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Permafrost Food Storage Monitoring and Vulnerability Assessment in Utqiaġvik, Alaska

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ABSTRACT. Traditional Iñupiaq *sigḷuaq* are cellars excavated into permafrost for storage of large quantities of game, fish, and other foodstuffs harvested for subsistence. Permafrost provides both a cultural and regulatory ecosystem service to Arctic peoples. A cellar thermal monitoring program in Utqiaġvik (formerly Barrow), Alaska, documented catastrophic flooding, collapses, and other issues in these cellars related to warming climatic conditions, community functions, and development. This paper provides an update on the Utqiaġvik monitoring program, which was operational from 2005 to 2019. All five monitored cellars exhibited stable to warming mean annual internal temperatures over the period of observation. Two cellars flooded, another was abandoned because of sloughing walls, and two were functioning until the COVID-19 pandemic. Based on experiences gained from the 14-year Utqiaġvik monitoring program, we conduct a vulnerability assessment using the source-pathway-receptor-consequence (SPRC) model and identify several vulnerability reduction measures. We recommend the SPRC model to aid evaluation of specific vulnerabilities of cellars and other traditional frozen infrastructure, and to improve future monitoring methods and products through increased community participation. Any attempt to provide data for community-resilience decisions should start with identifying and communicating process components, thereby bridging stakeholder learning and responses (their "heuristics" in the SPRC model) and science-based knowledge.

Keywords: permafrost; cellars; climate change; ecosystem service; source-pathway-receptor-consequence model; sustainability

RÉSUMÉ. Le *sigḷuaq* des Iñupiaq est une cave creusée dans le pergélisol pour stocker de grandes quantités de gibier, de poisson et d'autres denrées alimentaires récoltées à des fins de subsistance. Le pergélisol fournit aux peuples de l'Arctique un service écosystémique à la fois culturel et réglementaire. Un programme de surveillance thermique des caves mené à bien à Utqiaġvik (anciennement Barrow), en Alaska, a permis de documenter les inondations catastrophiques, les affaissements et d'autres enjeux concernant les caves et découlant de conditions liées au réchauffement climatique, aux fonctions communautaires et au développement. Cet article présente une mise à jour sur le programme de surveillance d'Utqiaġvik ayant eu cours de 2005 à 2019. Pendant la période d'observation, les cinq caves ayant fait l'objet d'une surveillance ont affiché des températures internes annuelles moyennes parfois stables, parfois en réchauffement. Deux caves ont été inondées, une autre a été abandonnée en raison de l'envasement de ses parois et deux autres étaient fonctionnelles jusqu'à l'arrivée de la pandémie de la COVID-19. En fonction des expériences tirées du programme de surveillance d'Utqiaġvik échelonné sur 14 ans, nous effectuons une évaluation de la vulnérabilité à l'aide du modèle des conséquences source-voie-récepteur et faisons état de plusieurs mesures de réduction de la vulnérabilité. Nous recommandons l'utilisation du modèle susmentionné pour aider à évaluer certaines vulnérabilités des caves et d'autres infrastructures gelées ainsi que pour améliorer les méthodes et les produits de surveillance futurs grâce à une participation communautaire accrue. Toute tentative de fournir des données en vue de la prise de décisions de résilience communautaire devrait commencer par la détermination des composantes du processus et par la communication de ces composantes, rapprochant par le fait même les apprentissages et les réponses des parties prenantes (les « heuristiques », selon le modèle susmentionné) et les connaissances basées sur la science.

Mots-clés : pergélisol; caves; changement climatique; service écosystémique; modèle des conséquences source-voie-récepteur; durabilité

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INTRODUCTION

In Utqiaġvik, Alaska, Iñupiaq excavate cellars, or *siglụaq*, into the underlying permafrost (perennially frozen ground) and seasonally frozen ground for the year-round cold storage of subsistence foodstuffs. Alaskan Iñupiat communities have constructed these cellars, often colloquially called "ice cellars" and "meat cellars," based on variable designs for at least a millennium (George et al., 2008; Nyland et al., 2017), as have other Indigenous and settler communities surrounding the Bering Sea (Maslakov et al., 2020; Yoshikawa et al., 2022). This example of frozen infrastructure demonstrates the diversity of Arctic ecosystem services that permafrost provides, including regulatory (consistent cold temperatures), provisioning, and culture.

The sustainability of *sigluaq* has been brought into question owing to the increasing frequency of functional issues attributable to warming climate conditions (e.g., Sakakibara, 2008; Brubaker et al., 2010; Eilperin, 2012; Kintisch, 2015; Naiden, 2022; Yoshikawa et al., 2022). Cellar functional failures include instances of bowing and sloughing walls, flooding, and collapse, where the stress of warming climate conditions is compounded by local development and other anthropogenic activities (Nyland et al., 2017).

