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Nalaquq ("it is found"): a knowledge co-production framework for environmental sensing and communication in Indigenous arctic communities

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Abstract

In 2007, the Yup'ik village of Quinhagak contacted archaeologists after locals found precontact artifacts on a nearby beach. This collaboration led to the subsequent excavation of Nunalleq, an important ancestral site threatened by climate change. Since then, an international research team has partnered with Yup'ik leadership in Quinhagak to address the larger impact of climate change. In turn, this article introduces Nalaquq—our framework for combining custom sensor networks with traditional knowledge to study *ellavut* (trans. "Our land and weather"). Doing so provides a guide for communication scholars interested in working alongside Indigenous circumpolar communities to visualize and communicate climate science.

Lay Summary

Yup'ik (pl. Yupiit) are an Alaskan Native community whose land is threatened by climate change. Our article outlines how sensors can help Yupiit monitor climate change and communicate traditional knowledge. We begin by discussing how Yup'ik science differs from western science and how we use sensor networks. Next, we introduce a sensor network we developed in Quinhagak, Alaska. Finally, we discuss the value of Indigenous knowledge for scholars of environmental sensing, public health, climate change, and communication studies.

Keywords: sensors, citizen science, Yup'ik, climate change, Indigenous, communication

Introduction and study area

Environmental sensors create new ways of communicating knowledge to effect social change (Gabrys, 2016, 2019; Thackeray & Hunter, 2010). Yet, these sensors—whether they be quotidian (e.g., cell phones) or otherworldly (e.g., Earth-observation satellites)—generate unpredictable networks of political organization that can undermine Indigenous sovereignty, cosmologies, and cultures. In response, our research team Nalaquq was created by Yup'ik (pl. Yupiit) leadership in Quinhagak, AK (Figure 1) to design sensor networks that strengthen *yuuyaraq* (trans. "The Yup'ik way of life"). Accordingly, our contribution to this special issue discusses the benefits, challenges, and ethical questions surrounding the use of sensors to conduct research alongside Indigenous circumpolar communities.

Our research design blends Yup'ik and western science with established knowledge co-production frameworks (Carlo, 2020; Yua et al., 2022) to communicate our results and offer advice for future work on Indigenous lands. Since many of our readers may not be familiar with Yup'ik cosmologies, we have organized this article using a traditional academic research format that also incorporates advice from our Yup'ik co-authors in the form of *qanruyutet* (trans. "wise words of wisdom"). Thus, we begin by introducing our study area to describe the challenges of communicating sensor data to circumpolar communities. Then, after a brief literature review, we offer a warning in the form of an *aarcirtuun* (trans. "cautionary tale or warning") about the dangers and limitations of sensor-based research without adequate oversight. Next, we present our methods for co-producing knowledge before sharing four examples of how sensors can effectively be used to study Yup'ik place names, coastal erosion, monitor salmon, and assist Search and Rescue (SAR) teams. Finally, we end with a discussion section that includes specific suggestions for communication scholars interested in conducting similar research with Indigenous communities. At every stage,

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Figure 1. The location of Quinhagak within the Yukon–Kuskokwim (Y–K) Delta. Image credits: Jonathan Lim and Nalaquq, LLC (2023).

we provide example workflows, sensor selection advice, and best practices so that the lessons learned in Quinhagak may be shared with others.

Study area: *Ellavut* (trans. "our land and weather")

The Yukon–Kuskokwim (Y–K) Delta is a vast, windswept tundra in Southwest Alaska spanning 150,000 km^2 of coastal mudflats, lakes, sloughs, and rivers. It is also the ancestral homeland of the Yup'ik, who are Alaska's largest Native community, residing in 58 coastal villages with populations ranging from ∼25 to 1,000 persons (Miles, 2018) (Figure 2). Today, the primary methods of travel across the Y–K Delta include small marine vessels (>10 m in length), Cessna-style airplanes, all-terrain vehicles (ATVs), and snowmachines. There are no roads linking villages, and paved streets are non-existent with the exception of Bethel (population of 6,000), a regional hub on the Kuskokwim river. In the late spring, summer, and early fall, cargo and dry goods are delivered via shipping container barges (Figure 3). Finally, cellular service is limited, and many communities lack reliable internet (Figure 4).

Accordingly, the Y–K Delta's location and infrastructure pose serious limitations to the robust use of remote sensing, embedded networks, wearable sensors, and Internet of Things (IoT) devices for climate science. At the same time, however, Yup'ik communities would benefit immensely from additional environmental sensors to document climate change in the form of rising sea levels, increased erosion, and unpredictable weather. Together, these factors have made village travel more dangerous (Cold et al., 2020; Herman-Mercer et al., 2016; Moerlein & Carothers, 2012; Ristroph, 2019), disrupted subsistence (Fienup-Riordan, 2000, 2010; Fienup-Riordan & Rearden, 2012), and threatened traditional sites associated with Yup'ik material culture and history (Britton & Hillerdal, 2019; Hillerdal et al., 2019). Yet, sensor-based environmental monitoring in the Y–K Delta has been constrained to satellite remote sensing, visual surveys by piloted aircraft, NOAA weather stations installed at regional airports, and the use of sonar sensors and telemetric tagging for monitoring salmon. In addition, communication of data produced by these sensors has been limited to government reports and academic publishing with the exception of projects such as Kusko.net and the EKOLA Yup'ik Atlas that visualize existing data for community use. There is, therefore, a demonstrated need for additional sensor networks to communicate climate change and strengthen Alaskan Native tribal sovereignty.

Literature review: *Qanruyutet* (trans. "wise words") on Indigenous sensor networks

Sensor networks substantiate predictive, high-volume, and densely populated networks where analytics, data storage, and device management shape how we transmit and receive information (Andrejevic & Burdon, 2015). In this manner, they generate new ways of organizing information that far exceed the sum of their parts. In the Y–K Delta, however, aside from personal cell phones and hand-held GNSS units, sensors are largely absent from daily life. Furthermore, even in cases where sensors are present, they often operate outside of a robust network of cellular internet, wifi hotspots, and continuous software updates. The capacity to repair devices is also much lower compared to more urbanized settings, given the lack of access to spare parts and qualified technicians. Finally,

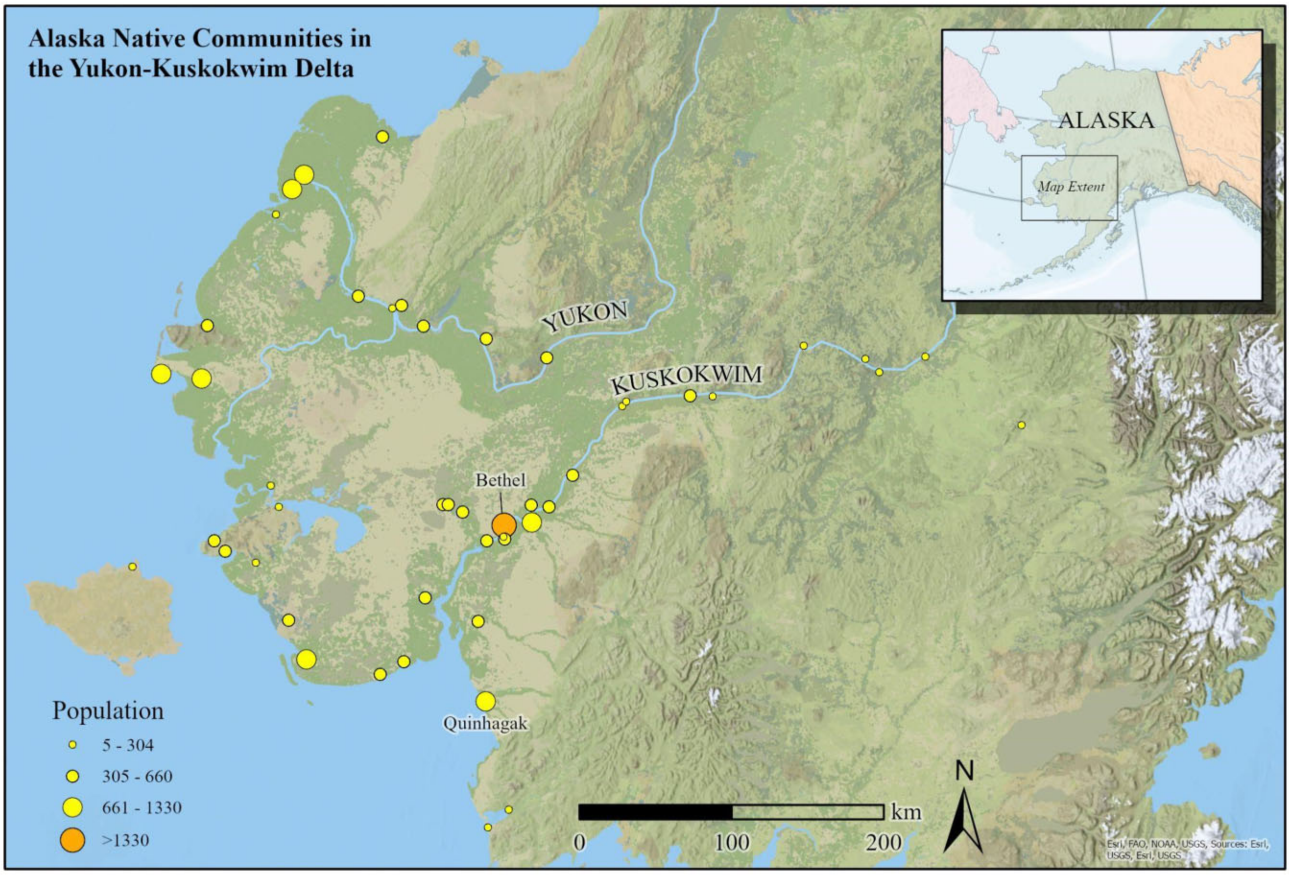

Figure 2. Location and population size of communities in the Yukon–Kuskokwim (Y–K) Delta according to DCCED certified population counts (2021). Communities were assigned to one of four size classes through a Jenks (Natural Breaks) classification. Image credits: Jonathan Lim and Nalaquq, LLC (2023).

Figure 3. Barges provide coastal villages with supplies. In Quinhagak, however, coastal erosion has made navigation more difficult. In response, our team trained local pilots to map shipping channels and monitor barges that have run aground. Here, Yup'ik pilot Bryan Jones uses a UAV to survey a grounded barge in 2022. Image credits: Bryan Jones and Nalaquq, LLC (2022).

