2021). Noteworthy differences are that respondents reported impacts to the school which Buzzard and Overbeck (2021) did not mention and more frequent impacts to the airport that remained undocumented by Buzzard and Overbeck (2021). Similarly, damaged or impassable roads and damages/breaches to the sewage lagoon were more frequently reported by respondents. Reasons for these discrepancies can be explained by varying experiences, actual exposure, and definition of what a significant storm may entail. For example, what people think of as storminess and what meteorologists or coastal researchers might analyze as a storm may have very little in common. Also, events with minor flooding could have been associated with high windspeeds causing significant damages to buildings and other infrastructure that are not flood-related. Also, ATV's are more common compared to cars and trucks in Alaska's rural communities (Schwoerer et al. 2020), yet their drivers might be more prone to minor flooding on road ways compared to drivers in heavier cars and trucks, exposing a larger portion of the population to minor flooding on roads.

The above-described differences also illustrate that local knowledge can play a significant role in documenting historic impacts. Even though recalling historic events is subject to inaccuracies, our results showed consistency and a more nuanced description of impacts on people compared to earlier work (Buzzard and Overbeck 2021). Communities' experience with change is heterogeneous and associated with place-based understanding of values, loss, prior efforts, new priorities, and other factors (Whyte et al. 2016). The approach if scaled up across more communities can improve understanding of local context, values, assets, and constraints for action on resilience and adaptation planning (Degai et al. 2022). Filling local data gaps by monitoring change, specifically societal impacts of multi-faceted change on health and well being, enables data-driven decision-making on adaptation and mitigation investments (Bronen 2015; Bronen et al. 2020; Brubaker et al. 2011a, b; Woo et al. 2020). It also contributes to a growing literature on value vs. place-based approaches to adaptation, including limits to adaptation, examining loss nuanced and sensitive to people's lives and culture (Tschakert et al. 2017).

We did not conduct a non-response survey to address specific selection bias. Since the survey was aimed to conduct a census of local households and 85% of all households took part in at least one of the two surveys, we do not expect responding households to be different from the 20 non-responding households. Given the high response rate, we generalized the results of the survey to the population. In such case, we consider bias introduced by either over- or under-representation of parts of the population to be minimal.

Results from the IES demonstrate elevated levels of psychological distress indicators that could flow from the pathways described above. As stated earlier, Hooper Bay experiences the tragic burden of suicide disparities with young people at highest risk. Climate change can compound this threat by disrupting traditional practices that promote health and mental health of all members of these highly connected kinship-based communities. A recent chapter in a volume dedicated to examining the “Risky Futures” of Arctic communities, illustrates ways in which young people in rural Alaska Native communities are learning to weather the storms in their lives using place-based survival skills to navigate storms and threats out on the land and water (Rasmus 2022). The socio-ecological anxiety indicated with the IES cluster scores could reflect collective concerns about protecting young people and the threats that climate change presents for cultural continuity and community health.

Relocation and buyout

The very high level of support for relocating the community and agreeing to buyouts needs to be viewed within the socio-economic and biophysical contexts. First, current living conditions driven by inadequate housing and overcrowding are affecting response to the relocation and buyout questions. Some formerly Hooper Bay households have relocated away from Hooper Bay in the past decade due to the housing situation. Current residents may view relocation as a path towards more and better housing in general, as the entire village would need to be rebuilt. Similarly, individual buyouts would provide current residents on the cusp of moving the financial resources to change their own living conditions by moving elsewhere. Individual buyouts may also offer these households more certainty for improving their living conditions compared to community buyouts, yet more research is needed to investigate the relationships between adaptation options (e.g., protect in place) and socio-economic conditions. Second, the stated reasons for relocating are consistent with the results of other survey questions that illustrate heightened awareness of environmental change and what that change means for the future existence of the community, a finding widely supported in the literature (Roderick 2008; Huntington et al. 2017; Hueffer et al. 2019).

Most residents are in favor of a community buyout of which most support the option of keeping the funds to move as a community in its entirety. This result is evidence for strong social bonds between community members, resulting in a strong community fabric, social cohesion, and strong social and cultural capital (Haley and Magdanz 2017). This finding is consistent with other studies who found Indigenous populations place high value on sharing and exhibit a strong sense of belonging and place attachment (Wexler

2014; Philip et al. 2022). These bonds may include being simultaneously connected to the other community members and the specific geographic location of the community. The ability to keep relocation funds within the community provides a unique opportunity to maintain this social network and community. Given the growing stress of coastal hazards, communities face the difficult question of how to balance community and geographic location. Relocation of Newtok, Alaska, showed that new town sites require access to natural resources that are similar to current access, ensuring the continued existence of a mixed cash-subsistence economy that forms the economic backbone for most of Alaska’s rural villages (Fall 2016; Ristroph 2021).