The work reported here represents an update on a long-term cellar monitoring program in Utqiaġvik, Alaska (Nyland et al., 2017) and a case study that builds on Yoshikawa et al.'s (2022) recent regional synopsis of cellars in Bering Strait communities. We also explore the sustainability of this traditional food storage practice using the source-pathway-receptor-consequence (SPRC) model previously employed in flood hazard mitigation (e.g., Plate, 1999; Schanze, 2006; Narayan et al., 2014). We chose the SPRC model to explore sustainable adaptation in this example of Indigenous infrastructure because it reveals alternative causes and effects with clearly identifiable disruption points where vulnerability reduction measures can be applied.

Until recently, cellar monitoring has largely involved a unidirectional flow of information communication where scientists simply informed the public. A lack of discourse between scientists and stakeholders has resulted in minimal community input and decreasing participation in the monitoring program by cellar owners. The SPRC model may provide an opportunity for improved community-based monitoring efforts based on an extended discussion of experiences surrounding data collection limitations with the Utqiaġvik cellar monitoring network, other related monitoring and engineering projects conducted in this community, community-based monitoring initiatives, and locally expressed sustainability concerns.

Study Area

Utqiaġvik, previously known as Barrow, Alaska, before its name change in December 2016 (Hersher, 2016; Oliver, 2016), is the northernmost community in the United States and the largest native community in Alaska's North Slope Borough (71.3˚N, 156.5˚W) (Sturm, 2002). Situated just south of Point Barrow, the community is framed by the Chukchi Sea to the west and the Beaufort Sea to the east and boasts a robust Iñupiat subsistence hunting culture sustained by bowhead whale, walrus, seal, fish, duck, and other local game.

In a survey of cellars conducted in 2012, Nyland et al. (2017) mapped 71 cellars in Utqiaġvik. Utqiaġvik is an ideal environment for traditional refrigeration technology, as it is underlain continuously by cold (approximately −9˚C at 15 m depth) permafrost greater than 300 m thick (Shiklomanov et al., 2010; Romanovsky et al., 2015). However, Utqiaġvik has undergone significant climate warming over the last century (e.g., Lachenbruch and Marshall, 1986; Blunden and Boyer, 2022), and corresponding environmental and community changes threaten the structure and function of cellars. As early as the 1970s, research documented community observations from Utqiaġvik and other Indigenous Arctic communities on the changing occurrence and intensity of storms, thinning sea ice, and changing taste and appearance of meat stored in cellars (e.g., Cochran and Geller, 2002; Cochran et al., 2013). Additionally, thermokarst depressions, or ground subsidence due to underlying permafrost thaw, develop and undermine cellar structural integrity. Declining confidence in the reliability of cellars to provide cold, dry, and safe spaces has contributed to changing use and abandonment. The loss of these cellars has substantial ramifications for cultural, economic, and potentially public health, as discussed in Nyland et al. (2017). The practice of storing, aging, and sharing meat in cellars is a significant part of Inupiat culture. Using electric freezers to store the volume of meat harvested annually is challenging from a practical standpoint and economically costly. Additionally, meat aged in cellars is a culturally preferred taste (Cuomo et al., 2008) and has much less chance of botulism than in sealed containers in electric freezers.

Mean annual air temperatures recorded by the National Weather Service in Utqiaġvik increased at a linear rate of 0.19˚C yr^1 (0.42 R^2) over the period that cellars have been monitored (2005–19) (NOAA, 2018). In the undisturbed tundra environment surrounding Utqiaġvik, mean annual air temperatures have increased by 2.7˚C (Wendler et al., 2014). In response, permafrost temperatures at 15 m depth in surrounding natural environments have risen by 1˚C. The thickness of the active layer of permafrost (that is, the annual depth of thaw measured from the ground surface) has also increased (Shiklomanov et al., 2010; Romanovsky et al., 2015; Nyland et al., 2021). Changing permafrost temperature and thaw depth threaten cellar temperature regulation and the structural stability of the chamber and entrance shafts. Additionally, increased coastal erosion surrounding Point Barrow has been related to a decrease in landfast ice and increased occurrences of wind/wave events (e.g., Rolph et al., 2018; Bogardus et al., 2020). Cellars located along the shore, particularly in Utqiaġvik's older neighbourhood, still called Barrow, have already been lost