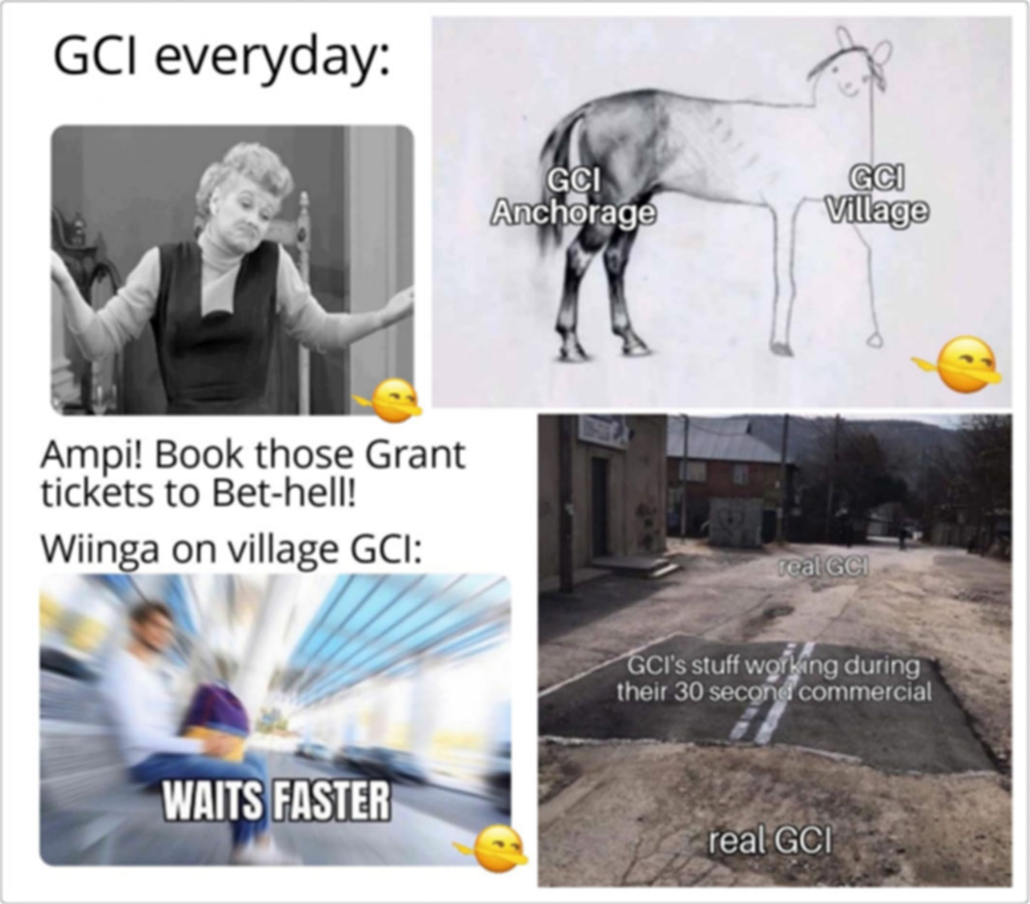

Figure 4. Facebook posts and memes about the lack of connectivity provided by the sole internet provider (GCI) for coastal villages. Image credits: Yup'ik Memes (2022).

researchers must consider the risks posed by sensor networks given the power of new technologies to disrupt Indigenous knowledge and practice (Abdilla et al., 2020; Loft & Swanson, 2014; Kawagley, 2009; Townsend et al., 2005).

In response, we follow in the footsteps of scholars who have called to decolonize communication studies (Denzin et al., 2008; Dutta et al., 2021; Langmia, 2022; Magallanes-Blanco, 2022b; Makoni & Masters, 2021) and those interested in collaboratively designed research that leverages meaningful data as a strategic resource reflecting tribal needs (Adams & Faulkhead, 2012; Peltier, 2018; Rainie et al., 2017; Smith, 2021). Relying on sage advice that local knowledge is often the best knowledge, we prize the ability of Indigenous communities to work within the constraints of limited information and communications technology (ICT) networks to develop novel solutions—whether by leapfrogging technologies or by utilizing devices in unexpected ways to avoid detection, thwart censorship, and subvert colonialism (Kavoori & Arceneaux, 2006; Magallanes-Blanco, 2022a; Mukherjee & Singh, 2017; Parks & Mukherjee, 2017). But we also recognize the dangers of expanding broadband access, Geographic Information Systems (GIS), and modern telecommunication infrastructure through coercive colonial structures (Chakravartty, 2004; Mukherjee, 2019) that erase Indigenous knowledge under the guise of progress (Dutta et al., 2021; Dutta, 2018, 2020; Niosi, 2021; Watson & Huntington, 2014). Here, we remember that colonialism is a system rather than an event (Tuck & Yang, 2012; Veracini, 2011; Wolfe, 2006) and that digital colonialism reproduces erasure through inaccessible technologies that are impossible to use in local contexts (Carroll et al., 2020; Gupta et al., 2023; Klehm, 2023; Schneider, 2022; Snelgrove et al., 2014).

Sensor societies imply dense networks of relation and transformation that have been theorized as cosmological in nature (Ballestero, 2019; Gabrys, 2019, 2022). Yet, as scholars of computer-mediated communication have noted, academic scholarship either ignores Indigenous cosmologies in favor of western ones or reduces the vibrant multiplicity of Indigenous perspectives into a static, monolithic whole (Abdilla et al., 2020; Lewis et al., 2018). Alternatively, we root our sensor networks in specific Yup'ik ways of knowing that reject positivist and post-positivist approaches in favor of research that is transformative, decolonizing, empathetic, and participatory (Barnhardt & Oscar Kawagley, 2005; Hillerdal et al., 2019; Kawagley, 2009; Knecht & Jones, 2019). In practice, this means that we design sensor networks alongside the Yup'ik taxonomy of *qanruyutet* (trans. "wise words of Elder instruction") that includes *inerquutet* (trans. "admonishment and prohibitions") and *alerquutet* (trans. "proscriptions") (Fienup-Riordan, 1995). For instance, we listen to *inerquutet* when they are offered, such as the admonishment provided by Yup'ik co-author Lynn Marie Church during a Fall 2022 planning session,

> I am sick of researchers telling us that climate change is happening. We don't need to be told that permafrost is melting. We know our houses are sinking. We see it here in the village. We don't need studies; we need solutions.

We hope this *inerquun* does not fall on deaf ears, and we embrace *alerquutet* that stress best practices for addressing community concerns. Thus, before outlining our methods for co-producing knowledge, we offer one representative anecdote in the form of an *aarcirtuun* (trans. "cautionary tale") to demonstrate the danger of reproducing colonial logics with sensors.

Warren's *aarcirtuun*: How not to use sensors

We believe that sensor networks excel at quantifying landscapes while Indigenous knowledge provides detailed information about how to use these data to study climate change. Yet, as many communication scholars have shown, it can be difficult to separate western research methods and technological innovation from settler-colonial logics of removal (Dickinson et al., 2006), exclusion (Denzin et al., 2008; Dutta et al., 2021; Endres, 2009; Hirji et al., 2022; Rowe & Tuck, 2017), exploitation (Wyck, 2010), and data extraction (Dutta et al., 2021; Hirji et al., 2022; Rowe & Tuck, 2017). Thus, researchers on Indigenous lands must consider how sensor networks—as "always on" instruments of passive data collection—(re)produce political hierarchies, modes of citizenship, and existing inequities by erasing (or otherwise minimizing) Indigenous knowledge (Andrejevic & Burdon, 2015; Davis et al., 2021; Gabrys, 2016, 2019). To this end, we find that many climate scientists have wasted valuable time using sensors to corroborate Indigenous science as "true," "valid," or "useful." Not only is this frustrating, but also it has tangible repercussions for communities who face rising sea levels, increased coastal erosion, and village relocation.

For example, when discussing climate threats to Quinhagak during a 2022 recorded interview, Yup'ik co-author Warren Jones outlines a far too common situation where environmental monitoring technologies duplicate, rather than extend, traditional knowledge:

> **Sean:** What are the biggest threats to your land right now?
>
> **Warren:** Erosion. Erosion is number one. The past seven years or so it has been so fast [that] we can't keep up. The old runway [on the Qanirtuuq river] for example (Figure 5). It was gone as soon as they quit putting sandbags up. Do [we] get that land back? No.
>
> Today there are bigger storms, bigger waves, and more rain in July. It should be raining at the end of August or September.... And this summer it is too hot, so there are no berries. So, people are going further to pick [berries] and families [must] chip in for fuel.
>
> Things are happening so fast. It is scary. So, we have to adapt to new ways of hunting. The old ways are going. Now it is more dangerous. We have to adapt; there is no way around it.
>
> But we [also] need the proper paperwork: Here is a good example: The old runway was eroding so fast, so we set up a grant, and we got it.... So, we told the agency we thought the river was going to go this way [towards the old runway and school]. It was not a big grant, maybe a little over 200,000 dollars. But they told us that we needed another study to get bigger grants to protect the erosion. After spending 100,000 on this study it pretty much told us where we knew the river was going to be. And I told them, "if we had bought boulders [instead of commissioning a study] this wouldn't be eroding." So traditional local knowledge is needed, but at the same time, you need to have that paper and data for the grant people to understand. It's frustrating.

The study Warren references is a 2018 feasibility report on the Kanektok (var. Qanirtuuq) River (CRW Engineering, Inc., 2020). Over three days, consultants met with 13 community members, writing in published field notes that:

> ....George Pleasant's grandmother was a shaman who had predicted the community would move 5 times and their fifth spot would be final. The current location of the community is their third. Residents are concerned about the river cutting through the old runway, impacting the village and destroying access to gravel.... [During one meeting] John N. Fox addressed the group in Yupik [sic] and reminded everyone about the prediction that Quinhagak would move five times and they are on the third move. (Herrera Environmental Consultants, 2019, p. 20)

With this ethnographic information in hand, scientists utilized a standard environmental sensor network to measure erosion along the Qanirtuuq river. First, bathymetric and lidar sensors were employed to establish river depth and flow. Next, survey-grade differential Global Positioning System (GPS) sensors were used to record locations at risk from coastal erosion. Finally, satellite imagery was combined with hydrological data to create a composite map of the Qanirtuuq river showing potential flood plains for 2- and 100-year flooding events. Data were communicated as fold-out maps within a spiral-bound report, and digital resources (including the underlying datasets) were not provided to community members. The total cost of the study was $267,000 (CRW Engineering, 2020).

Importantly, Warren's frustration with this report does not stem from the use of sensors to study climate change. Rather, he raises important questions about the underlying assumptions many researchers hold about the validity of Yup'ik science (lit. "*Yuungnaqpiallerput*: our genuine way of subsistence living"), which result in sensor networks that simply quantify local knowledge rather than amplifying it through innovative solutions created with community input and oversight. Within this paradigm, sensor networks are (at best) able to produce data that are accepted as legitimate by political institutions and (at worst) produce redundant, superficial, and patronizing distillations of Indigenous science. In turn, we see this paradigm as a communicative failure that operates on two levels: First, outside researchers often overlook Indigenous knowledge because they are not equipped to

Figure 5. A 2021 aerial photo of erosion along the Qanirtuuq River at the old airport. Image credits: Jonathan Lim and Sean Gleason (2021).

recognize it as scientific. Second, data produced by these sensor networks are often not accessible to local communities.

In response to Warren's *aarcirtuun*, we draw from the *qanruyun*, *Ciutek-gguq iinguuk"* (trans. "Ears, they say, are eyes") to develop specific *caliyarat* (toolkits, lit. "ways of working") for community-based climate science with sensors. The selection of a "toolkit" metaphor is intentional given the need for practical solutions for climate change and the Yup'ik *alerquun* that "one learns best by doing." Thus, for each toolkit, we also provide *qanruyutet* for conducting interviews, selecting sensors, and communicating data in ways that strengthen Yup'ik cosmologies and empower local communities. In the following section, we introduce these *caliyarapiaput* (methods) before detailing their use in four case studies.