The accepted individual buyout amounts directed at individual households within the 25th and 75th percentile (Fig. 4) were within a range consistent with real estate values and caps set by NFIP (Alaska MLS 2022; Stern 2022). The median WTA of \$66,000 needs to be viewed in light of the largely non-existent housing market and predominate subsidized housing that keeps housing prices for Indian/Alaska Native restricted deed title homes low and below construction costs (Ristroph 2021). WTA amounts above \$200,000 may indicate that people are aware of much higher construction costs compared to common sales prices through regional housing authorities. The four respondents indicating WTA of \$0 and two respondents who stated WTA of \$60 and \$80 can either be considered protest votes showing disagreement with individual buyouts in general or a lack of understanding. Some respondents had difficulty understanding the buyout question which may have resulted in their willingness to accept a \$0 buyout.

Policy implications

The study results illustrate that broad elicitation of rural residents improves understanding widely varying livelihood impacts from climate change that are specific to geographic, socio-economic, and cultural conditions. Population-wide data collection can help adequately inform the design of climate policy and financial instruments (e.g., buyouts) tailored to the specific needs of communities. Approaches that bring to light the often hidden economic and health-related costs of climate change to underserved communities are critical for achieving more equitable climate change solutions, especially in underserved communities that are more vulnerable to disasters (Vilá et al. 2022).

Besides broader data collection, simply a higher level of engagement with affected communities is needed to co-design tailored solutions (Degai et al. 2022). Such engagement should be viewed in the context of the effects of colonialism and forced settlement (Berardi 1999) and injustice and inequities in climate governance that continue to this

day (Marino 2018). These inequities are compounding vulnerabilities for underserved communities struggling with overly bureaucratic and top-down, agency-driven climate adaptation policies (Marino 2012; Ristorph 2017; Marino 2018).

This study also showed the need for financial instruments that reduce risk of extreme weather events for local households. Given the frequency of severe weather events documented in this study and the lack of financial resources to cope with lost property, households can be stuck in a poverty trap with extreme weather events slowly but constantly eroding their ability to restore lost or damaged assets critical to local livelihoods and food security (OECD 2002; Chen et al. 2022). Weather index-insurance that is used to manage weather-induced financial risk for farmers in developing countries could also serve as a risk management tool for underserved communities adapting to increasing coastal hazards (Sinnarong et al. 2022). This type of insurance would create payouts to affected households when certain environmental conditions are met (e.g., coastal flood height exceeding a pre-determined threshold) and avoid bureaucratic processes that commonly slow or prevent timely relief (Singh 2022). Index-insurance is particularly effective in reducing financial risk for households affected by repetitive environmental disasters and the effects of climate change as it provides immediate access to micro-credit as an additional financial backup (Singh 2022; Sinnarong et al. 2022). Studies like this assessing the direct costs of extreme weather events provide essential data for evaluating financial viability, pricing, and design of index-insurance.

Lastly, the study contributes to and emphasizes the need for designing proactive relocation programs for responding effectively to anticipated, chronic, and progressive coastal hazards like sea level rise. There is a growing research need for advancing climate policy that's flexible in accommodating both individual and collective large-scale efforts, uses innovative financial mechanisms to reduce risk in the near and long-term, and account for various objectives including preserving Indigenous culture, alleviating long-lasting housing inequities, supporting social cohesion, and boosting economic and community development (Bukvic and Borate 2021).

Conclusion

This study developed a short questionnaire to illuminate otherwise hidden but significant climate-related livelihood impacts from extreme weather events in one of the USA's most underserved and climate threatened remote Arctic communities. Findings underline a community-level preoccupation with coastal climate threats that

manifests primarily in intrusive and distressing thoughts of consequences from storms and other destructive climatic events. The study frames this finding in the context of reported human observations of more frequent and intensifying coastal storms that result in significant and frequent financial hardship from loss and damage of private assets that are essential to well being and food security. Direct cost assessments of lost property contribute essential information for designing risk management tools. The study concludes that climate policy and response need to account for community-specific socio-economic, health, and biophysical factors. More research is needed to address needed policy designs for underserved but disproportionately affected communities that face repetitive environmental disasters but need tailored approaches to suit their complex needs. Illuminating the hidden costs of climate change gives underserved communities the data to support much needed community-driven climate action.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10113-023-02080-9>.

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Author contribution TS: formal analysis, survey management, methodology, writing—original draft preparation, writing—review and editing, funding acquisition. KB: methodology, writing—review and editing, funding acquisition. SR: writing—original draft preparation, writing—review and editing. JJP: data collection, writing—review and editing. NWN: writing—review and editing, funding acquisition. TR: project administration, writing—review and editing, funding acquisition.

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Data availability All study participants consented to making the dataset available for public use after completion of the current study. The dataset generated and analyzed during the current study is available at the National Science Foundation's Arctic Data Center: <https://doi.org/10.18739/A29Z90D3V>.

All subjects gave their informed consent for inclusion before they participated in the study. No identifying information related to subjects was included in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the University of Alaska Anchorage Institutional Review Board under project 1501629.

Declarations

Conflict of interest The authors declare no competing interests.

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