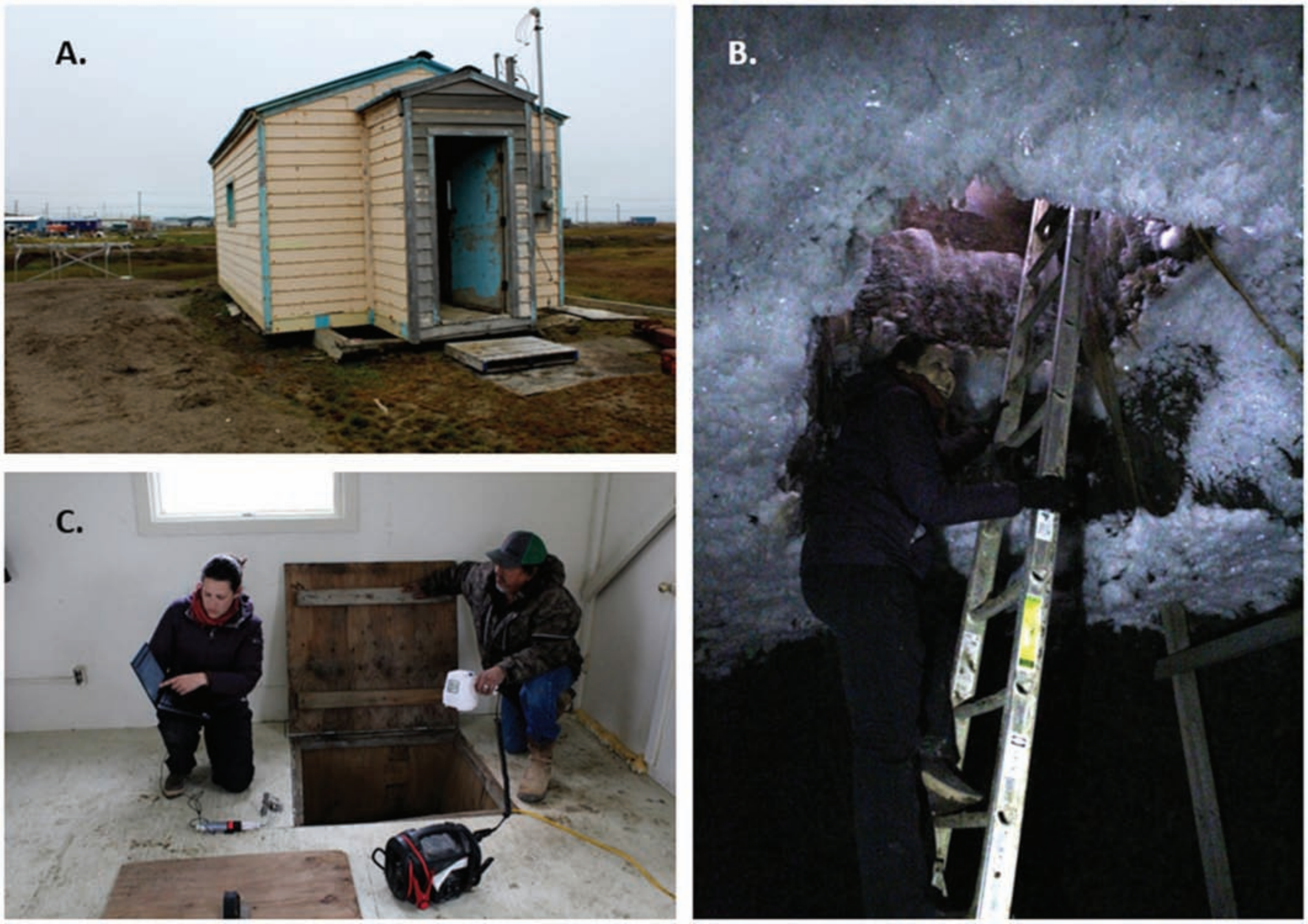

FIG. 1. A. Typical shed over a cellar entrance in Utqiaġvik, Alaska. This is the community cellar administered by the Native Village of Barrow Iñupiat Traditional Government; the CALM program instrumented the cellar. B. CALM investigator descends into the cellar to download the previous year's thermal data and perform data logger maintenance. C. CALM investigator discusses the data logger and temperature record with a Native Village of Barrow employee. Photo credit: Lindsay Cameron.

to coastal erosion, and others are increasingly threatened despite public works' sandbagging efforts along the Chukchi Sea shore.

METHODS

While contemporary climate change has significant implications for permafrost and, therefore, cellars, it is important to note that permafrost is dynamic and that there have been documented cellar failures since the early 1900s (Stefansson, 1956; Nyland et al., 2017). To determine specific process drivers (i.e., elements activating change) behind failing cellars and to establish frequency information, the US National Science Foundation–funded Circumpolar Active Layer Monitoring (CALM) program (Nelson et al., 2021), in cooperation with several local whaling captains and the Native Village of Barrow Iñupiat Traditional Government, formed a cellar thermal monitoring network in 2005 (Klene et al., 2012; Nyland et al., 2017).

Researchers instrumented five cellars (four with entrances inside sheds and one exposed) located throughout Utqiaġvik with Onset HOBO® Pro (2005–12) and Pro V2 (2012–19) temperature data loggers to continuously monitor internal cellar air temperatures at hourly or bi-hourly intervals (Fig. 1). Researchers attached the temperature sensors to cellar supports or behind ladders to minimize damage to the instrumentation at a height of 1.0 and 1.5 m above the cellar floors. The network used findings from Nyland et al. (2017) to assess cellar depths. CALM personnel visited the cellars annually in August for data downloading and maintenance. The data loggers provide thermal measurements with ±0.30 to 0.21˚C accuracy for the 0 to −20˚C temperature range typically observed at the 2 m to 10 m depths of cellars in this community. For more detailed methodological description, including a map of locations of the instrumented cellars, see Nyland et al. (2017).