Methods: *Caliyarapiaput* ("Our genuine ways of working")

Yuuyaraq (trans. "The Yup'ik way of life") and knowledge co-production frameworks

There are numerous constraints to sensor networks in communities that lack reliable internet or the ability to process large datasets. Yet, as demonstrated, broadband access is not the largest barrier to communicating climate change. Rather it is the historical failure of western science to recognize Indigenous knowledge as authentic, rational, and valid. We are fortunate, however, that other Alaskan Native communities—most notably our colleagues at Ukpeaġvik Iñupiat Corporation (UIC)—have refined alternative models for research collaboration under the UIC Science, LLC in Utqiaġvik, AK (*UIC Science, LLC | UIC Alaska*, 2019). Broadly speaking, such initiatives derive from a co-production of knowledge (CPK) framework that combines Indigenous cosmologies and western methodologies to "generate new knowledge and understandings of the world that would likely not be achieved through the application of one knowledge system" (Yua et al., 2022, p. 35). In this manner, CPK embraces Mi'kmaq Elder Pauline Bernard's concept of *Etuaptmumk* (trans. "Two-eyed seeing") with additional emphases on project implementation, data sovereignty, and collaborative decision making (Broadhead & Howard, 2021; *Guiding Principles (Two Eyed Seeing) | Integrative Science*, n.d.; Moorman et al., 2021; Roher et al., 2021). Although CPK approaches vary, the framework moves beyond community-based research in the following ways:

- Data are owned by communities who have the ability to monetize, restrict, and determine fair use (Carroll et al., 2019; Rainie et al., 2019; Taylor & Kukutai, 2016). Community leaders must be able to create, replace, upload, and delete datasets (Carroll et al., 2020; *Indigenous Data Sovereignty*, 2023).
- Research outcomes are accessible to local communities (Behe et al., 2020; Inuit Circumpolar Council, 2022).
- Initiatives must develop capacity so that communities can continue interpreting data and conducting research at a project's conclusion (Callaghan et al., 2020).
- Communities must establish long-term, meaningful relationships with outside researchers (Tondu et al., 2014).
- Outside researchers should work with communities to find solutions that decolonize research by recognizing Indigenous ways of knowing as equal to western epistemologies (Carlo, 2020; Yua et al., 2022).

Nalaquq (trans. "It is found"): Determining community goals and ownership

CPK with sensor networks thus requires thinking carefully about local communities and the proposed aims of a given project (Brinker et al., 2015; Gabrys, 2019; Oblak, 2003;

Figure 6. An organizational chart of Yup'ik controlled tribal entities affiliated with Nalaquq. With the exception of Calista, all organizations are located in Quinhagak. Image credits: Sean Gleason and Nalaquq, LLC (2023).

Peter et al., 2021; Wehn et al., 2021). In turn, our team has worked together since 2017 and includes: (a) a Yup'ik computer scientist/linguist (author 9), (b) Yup'ik researchers who are current or former land managers (authors 5, 6, 7) in Quinhagak, and (c) non-Yup'ik academic researchers specializing in communication studies (author 1), community-based archaeology (authors 10, 11), animation (author 8), and remote sensing (author 2). In addition, our advisory board includes Yup'ik leaders (authors 3, 4) who review data on behalf of Qanirtuuq, Inc., the Alaskan Native-owned corporation in Quinhagak founded under the Alaska Native Claims Settlement Act (ANCSA) of 1971 (Figures 6 and 7).

Regular in-person meetings, focus groups, and community roundtables are also essential to our co-production framework. We use these mechanisms to refine project goals, gauge interest, and determine how to best communicate data. We prefer meeting during the "freeze-up" and "break-up" seasons and communicate the importance of the Yup'ik

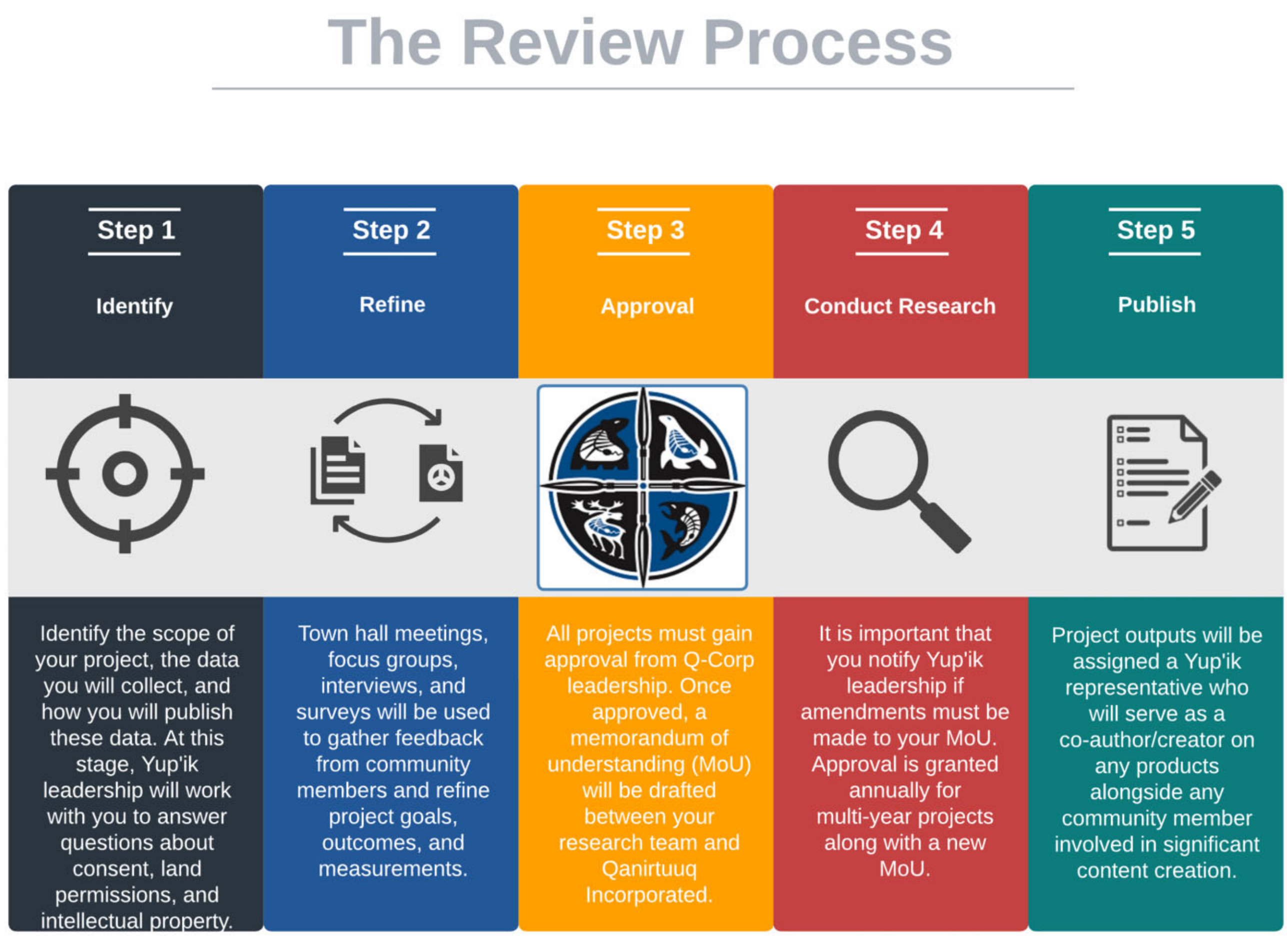

Figure 7. Our review process includes five phases to ensure the co-production of knowledge. Image credits: Sean Gleason and Nalaquq, LLC (2023).

subsistence calendar to new researchers (Figure 8). Nalaquq also relies on regional planning sessions, such as the 2023 Y–K Delta roundtable hosted by Calista, to gather feedback from other tribal leaders about the use of sensor toolkits for monitoring village infrastructure. For every project, Nalaquq requires that non-Yup'ik researchers visit Quinhagak to meet with tribal leadership to determine appropriate research outcomes (Figure 9). Additionally, weekly virtual meetings allow tribal representatives to monitor ongoing projects and suggest revisions as necessary.

CPK frameworks also require that research teams structure ethics reviews, intellectual property, and goal-setting mechanisms under the oversight of relevant Indigenous authorities. Accordingly, we embrace project outcomes that are accessible, visual, and useful for local populations (Figure 10). Our sensor networks in Quinhagak are owned by Qanirtuuq Inc., so all data are expressly controlled by the village's corporation whose board of directors decide what data, products, and workflows should be published or monetized. For each project, Nalaquq also provides training so that Yup'ik researchers have the ability to redact or edit data in accordance with our internal data sovereignty policies (Figure 11). Due to limited broadband access, we store data on local workstations in Quinhagak with adequate software for on-site processing (Appendix Table A2). Following *alerquutet* and *inerquutet* from Yup'ik leadership, our community training documents are highly visual and written at a 3rd to 8th grade reading level. In large part, these best practices were inspired by the Nunalleq Educational Pack, which involved community storyboarding, feedback sessions, and educational outreach at the Kuinerrarmuit Elitnaurviat school in Quinhagak (Watterson & Hillerdal, 2020).

Angalkucuaraqegtaaraat (trans. Many good small shamans)

Finally, Nalaquq's co-production framework draws explicitly from Yup'ik traditional beliefs to determine sensor use and selection. For instance, Yup'ik cosmologies root all life within an ensouled universe where animal/human transformation is possible through respectful, reciprocal actions between animals, humans, and material culture (Fienup-Riordan, 1995). This is, perhaps, best illustrated by the "Boy Who Lived With Seals." According to this oral legend, a village faced starvation as hunters were unable to provide for their families. Leaders from the village consulted a local shaman who, in turn, selected a young boy from a prominent family. The shaman made an *akutaq* (lit. "mixture") from seal oil and berries, which transformed the boy into a seal. Next, the shaman took the boy to an ice hole where he was introduced to his home under the sea. Here, the boy listened to elder bearded seals in the *qasgi* (communal men's house) and learned that seals willingly gave themselves to virtuous *nukalpiaq* (trans. "providers") who cleared ice holes for the seals, hunted them

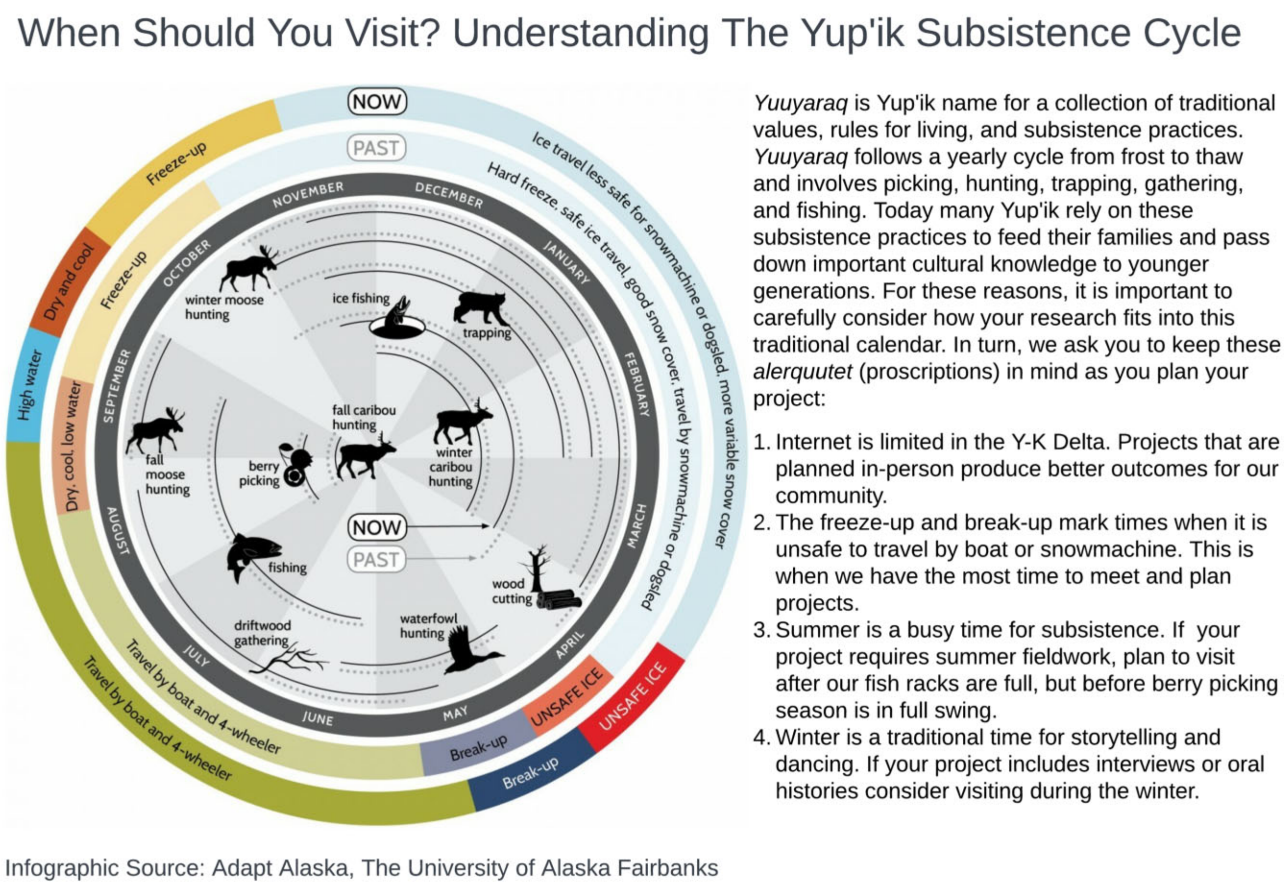

Figure 8. An image from Nalaquq's collaboration guide about how to best plan community meetings with the Yup'ik calendar. Image credits: Sean Gleason and Nalaquq, LLC (2023).

ethically, and ensured that all catch was shared. The boy was instructed to keep a watchful eye on all hunters before offering himself to a worthy individual. After doing so, the boy returns to his human form, where he is found by his parents naked and shivering by an ice hole. The boy then grows up to be a *nukalpiaq* (trans. "a successful hunter and provider") who teaches the village the proper rules for seal–human interaction to avoid starvation.