RESULTS

The Utqiaġvik cellar monitoring network yielded a 13-year thermal record that ended the summer preceding the COVID-19 pandemic (Fig. 2). During the 14-year

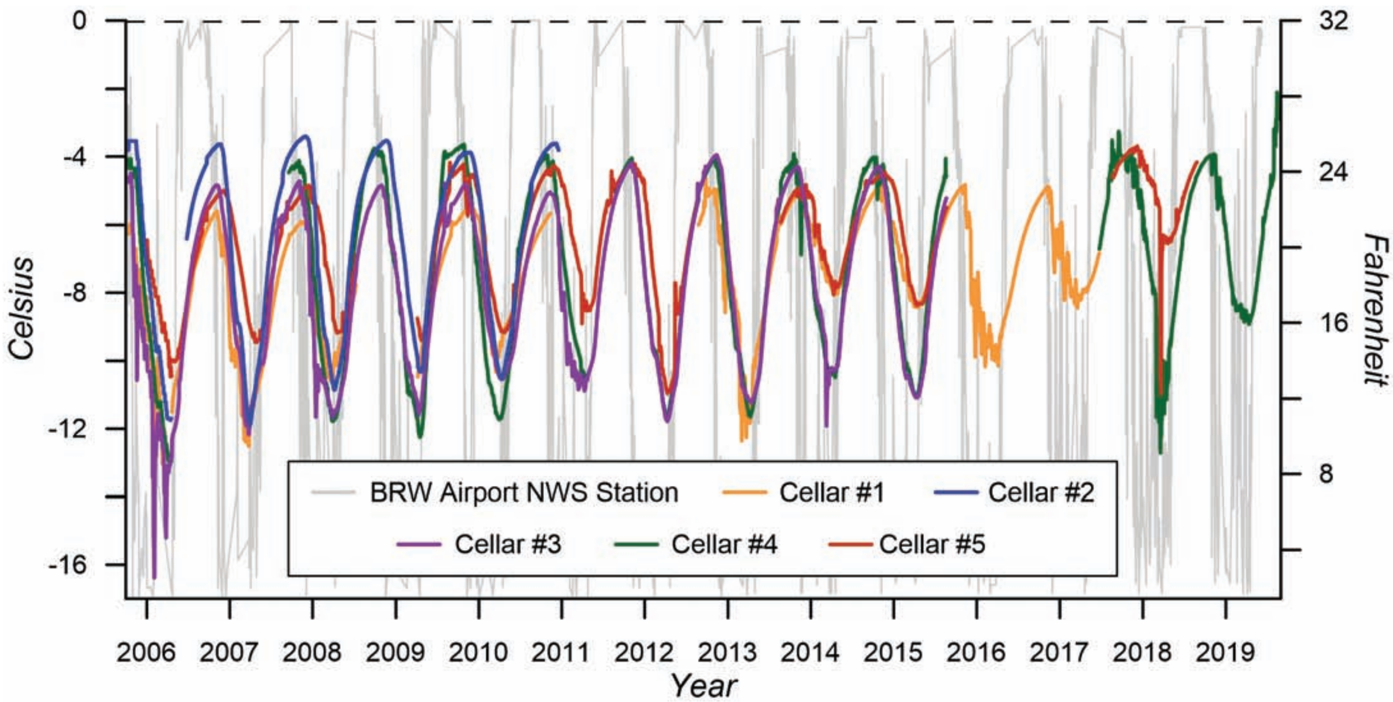

FIG. 2. Daily mean internal air temperatures for the five instrumented cellars from October 2005 to August 2019 and 2 m air temperature from the National Weather Service (NWS) station at the Wiley Post–Will Rogers Memorial Airport (BRW). Discontinuous lines indicate breaks in the data record due to instrument malfunction, lack of cellar access for instrument maintenance, or from an instrument that has gone missing. Dashed line across the top of the graph indicates the freezing point of water.

instrumental period (2005–19), all cellar temperatures remained sub-zero, with maximum daily temperatures in the five cellars ranging from −3.3˚C to −4.6˚C, and minimum daily temperatures from −11.0˚C to −16.4˚C. Internal cellar air temperatures have an annual cycle that lags behind that of the atmosphere by a few months in summer, and less in winter. Short-duration deviations, or spikes, in the daily temperature record are associated with cellar use and opening of access points, allowing internal temperatures to synchronize with the more extreme fluctuations in daily atmospheric temperatures. Opening doors in winter to refreeze the interior of cellars is a regular maintenance practice seen in communities throughout coastal Alaska and Chukotka (Maslakov et al., 2020; Yoshikawa et al., 2022). For instance, the records from two cellars (cellars Nos. 4 and 5) in spring 2018 showed that the cellar hatch and shed doors at both were left open during the first two winters, and that shed and hatch doors of cellar No. 5 were left open starting in early March. In both cellars, this was done to lower internal cellar temperatures, refreeze walls after excavation, and to rid the cellars of undesirable odours.