Likewise, our sensor networks emphasize the respectful, fluid, and reciprocal relationships between humans and nonhumans. Specifically, we draw from traditional Yup'ik beliefs regarding *Ellam Yua* (trans. eye of awareness or spirit of the universe)—an omnipresent force within a larger ensouled universe that regulates animal–human relationships through specific subsistence activities. Historically, this animating spirit was represented through concentric circle motifs (*ellanguaq*, lit. "pretend universe") found on hunting equipment, tools, dance regalia, masks, and jewelry to communicate the importance of nonhuman perspectives and knowledge. Accordingly, these subsistence technologies were viewed as important devices for maintaining a mutual ethic of care and cooperation among species (Figure 12).

We believe *Ellam Yua* speaks to the ability of materials–whether they be silicon or organic—to enable multivalent awareness (Yup'ik: *ellange*)—through augmented realities (Yua et al., 2022). In this tradition, Yup'ik subsistence science has long recognized the benefit of "bird's eye" perspectives for hunting and navigation. Notably, Yup'ik cosmology posits that humans were created by a Raven (Nelson, 1899), and pre-contact Yupiit adorned hunting implements—including seal-skin kayaks, hunting hats, and harpoon parts—with bird motifs in the belief that doing so allowed hunters to survey the landscape from a top-down perspective and appear before seals as birds of prey (Fienup-Riordan, 1990) (Figure 13).

Today, Nalaquq extends this cosmological "bird's eye" perspective through the use of GNSS receivers and unmanned aerial vehicles (UAVs) (i.e., drones). In fact, Yup'ik elders often make this connection explicit by referring to such sensors with the verb *angalki-* (trans. "To perform shamanic acts") (Cusack-McVeigh, 2017; Fienup-Riordan & Rearden, 2012; Smith & Gleason, 2021).[1] Rather than acting as an impediment to Yup'ik cosmologies then, we believe that the careful selection of environmental sensors strengthens traditional beliefs by extending human perception across landscapes and species. In turn, we propose an environmental toolkit (Appendix Table A1) to enable bird's eye perspectives and provide additional knowledge about *ellavut* (trans. "Our land and weather"). Each sensor has undergone rigorous testing by researchers and community members in Quinhagak. The total cost of our toolkit is less than 5,000 USD, and it can be easily transported by snowmachine, ATV, and small skiff. Our core sensors include handheld GPS units, survey-grade differential GNSS receivers, mobile processing stations, portable microphones, digital cameras, and small consumer-grade UAVs. In particular, we favor the use of UAV imagery

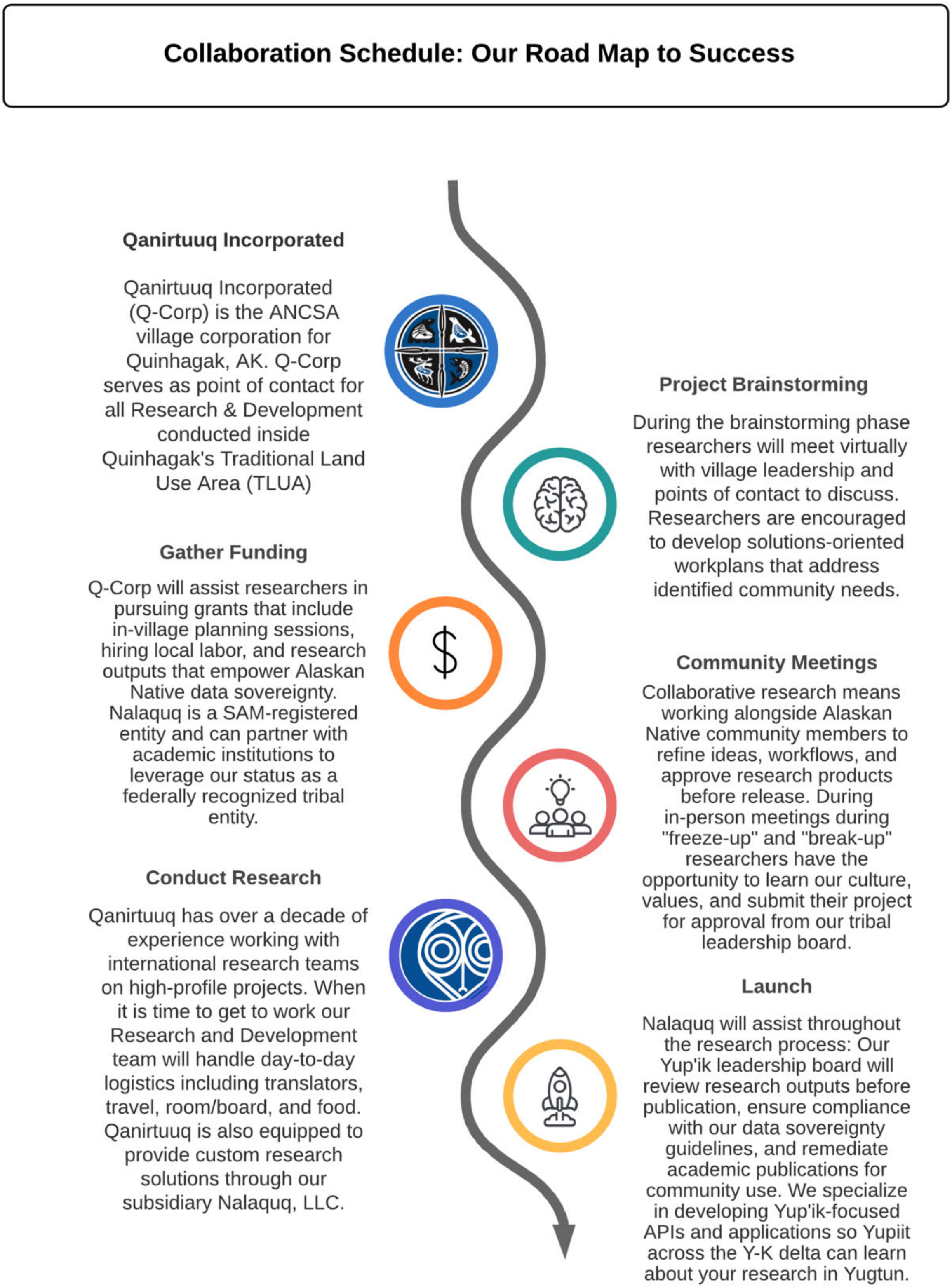

Figure 9. A sample collaboration schedule, which outlines the process workflows and ethical commitments for Nalaquq researchers. Image credits: Sean Gleason and Nalaquq, LLC (2023).

whenever possible given: (a) the ability of Yupiit to collect data with limited broadband access and (b) the fact that, once collected, local communities own the data, which is not the case with satellite imagery (Gleason et al., 2023; Lim et al., 2022, 2023).

Results: *Kangingelput* (trans. "What we discovered")

Yugtun placename surveys

Our CPK framework follows in the footsteps of Elders who have shown how Yup'ik science is geared towards developing

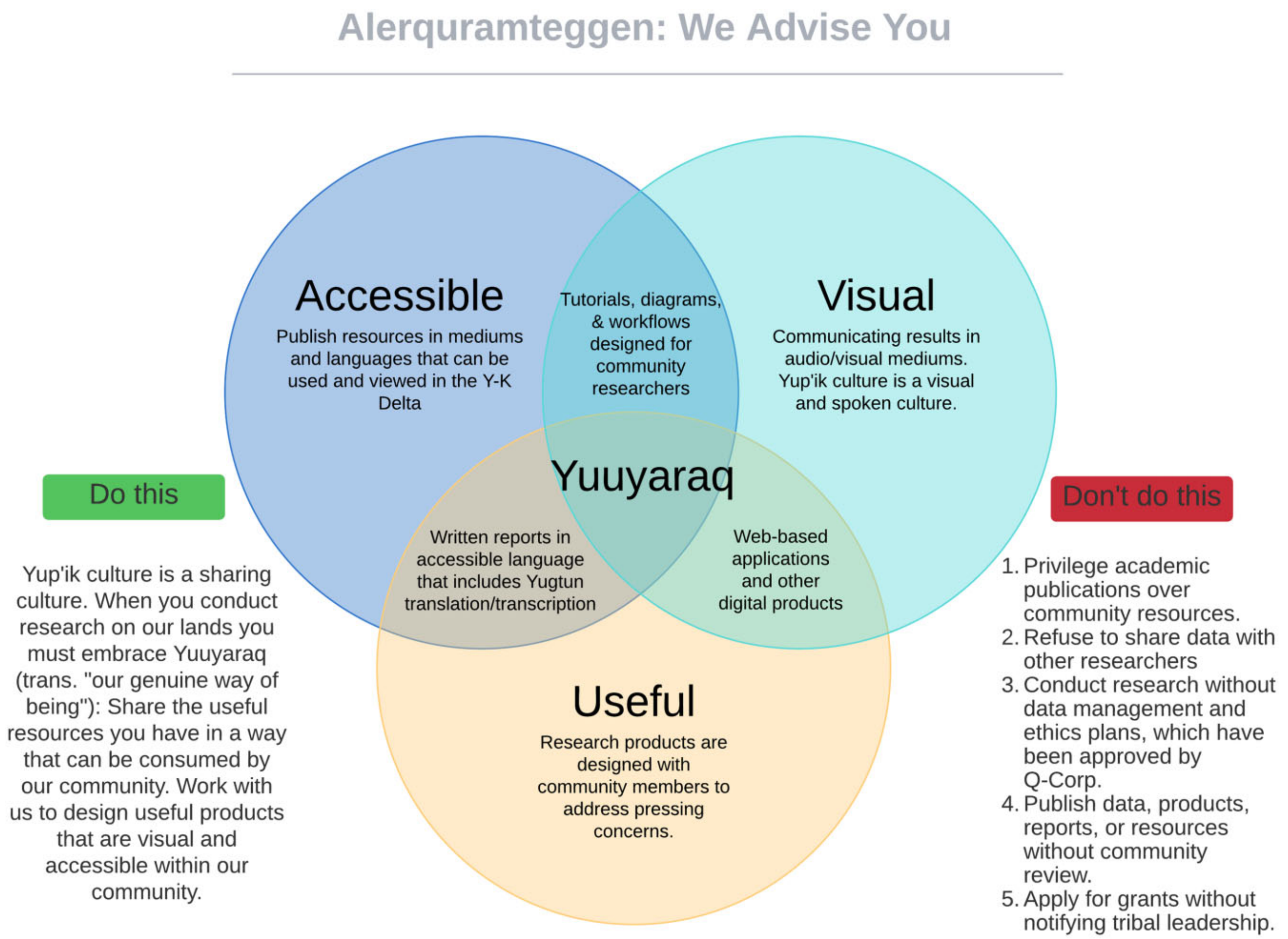

Figure 10. Nalaquq requires that all research results in products tailored to Yup'ik audiences. Image credits: Sean Gleason and Nalaquq, LLC (2023).

pragmatic outcomes through experimentation, while western science aims at testing hypotheses to explain how these outcomes were achieved (Barnhardt & Oscar Kawagley, 2005; Fienup-Riordan, 2007; Kawagley, 2009). Within the context of circumpolar inquiry, this means recognizing that oral cultures develop situational, use-based taxonomies (Ong, 2002) and that Indigenous cosmologies produce highly accurate, scientific ways of knowing (Abdilla, 2018; Fienup-Riordan & Knecht, 2015; Kimmerer, 2013; Smith, 2021). For example, the Yup'ik taxonomy for seals contains both one-to-one relationships to Latin binomial nomenclature as well as further distinctions based on age, appearance, and use (e.g., *maklacuk*: "adult bearded seal with a small body but the head, flippers, and intestines of an adult") (Fienup-Riordan, 2007, p. 25). Likewise, Yup'ik tree classifications include subdivisions based on use and appearance (e.g., *kenqeggialnuq*: wood that does not burn well). Finally, Yugtun's scientific nomenclature about edible plants also communicates information regarding sex, height, coarseness, health, location, and use (Fienup-Riordan, 2007, 2021; Jerigan, 2014).

The specificity contained within Yup'ik subsistence knowledge is a byproduct of Yugtun's postbasing syntax. Yugtun—like all Inuit languages—is a polysynthetic, agglutinative language where words are constructed through the combination of root morphemes and post bases to create meaning (Jacobson, 1984). The sentence "I have two small sensors", e.g., can be expressed in Yugtun with one word:

Elpeksuutecuaregka (trans. "my two small sensors")
(1) (2) (3) (4) (5)
Elpek + suute+ cuara + ag+ka
(1) (2) (3) (5) (4)
to sense + device to + small+two+ my

Postbasing syntax is a common feature of Indigenous languages that has important implications for environmental communication. Notably, Indigenous languages like Yugtun, result in long "sentence words" that contain hyper-specific ecological knowledge that is lost in translation.

For these reasons, our first co-produced sensor network was designed to record, visualize, and communicate Yugtun place names near Quinhagak. This project was commissioned by Qanirtuuq Incorporated in 2018 to extend a 1999 paper report of Yugtun place names compiled by a former village land manager (co-author Joe Pleasant). Specifically, Yup'ik leadership expressed interest in: (a) expanding Joe's place name study with additional onsite interviews, and (b) communicating this information through digital GIS layers that could be loaded onto handheld GPS units. After consultation with Qanirtuuq's legal counsel in 2019, village leadership decided

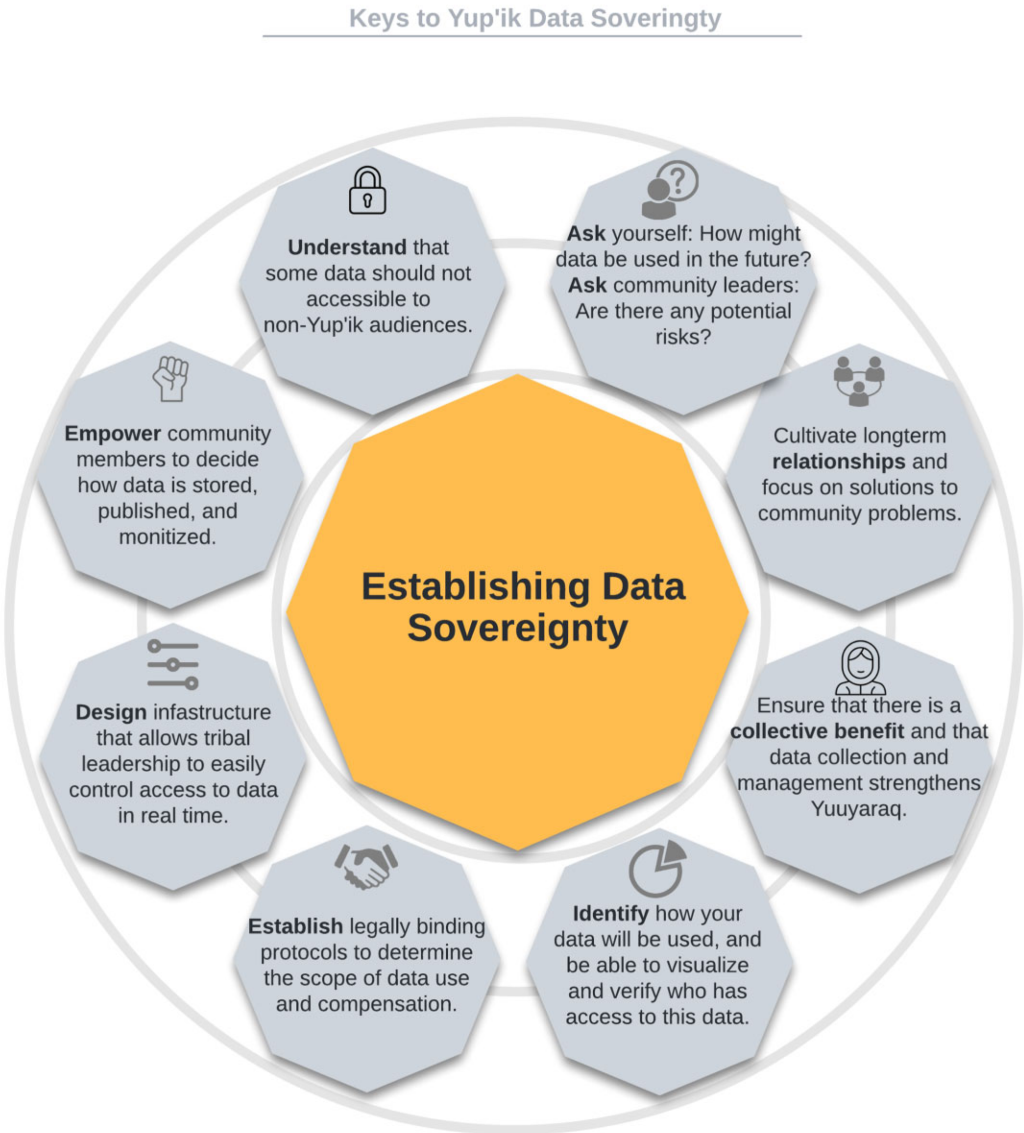

Figure 11. Nalaquq's approach to data sovereignty emphasizes usability, ownership, and RESTful APIs. Image credits: Sean Gleason and Nalaquq, LLC (2023).

what datasets could be published, and from 2019 to 2022 Nalaquq conducted over 20 GIS-aided interviews in Quinhagak about subsistence sites along the Agalik (var. Arolik) and Qanirtuuq (var. Kanektok) rivers. During these interviews, participants reviewed UAV footage of each river system to identify features under threat from erosion (Figure 14). During one such interview, Joe identified the following place name as significant (Figure 15):

> This is *Angyarrairyaraq*–where you leave your boat. It is where you leave your boat because the river is so shallow. It gets really shallow up here. The only time we go up is when you have a really tiny boat [like] a 16 ft flat boat. Those Lunds (v-hulled vessels) they like to go [pantomimes running aground] here. They are no good. Only a flat boat or tiny boat [will work]. Over here it gets shallow across, so we don't go up there....it's been like that [for a long time]. *Angyarrairyaraq*–where you leave your boat.
>
> So most of the [subsistence] camps are down here [Joe points downriver before *Angyarrairyaraq*], the only time they can go up there is winter time for particular camping stuff. You can only get up when it is flooded or in the winter. That is what they [Elders] used to do. In wintertime, they used to take the dog sleds and go up here because it is so shallow.

Angyarrairyaraq is a place name that is not easily translated into English. Yet, Joe utilizes the place name as an epanalepsis (e.g., repetition at the beginning and ending of clauses) to: (a) help recall why the vast majority of subsistence locations (e.g., fish camps, berry patches, and moose hunting grounds) occur downriver of *Angyarrairyaraq* and (b) discuss the importance of traditional knowledge before the introduction of snow machines (Lanham, 2012). In this manner, Joe's knowledge about *Angyarrairyaraq* demonstrates the immense value that Indigenous place names hold for environmental communication.

Yup'ik place names may be whimsical (e.g., *Anaqsungaarrvik*, "Place of Sudden Defecation") or serious, but they are always functional and always instructive. On Nelson Island, for instance, individual river bends are given names, like "place where kayaks dock," to denote where chum salmon spawn every year. In this way, as Elder Paul Charles of Nelson Island notes, "these names were like street signs" (Rearden et al., 2011, p. xxxvii). Yet, today publicly accessible mapping projects—such as Google Earth or OpenTopo—do not include such place names. In addition, federal and state mapping projects often replace Yugtun place names with English ones. Our solution thus addresses these concerns by digitizing a database of over 210 Yugtun place names for Qanirtuuq, Inc.'s land manager's office. In 2023, we will distribute subsistence maps containing these place names to community members via micro-SD cards for use with hand-held Garmin GPS units.

Figure 12. Top: Animal transformation motifs found in a human/walrus mask and a seal-shaped *uluaq* (semilunar knife). Bottom: *ellanguaq* (trans, concentric circle motif, lit. "pretend universe") motifs scribed in jewelry from the Nunalleq collection. Image credits: The Nunalleq Culture Center and Richard Knecht (2021).

Salmon surveys

In 2022, both commercial and subsistence salmon fishing were closed along the Kuskokwim river, leading to concerns from Yupiit who rely on this vital resource. To address this concern, Nalaquq worked with local fishermen in Quinhagak to determine alternative methods of salmon counting: First, we visited Yup'ik fish camps and conducted interviews focusing on the landscape features (gravel bars, oxbow lakes, and sloughs) that provide ideal habitats for spawning salmon. Next, we met with village Elders to gauge how climate change has impacted spawning cycles and the relocation of intergenerational fish camps along the Qanirtuuq River. This mixed-methods approach yielded two suitable test locations where the depth, flow, and location of river channels provided optimal conditions for UAV surveys (Figure 16). After extensive testing and development, a sensor workflow was devised using a consumer-grade UAV equipped with a polarized lens filter to track and count migrating salmon (Figure 17).

The total cost of this toolkit was less than 3,000 USD. Moreover, since it was designed alongside Yup'ik researchers it is durable enough to withstand daily travel by boat and can be utilized in areas lacking cell or internet service. Local pilots were trained in less than a week to conduct surveys, and datasets are easily visualized with software and training available to Alaska Native land managers under a cooperative agreement with the Bureau of Indian Affairs. Most importantly, however, this solution amplifies—rather than validates—Yup'ik subsistence science to provide a custom solution to a pressing community concern. With this toolkit, Yup'ik communities can now produce data to establish future salmon fishing quotas.