If uninterrupted, a given year of data collection yields 4380 or 8760 internal temperature observations for bi-hourly or hourly collection intervals, respectively. We calculated mean annual internal air temperatures (MAIAT) for years with complete records (>360 days of bi-hourly temperature readings) finding that these remained relatively consistent (Fig. 3). Cellar annual internal air temperatures ranges were from 2.2˚C to 0.6˚C. Two cellars had stable MAIAT but flooded. Three cellars showed increases in MAIAT ($R^2 > 0.70$) (Fig. 3). It is important to note that we calculated these trends based on few data points (see values displayed in Fig. 3).

DISCUSSION

Challenges with the Current Monitoring Network Model

Cellars included in the CALM monitoring network yielded significantly fewer data over the last five years of the instrumented record (Table 1). In the last three years of the record, data were only retrieved from cellars No. 1 and No. 4. Data gaps or discontinued cellar data records were due in part to instrument failure, but primarily lack of access, misplaced instruments, and animals (such as weasels) disturbing or damaging the instrumentation.

Cellar No. 2 flooded catastrophically in the spring of 2010, ending this short data record. Ownership and questions of how to obtain appropriate permissions to access cellars No. 3 and No. 5 limited these records. In addition, multiple data loggers were removed from cellar No. 5 when the cellar was cleaned or meat was moved. Cellar No. 4 is readily accessible but has been consistently used by weasels, reducing its use by the community and making data logger maintenance difficult. Lastly, cellar No. 1, a particularly deep cellar (6.8 m), has experienced significantly bowed walls in the entrance shaft (lined with wood) and sloughing walls within the cellar. Bowing

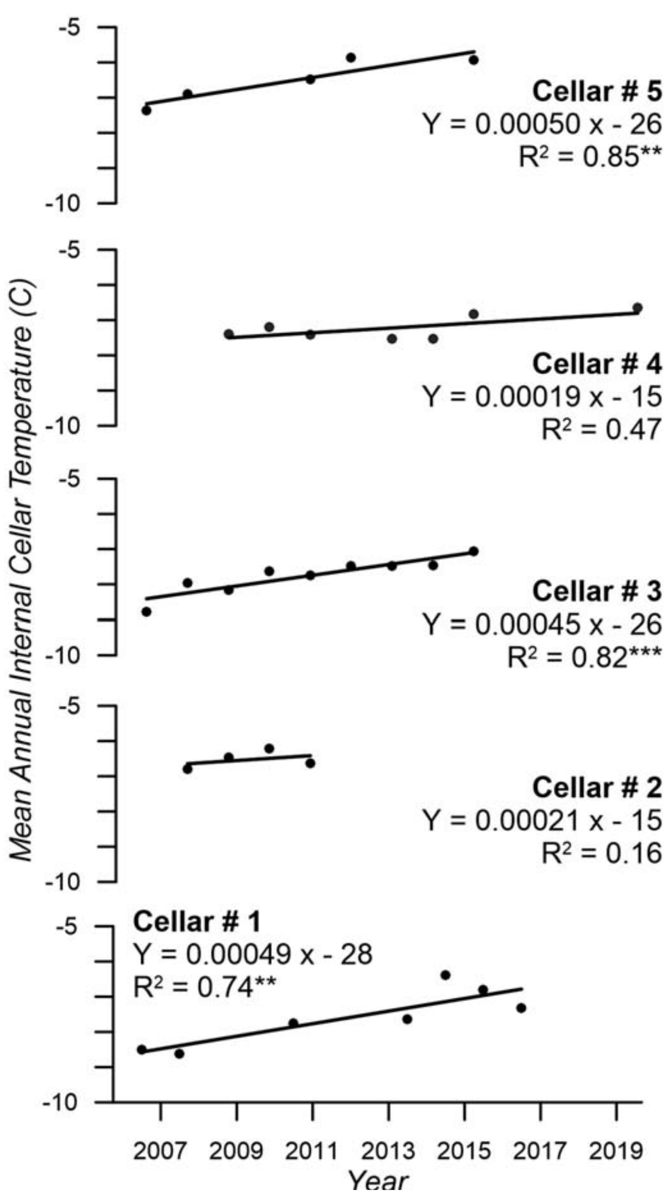

FIG. 3. Graphs of individual cellar mean annual internal air temperatures (black dots) for years with complete records (>360 days). Black lines indicate linear trends in these data, equations, sample size (n), and corresponding goodness of fit (r^2) are provided on each graph.

began before monitoring equipment instillation in 2005, but continued deformation makes safety a serious concern when descending the shaft for data logger maintenance when permission is granted. In August 2022, CALM personnel returned to and entered cellars No. 4 and No. 5. Both had been in use up to 2019, but by the time of their return, neither was in use owing to partial flooding during pandemic quarantine and consequent limited access for CALM personnel. These results support the conclusions in Nyland et al. (2017) that the cellar collapses were not driven exclusively by a thermal threshold being crossed, but rather, by an interaction of thermal and anthropogenic factors reducing the mechanical integrity of these structures.