Figure 13. Left: A pre-contact owl-to-seal transformation ivory harpoon toggle from the Nunalleq Heritage Museum in Quinhagak. Image credits: Richard Knecht (2023). Right: A Yup'ik hunting hat with sea-bird imagery from the Edward Nelson collection at the National Museum of Natural History. Note the *Ellam Yua* in the eye of each bird. Image credits: Edward Nelson (2007).

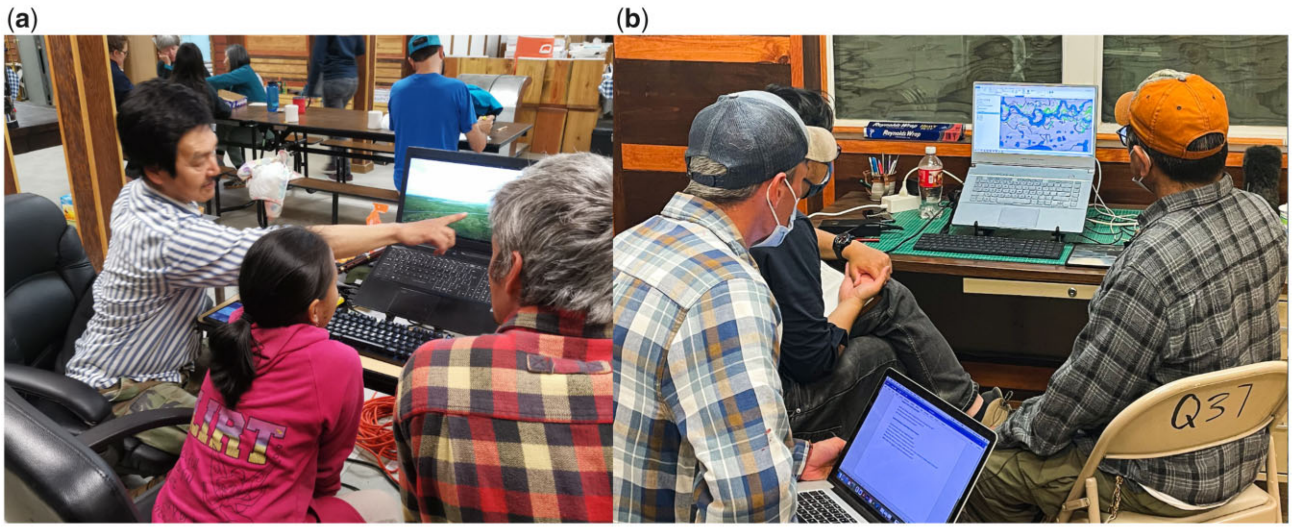

Figure 14. Two photos from Geographic Information Systems (GIS)-aided interviews with John Foster (left) and Joe Pleasant (right). Image credit: Nalaquq, LLC (2021).

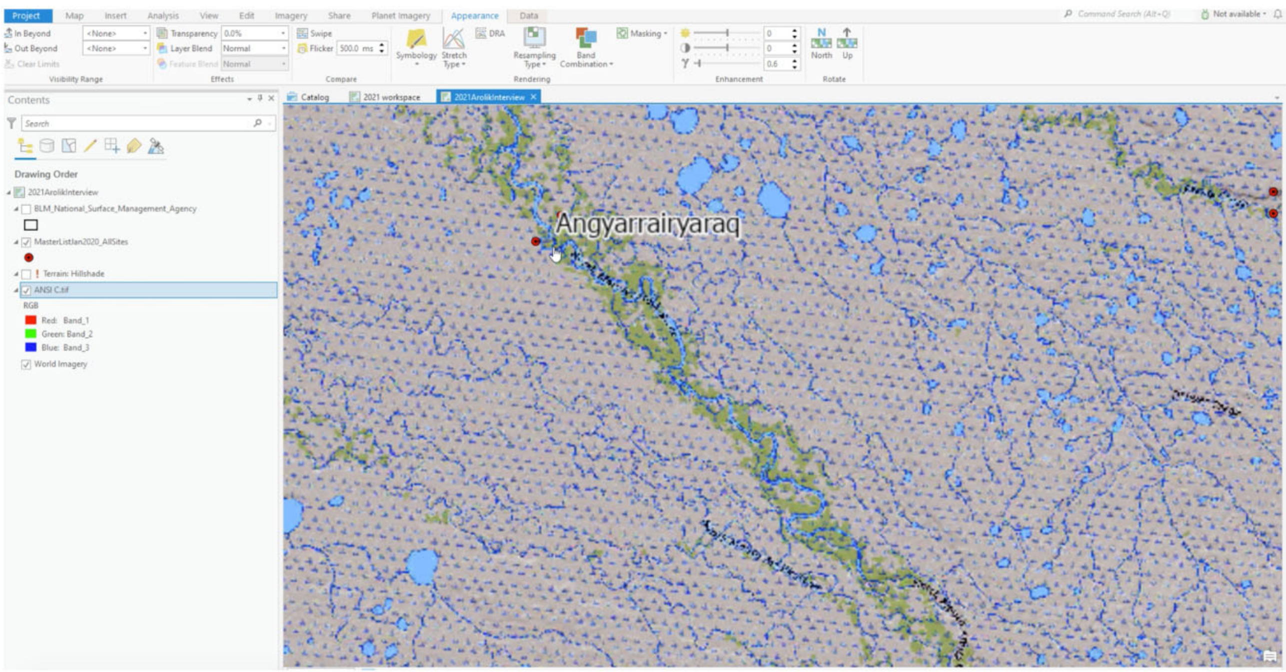

Figure 15. A screenshot from a 2021 Geographic Information Systems (GIS)-aided interview with Joe Pleasant highlighting *Angyarrairyaraq*. Image credit: Nalaquq, LLC (2021).

Riverine erosion

Public health researchers, anthropologists, archaeologists, and communication scholars have all noted the importance of subsistence activities to the Yup'ik cosmology (Fienup-Riordan, 2000, 2021; Fienup-Riordan & Knecht, 2015; Gleason, 2019a; Hillerdal et al., 2019; Hopkins et al., 2007; Knecht & Jones, 2019; Smith & Gleason, 2021; Stariwat, 2016). However, Yup'ik subsistence infrastructure (e.g., fish racks, berry camps, boat docks, smokehouses) has historically been overlooked in federal and state mapping projects. As a result, such infrastructure has been excluded from recent actuarial estimates of climate change-induced damage even though residents rely on this infrastructure to feed their families and pass down important cultural knowledge (Gleason et al., 2023; Lim et al., 2023).

In 2021 and 2022, Quinhagak community members requested a solution to identify subsistence areas under threat from erosion along the Qanirtuuq river. During planning sessions, Yupiit expressed that this sensor network should:

- Provide accurate estimates of land change over the past 20 years that Elders could review visually.
- Quantify the impact of coastal erosion on individual ANCSA 14(h) allotments, which represent documented subsistence sites granted to Alaskan Native shareholders

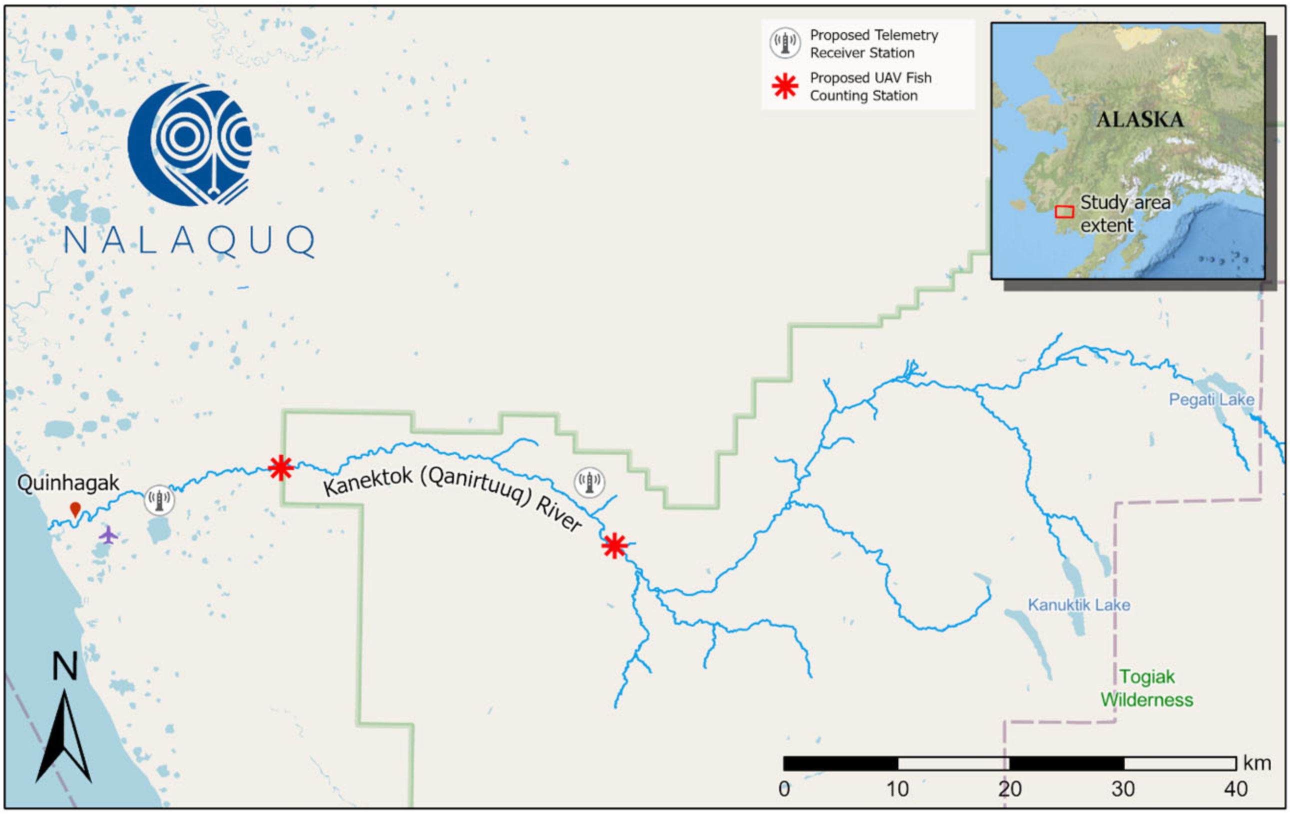

Figure 16. Proposed test sites for salmon surveys along the Qanirtuuq River. Each site was selected by community leaders drawing from local knowledge. Image credits: Jonathan Lim and Nalaquq, LLC (2022).

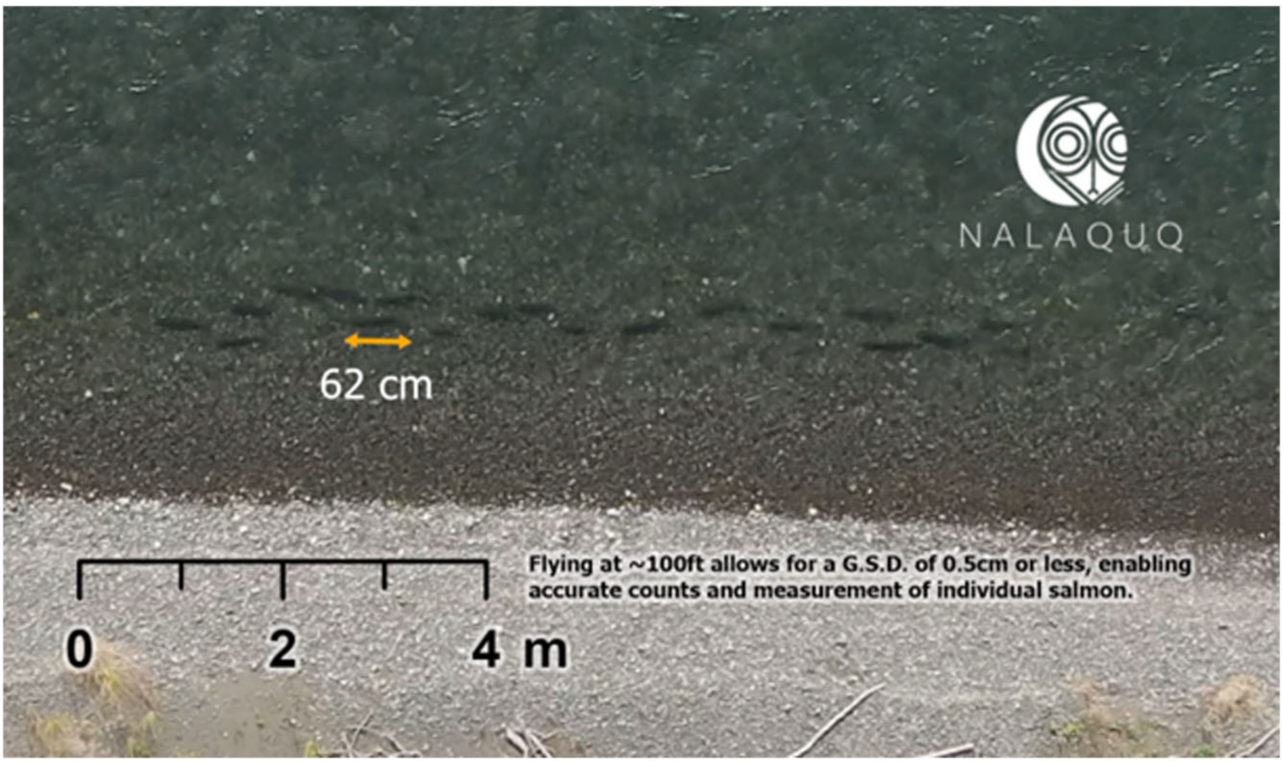

Figure 17. Quadcopter unmanned aerial vehicles (UAVs) are more versatile than fixed-wing aircraft for monitoring salmon, allowing pilots to hover in place to count large schools. Image credits: Jonathan Lim and Nalaquq, LLC (2022).

and their descendants by the Alaskan Native Claims Settlement Act of 1971.
- Estimate monetary damages to traditional subsistence infrastructure including boat docks, subsistence camps, and fish drying track.

Our first step was to digitize over 400 print maps to quantify erosion at important ancestral sites (Lim et al., 2021). Next, we conducted interviews to understand the relationship between ANCSA 14(h) allotment selection and traditional subsistence. During one interview Yup'ik co-author Warren Jones articulated the relationship between subsistence and ANCSA 14(h) selection by explaining the importance of erosion data:

> **Sean**: And when people picked [ANCSA 14(h)] allotments, they picked mostly on rivers and coasts, correct?
>
> **Warren**: Yes. Mostly where their grandparents, great-grandparents used to have subsistence campsites. Each allotment is usually from where they know their grandparents were and their grandparents before them. It's a family site [that's] passed on from generation to generation. But the rivers and coastlines are also the places where erosion is happening the most. So, I've asked the state "if I lose 50 feet from the bank from my native allotment, does that portion on the river belong to me? Or does the bottom of the river still belong to me?" I haven't gotten that answer yet.
>
> **Sean**: And there hasn't been anybody who's been able to re-pick an allotment because [it's] eroded.
>
> **Warren**: No. That would be something the state needs to figure out—how to let people pick when their sites have eroded. As soon as there's water, the state claims it's theirs. But that allotment was given to us, and we can't control where the river's going. As soon as there's water, the state says it's their property. But I don't agree with that. I really don't.

To address this inequity—and provide a way to quantitatively assess erosion—Nalaquq developed a UAV mapping workflow for sites selected by village leadership (Lim et al., 2023). Doing so, allowed us to estimate the erosion risk for 12 Native Allotments along the Qanirtuuq River (Figure 18). Next, we cross-referenced these locations during community mapping sessions and onsite field visits to record subsistence infrastructure lost or under threat from riverine erosion (Figure 19). As a result of these efforts, Qanirtuuq Inc is now equipped with a longitudinal (1900–2022) GIS database to calculate the monetary impact of

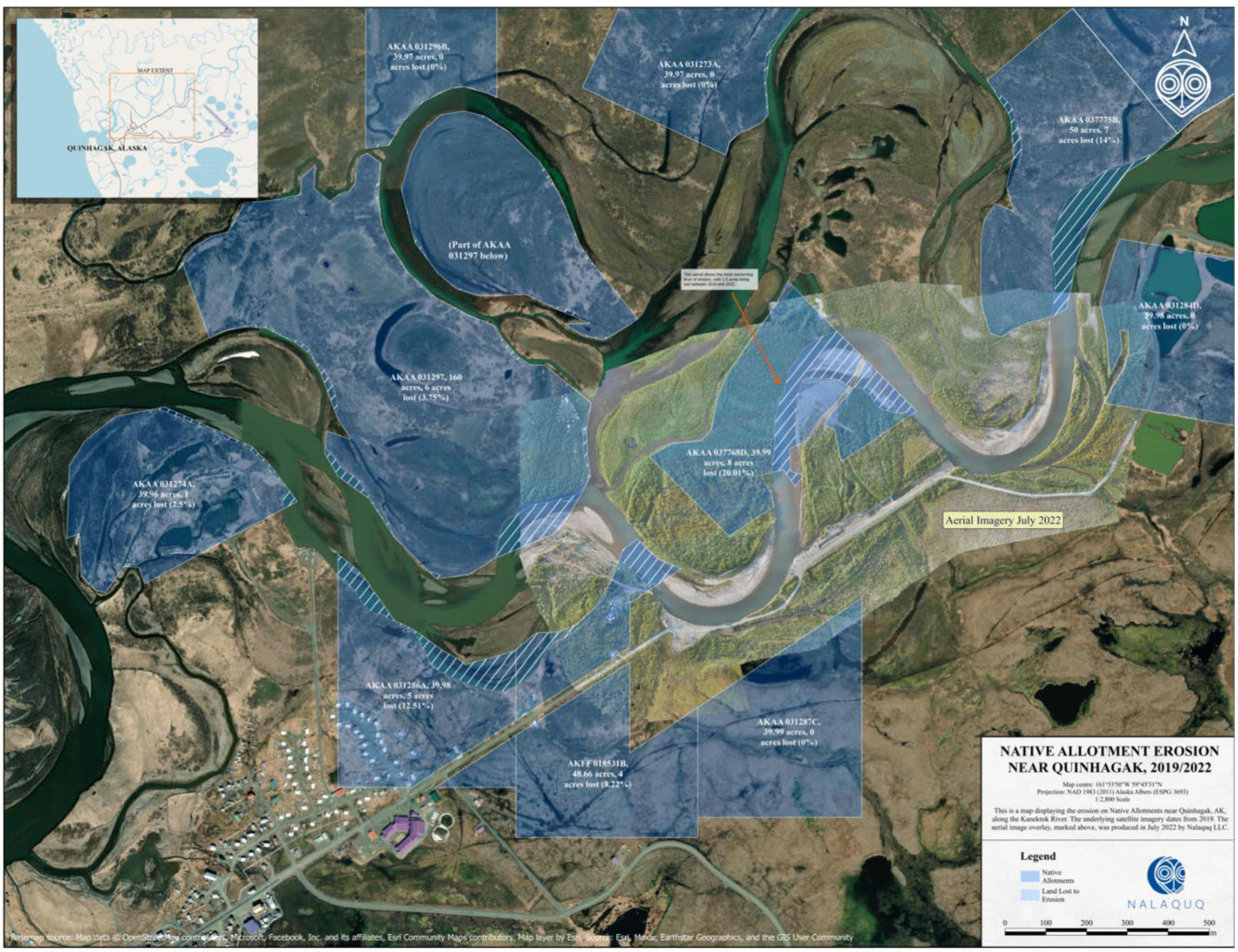

Figure 18. A 2022 map of erosion at ANCSA 14(h) Native Allotments along the Qanirtuuq River. Image credits: Jonathan Lim and Nalaquq, LLC (2022).

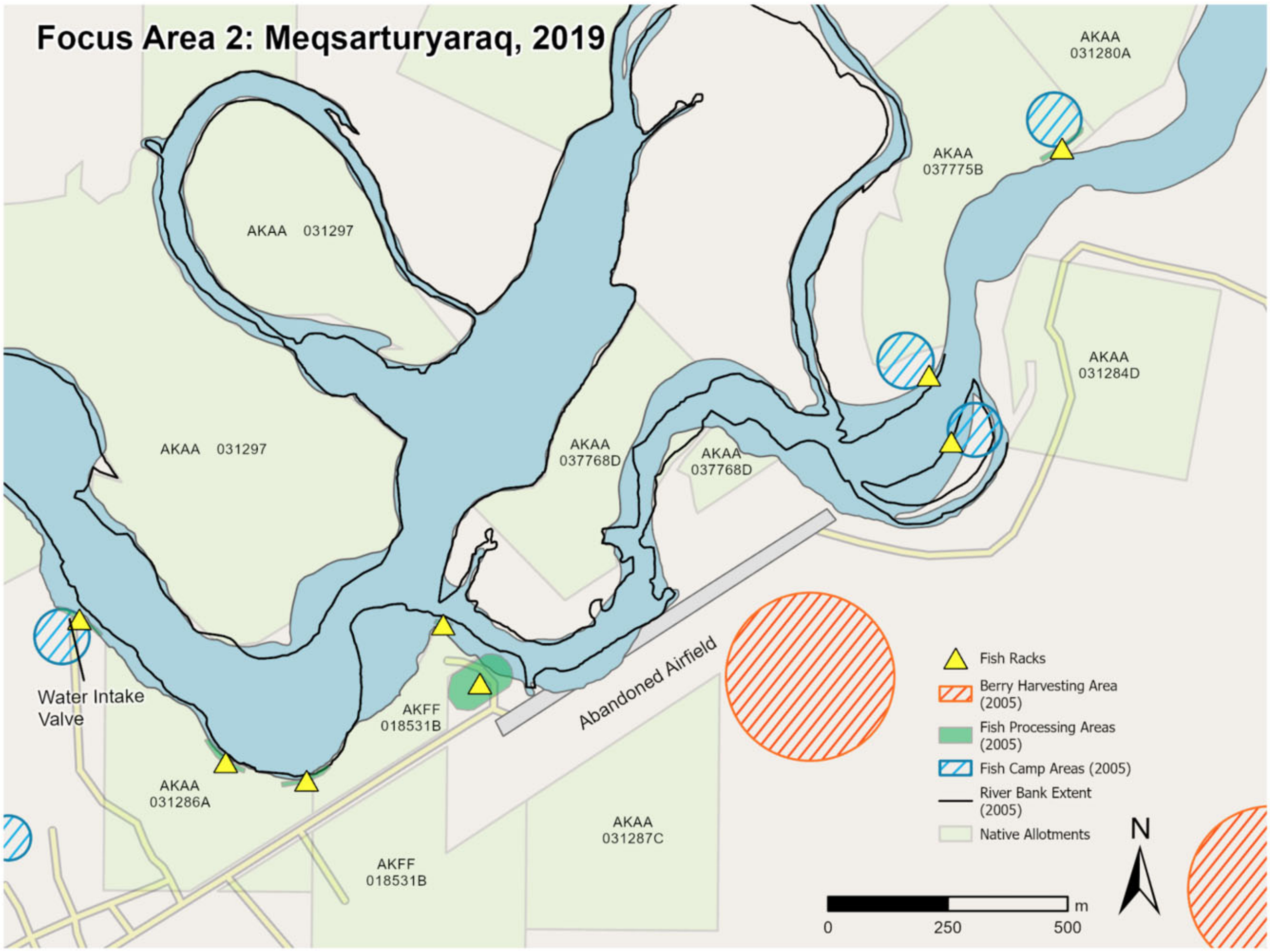

Figure 19. A map visualizing subsistence infrastructure under threat near Quinhagak's old airport. Note the drastic riverbank erosion between 2005 and 2018 causing damage to fish racks and camps. Image credit: Nalaquq, LLC (2022).

climate change and visualize the damage to legally protected ancestral subsistence sites. As part of our co-produced framework, academic researchers also led a month-long training workshop for Yup'ik drone pilots about planning automated flight missions, installing sensors, piloting aircraft, and collecting data (Figure 20).