Permafrost cellars, including those within the monitoring network, are failing. Researchers and community members are considering and testing a variety of adaptation practices including installation of thermosyphons (passive heat exchange devices) to artificially lower ground temperatures (e.g., Wendler, 2011), other measures to stabilize cellars, and excavation of new cellars further inland to avoid the impacts of coastal erosion (e.g., Naiden, 2022). However, drivers and related processes associated with these failures are unclear, given the data currently available.

SPRC Model Applications for Cellar Monitoring

The SPRC model was originally developed for flood risk management as a simple, deterministic way to identify causal process–based chains (Plate, 1999; Schanze, 2006; Narayan et al., 2014). Since its introduction for coastal risk management, the SPRC model has been applied in decision support systems to: 1) aid in communication to stakeholders through heuristic or cognitive strategies for decision-making; and 2) identify links in process chains, and particularly, specific connections where vulnerability reduction measures can be implemented (e.g., Kane et al., 2014; Narayan et al., 2014).

While users caution that the SPRC model can be an oversimplification of complex systems and lead to biased results (e.g., Touili et al., 2014), its simplicity is also one of its most valued qualities. The simple and flexible format of the SPRC model makes it easy to communicate and edit with stakeholder input and a practical means of implementing effective vulnerability reduction measures. Through the identification of causal linkages, vulnerability reduction measures can be implemented to modify pathways or adapt receptors to lessen or prevent negative consequences (Kane et al., 2014; Narayan et al., 2014).

We applied the SPRC model to the failing cellar phenomenon in Utqiaġvik to assess the sustainability of the traditional practice and of monitoring efforts based on informal conversations with cellar owners and whaling crews (Fig. 4). The model revealed two overarching primary sources: 1) the warming local climate; and 2) anthropogenic activities. These sources each have respective pathways that impact receptors (the cellars). For example, a warming climate with less shorefast sea ice during the year can lead to increased coastal erosion from wave action. Erosion can then lead to structural issues for cellars in close proximity to the shore, eventually causing flooding and collapse. An example of an anthropogenic source is snow removal from local roads. Large snowbank accumulations from clearing roads can significantly add to surface water after melt. Large snowbanks in the lee of snow fences in the community have also been found to significantly insulate the ground in winter months, preventing refreezing (e.g., Hinkel and Hurd, 2006). Meltwater is then unable to run off because drainage is reduced by permafrost aggrading into the base of the thick gravel roads required for construction on permafrost. This standing water drains to the lowest point available, such as into cellars, causing water to pool into, or outright flood these cellars.

TABLE 1. Utqiaġvik, Alaska, cellar monitoring network data matrix. Xs indicate years where network personnel retrieved data from each cellar. One year of data spans from August to August of the following year (YYYY–YY), depending on the date of annual data download. “End” indicates when the record stopped owing to lack of access. “Flood” indicates when a structural failure, such as inundation or “Collapse” ended the record.

Year	Cellar No. 1	Cellar No. 2	Cellar No. 3	Cellar No. 4	Cellar No. 5
2005–06	X	X	X	X	X
2006–07	X	X	X	–	X
2007–08	–	X	X	X	X
2008–09	X	X	X	X	–
2009–10	X	X	X	X	X
2010–11	–	Flood	X	X	X
2011–12	X	–	X	X	X
2012–13	X	–	X	X	–
2013–14	X	–	X	X	X
2014–15	X	–	X	X	X
2015–16	X	–	End	–	End
2016–17	X	–	–	–	–
2017–18	Flood/Collapse	–	–	X	–
2018–22	–	–	–	Flood	–

From interview-based studies of the SPRC model in the context of flood risk, science-based knowledge and community knowledge have been found to involve inherently different perceptions of risk (Kane et al., 2014; Touili et al. 2014). For example, where CALM personnel might see coarse-scale feedback mechanisms resulting in cellar failures, community members, based on their expert knowledge and heuristics, may notice cellar failures first as impacting cellar use and then seek process understanding in order to adapt (see arrows labelled “stakeholder heuristics” and “science-based knowledge” on Fig. 4).

Stakeholder risk perception is intrinsically focused on impacts to the receptor, or consequences. Therefore, we recommend that after constructing a SPRC outline (as in Fig. 4), good practice would include consulting with other stakeholders for input on possible alternative sources and pathways would be advantageous (e.g. Kane et al., 2014; Touili et al. 2014). Co-constructed risk management plans are also more likely to be implemented, given that these versions will likely be compatible with core community values and priority agendas (Kane et al., 2014; Touili et al. 2014).

Retroactively, using the lens of the SPRC model, we can view one product from the Utqiaġvik cellar monitoring network as fitting the model’s aim of developing a vulnerability reduction measure: the map of Utqiaġvik cellars. After CALM personnel learned of cellar owners’ concerns about construction and that snow plowing crews were unaware of cellar locations, our research team conducted a census of cellars in Utqiaġvik (Nyland et al., 2017). We mapped a total of 71 cellars and shared spatial data with North Slope Borough Community Planning and Development’s geographic information system department to help inform permitting and transportation management.

Following the stakeholder heuristics route through the SPRC model, cellar owners identified a consequence to the CALM science team members, who were then able to produce a map product to help mitigate the linkage between potential anthropogenic activity pathways and receptors. Revisiting an SPRC model for examining failing cellars with stakeholders may bring other applicable research initiatives to light and may also serve to increase stakeholder participation in the ongoing monitoring effort through improved collaboration.

CONCLUSION

The 13-year thermal record generated by the Utqiaġvik cellar monitoring network in Utqiaġvik shows that three of the monitored cellars have exhibited increasing mean annual internal air temperature trends. It is not possible to distinguish whether this is due to climate warming or to usage and leaving the door open in warmer months. Additionally, these trends are based on few data values and the record is discontinuous due to issues with instrumentation, cellar failure, and other limitations to cellar access. The influence of cellar use, particularly during periods when cellar doors are left open in warm months, has yet to be quantified. As there is no clear single driver of cellar degradation and functional failure, the interplay of both natural and societal variables warrants further investigation and requires development of a more robust dataset.

The current break in the CALM cellar monitoring network in Utqiaġvik presents an opportunity to reimagine, reframe, and ideally, include more cellars in the network for better representation within Utqiaġvik. Improvements to the network cannot be accomplished here without increased input from, and collaboration with, cellar owners and other stakeholders. Improvements are needed in terms of data ownership and related research question generation that must be shared between the scientific team and stakeholders. Optimally, this would lead to increased awareness and participation in the monitoring network, allowing researchers to better assist the community in monitoring thermal conditions within cellars, install thermosyphons, and develop other intervention strategies to maintain the cellars’ structural stability.

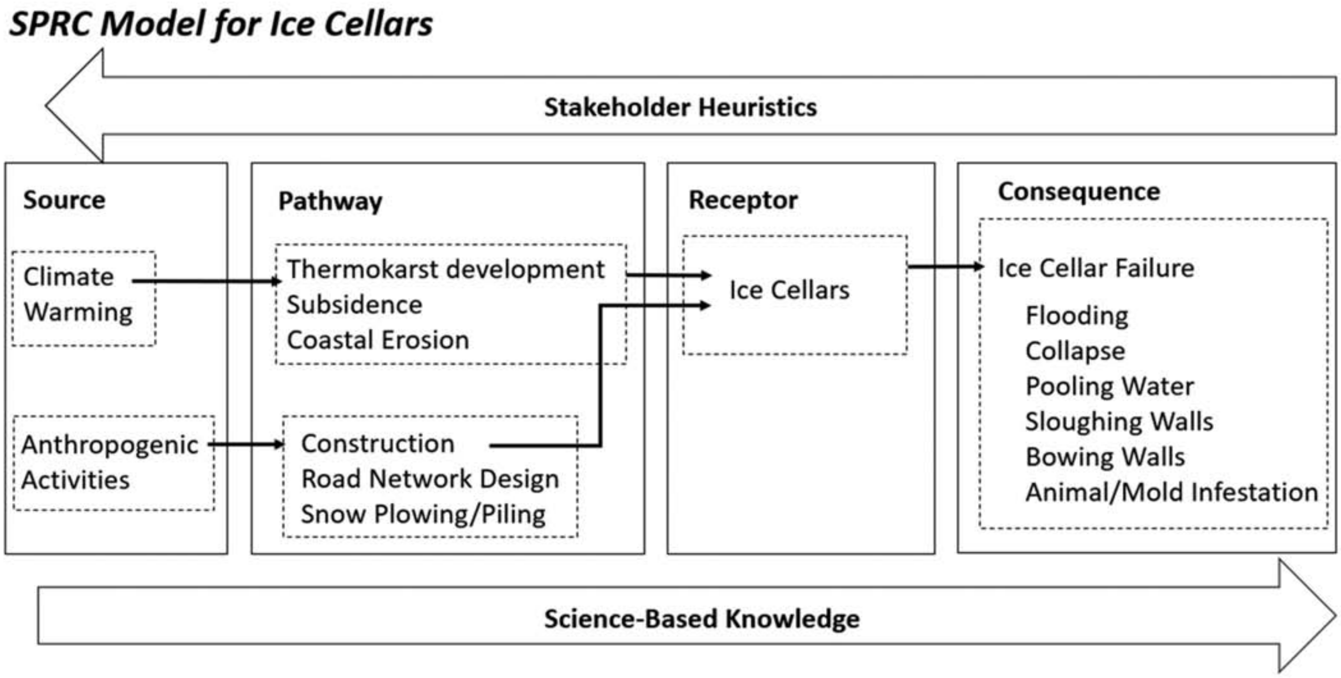

FIG. 4. Source-pathway-receptor-consequence (SPRC) model applied to cellar failures in Utqiaġvik, Alaska (Hinkel and Hurd, 2006).

Improvements to the monitoring network will require increased participation from cellar owners and other local stakeholders. Such a process could benefit from an in-depth ethnographic study of a single (or a few) cellars in the community using interviews and other qualitative techniques for narrative analysis. We recommend the SPRC model to improve monitoring efforts through increased collaboration. The model represents a flexible and collaborative framework leading to better understandings of the vulnerabilities of cellars constructed in permafrost. The advantages of this model are that it can be edited and extended by other scientists and stakeholders alike, facilitating joint research question and trajectory development to include vulnerability reduction measures. For instance, network co-ownership might be improved by using new instruments being developed by students at the University of Alaska, Fairbanks, that allow cellar owners to collect their own thermal data from cellars through a user-friendly interface (Granger, 2017).

Reframing of the Utqiaġvik monitoring network is in the initial planning stage and will include development of new research questions and methodologies based on equal input from the scientific team and stakeholders, similar to successful examples of community-based monitoring networks (e.g., Sparrow and Yoshikawa, 2012; Wilson et al., 2016; 2018; Klene and Nelson 2019). Since cellar monitoring in Utqiaġvik began in 2005, a number of guidelines have emerged about how to partner with communities (Fernandez-Gimenez et al., 2008). There are also calls to go beyond current scientific efforts and reward research carried out in collaboration with, or entirely by, community stakeholders with societal benefit such as in the case of the cellar map drawn by the CALM team (e.g., Noone, 2016). Resources are now available to aid scientists in their appreciation of Indigenous knowledge production (e.g., Kovach, 2021). The development of best practices to assist community-based monitoring (Sigman, 2015) in native communities (Johnson et al., 2015) and critical evaluations of those efforts (Thompson et al., 2020) provide advice on structuring these collaborations to be respectful, inclusive, and productive in terms of formulating research questions, data governance, and implementation. Large, successful collaborations, such as the Indigenous Observation Network in the Yukon basin watershed, provide examples of ongoing efforts to research, sustain, and protect resources. Their experiences of building research networks and social relationships provide lessons for others moving forward (Reed et al., 2022).

The emerging community-partnering guidelines extend to equitable data management. While some community-based monitoring programs have developed their own protocols to ensure accurate, precise, and reliable data and defended them against misperceptions of poor data quality (Herman-Mercer, et al., 2018), other guidelines focus on the distribution and management of data. These encourage the findable, accessible, interoperable, reusable (FAIR) data guiding principles (Wilkinson et al., 2016), but add a collective benefit, authority to control, responsibility and ethics (CARE) standard for Indigenous data (Carroll et al., 2020). This allows for the wide usage of data, but in ways that respect community stewardship. Further development of implementation criteria and Indigenous data management systems will allow these data practices to come to fruition (Carroll et al., 2021). Others have developed additional, encouraging improvements in practices, like MacLeod (2021), whose new format allows more respectful citations of oral interviews with Indigenous people.

Engineered solutions to the problems currently facing the continued use of cellars are within reach. Wendler (2011) modelled the impacts of thermosyphons on cellar structural integrity and function as a potential adaptation to warming climate. One community-researcher collaboration installed thermosyphons during the construction of a community cellar in Kaktovik, Alaska, in 2017 (Oliver, 2017). The Inupiat Community of the Arctic Slope recently used funds from the American Rescue Plan for initial work to study the effects of installing thermosyphons to provide supplemental cooling to some local cellars (Naiden, 2022).

Cellars continue to experience more frequent and novel issues that inhibit traditional uses. Informed adaptation decisions will require more consistent thermal and structural information from a thoughtfully constructed spatial sample of cellars in communities. Generating robust, long-term datasets will hopefully improve decision making strategies, not just for Utqiaġvik, but also other communities in Alaska's North Slope Borough (e.g., Brubaker et al., 2011) and around the Arctic (e.g., Maslakov et al., 2020) experiencing cellar failures. Based on our participation in long-term monitoring, we recommend that scientists seeking to initiate and continue partnerships with native communities should consult and be guided by community-based monitoring literature and knowledge co-production to shape their agenda.

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