Search and rescue

During focus group meetings in 2021, Yupiit raised repeated concerns about the delay in conducting SAR missions when waiting on assistance from the U.S. Coast Guard and Alaska State Troopers. For instance, on October 20, 2020, seven Quinhagak boaters were lost at sea, and it was not until October 27 that state and federal agencies were involved with the search before canceling operations indefinitely on October 31. Based on GIS interviews ($n = 6$) conducted with local SAR team members, it is probable that the missing vessel encountered mechanical problems before capsizing. Human remains were never found, and one SAR team member (co-author Warren Jones) was adamant in interviews about the usefulness of UAVs future operations:

> Once we heard troopers ended the search, [we] chartered a plane on low waters to fly the sandbars to see if there's anything, because these sandbars are huge. We had to wait for low water. And if a body's covered in mud–you are not going to see it. So, the use of drones is very, very well needed out there. There's big sandbars, and [the missing boaters are] probably out there somewhere…. Drones. That's probably the future there.

And:

> Last winter we had a guy that left Quinhagak around 10 in the morning from here to Goodnews Bay. It was okay when he left, but by afternoon it warmed up where it's raining. So about 9 p.m., Goodnews Bay calls that the person hasn't arrived. And it's dark and it's raining, with a little bit of snow. So, the first crew took off, and they had a message from someone in Goodnews that they found him, so the Quinhagak crew came back. Turns out he was still missing. So, the Quinhagak crew took off again. They were out another nine hours until my crew went to go resupply about 27 miles or so south of Quinhagak. It was pitch dark. It was raining. You couldn't see much. And it's a big country. We couldn't find a snow machine. If it broke down, it'd be on the trail. So, you're dealing with open water, a lot of slick ice, and open creeks. If we had a drone to help us with thermal [imaging], we would have found him right away.

Figure 20. Jeremy Hunter pilots a unmanned aerial vehicle (UAV) during an automated mapping mission in July of 2022. It takes approximately 1 month to train Yup’ik pilots. Image credits: Izac Olatunji and Nalaquq, LLC (2022).

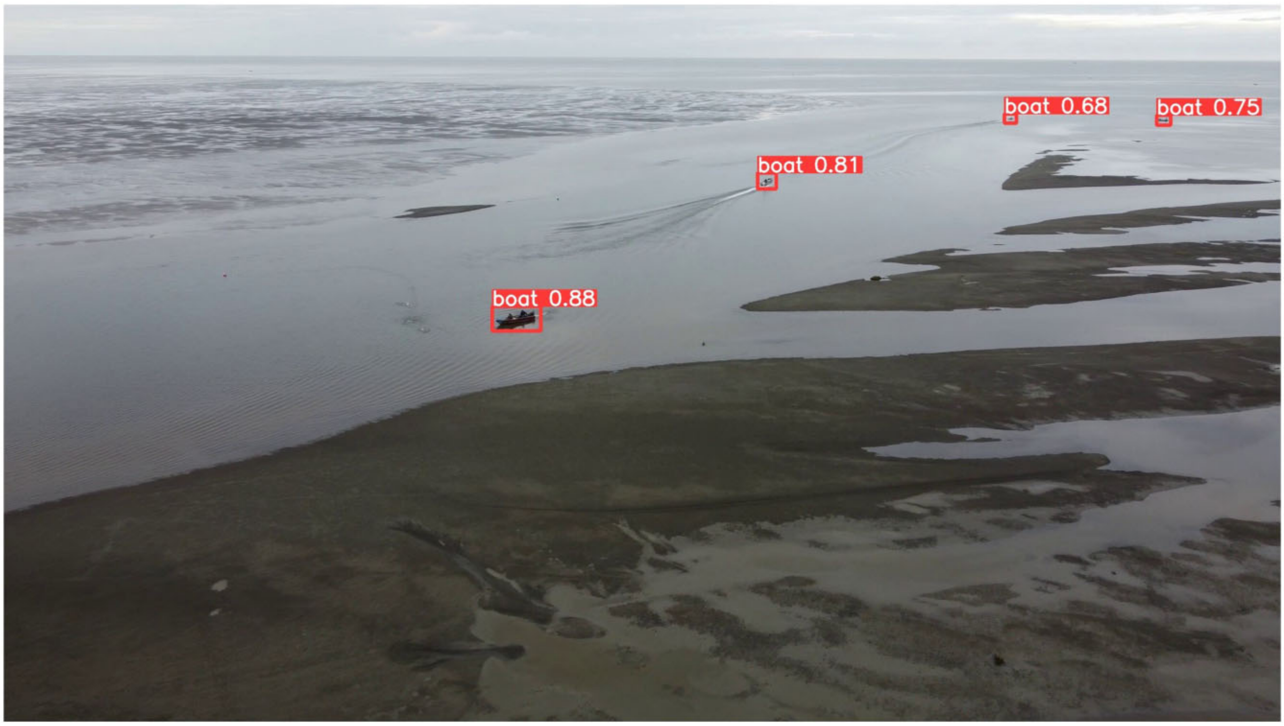

Figure 21. Object detection results on 2021 imagery collected from a test flight near Quinhagak. Image credits: Sean Gleason and Nalaquq, LLC (2022).

In response, Nalaquq spent 3 weeks in July 2021 with the SAR team in Quinhagak collecting video footage of small aluminum boats with UAVs. Using these videos, we developed an algorithm to detect small aluminum-hulled vessels using deep learning structures and pre-trained weights from Microsoft's COCO image dataset (Figure 21). The result is a custom Convolutional Neural Network that can be deployed over a search grid in real time to detect missing vessels using consumer-grade UAVs and live 4k video feeds. Future research is being conducted on how to best communicate these results to SAR operators during rescues. In 2023, Nalaquq researchers will also conduct additional SAR operations in Quinhagak to gauge the effectiveness of UAV-mounted thermal sensors for lost snowmachines. After sufficient research and development, Qanirtuuq, Inc. will decide whether to release this solution as a commercial product or publish it as an open-source toolkit for other Yup'ik SAR teams.

Discussion and conclusion: Toolkits for *Ellange-* (trans. "Awareness")

Sensor networks imply cosmologies. They enable, as Jennifer Gabrys (2019) notes, "particular political engagements and ways of being and becoming citizens" (p. 30). In this manner, sensor-based citizen science has the potential to create generative "imperative moods" geared towards action and awareness that structure larger ecological relationships of being. Here, Yup'ik cosmologies are well adept at understanding how new materials and technologies provide more-than-human ways of knowing. In turn, we believe that this knowledge holds important lessons for scholars interested in working alongside Indigenous communities.

A primary affordance of sensors is that they respond to stimuli through analog or digital signals to generate quantifiable outputs (Kalantar-Zadeh, 2013). A salient concern for communication scholars then is how to make sense of this quantification within the context of Indigenous lands and heritage. In other words, how can scholars harness the power of sensor networks as an emancipatory tool while minimizing potential harm? After careful consideration, we embrace calls from communication scholars to move beyond a positivist paradigm of "quantification-as-validation"; yet, we are unwilling to classify modern sensor networks or technologies as antithetical to Indigenous cosmologies. Instead, we believe that sensors are powerful tools capable of communicating traditional knowledge in ways that strengthen Yup'ik sovereignty. For instance, both the Yugtun place name and salmon counting projects required numerous onsite interviews with local fishers familiar with the Qanirtuuq river. In a July 2022 interview, e.g., co-author Warren Jones describes how a particular bend in the Agalik river creates an ideal fish camp location:

> Well, you've got to be where the fish are. And some of these areas we know are really good for fishing for dollies [trout]. That's what we target. And on the lower river, there used to be several fish camps for regular salmon fishing. So, a good fish camp would be something dry where you can have access to dry wood for your stove. [Like] a gravel bar with a little slough on the side.

Warren's insights were essential in determining suitable sites for fish surveys, and accordingly, Yup'ik and Non-Yupik researchers alike quickly realized the value of Yugtun place names for monitoring salmon populations. At the same time, however, the bird's eye view offered by UAV imagery provided a new perspective for generating additional insight. In this manner, the use of sensor networks not only reiterated the importance of local knowledge, but it also translated this knowledge into new forms of data to assert Alaskan Native rights to self-determined ecological management during annual negotiations with state and federal agencies about salmon fishing quotas.

As we have demonstrated, sensor networks and Indigenous cosmologies are not mutually exclusive. Yet, many sensor networks are not designed with rural, circumpolar, or Indigenous life in mind. Accordingly, when the goal of environmental sensing is to quantify Indigenous knowledge to validate it, researchers end up designing sensor networks that are fundamentally extractive. Within this paradigm, the primary logistical constraints include collecting, packaging, and exporting data in ways that can be actionable for non-Indigenous communities. Alternately, when sensor networks amplify Indigenous cosmologies, the focus shifts to a solutions-based model where the primary challenge is communicative: Here, sensor networks provide ways of extending Indigenous perception across landscapes, and the biggest challenge is communicating these data to community members. In practice, we find that there is no substitute for in-person workshops, community feedback sessions, and individual training. Furthermore, we strongly suggest that any researcher interested in conducting research alongside Alaskan Native populations first contact the village's Tribal Council or ANCSA corporation to draft a CPK framework outlining project goals, expectations, ownership, and outcomes.

With emerging ICT technologies, we believe that the future is bright for sensor-based citizen science. A notable example is SpaceX's Starlink, a relatively affordable satellite-based broadband service providing more than a terabyte of bandwidth per unit at its most basic tier of pricing. This technology is already in use in Quinhagak and village leaders recognize the value of improved broadband to create "always-on" online sensor networks for monitoring erosion threats in real time. Likewise, cloud-based computing allows Yup'ik land managers to use nonhardware intensive data processing workflows, like Google Earth Engine, saving communities costly investments in physical equipment. Finally, improved broadband access means that data from these sensor networks may now be hosted via web apps for community consumption.

In closing, we respectfully offer one final *qanruyun* (trans. proverb or teaching) in the form of an *alerquun* (trans. proscription or rule). It is a *qanruyun* derived from recent calls to rectify structural inequalities in digital spaces (Hatfield et al., 2022), move beyond Western epistemologies for place-based studies (Simmons, 2021), and include more Indigenous perspectives in applied communication research (Dutta, 2022). But it is also a *qanruyun* based on the polyphony of the word *ella* to mean "world," "outdoors," "sky," "universe," "awareness," "weather," and "sense." Thus, *Ellam Yua* is the person of the universe, the eye of awareness, and the central cosmological animating force that structures Yup'ik science. In turn, we suggest that researchers *ellange-* (trans. gain awareness) of the fact that Indigenous communities are adaptable, resilient, capable, modern, and competent. Yupiit, e.g., have long adapted western technologies—from shotguns, snow machines, and metal *cavek* (trans. toggle tip harpoons)—to their own cosmologies and culture. Thus, we believe that sensor networks pose a minimal threat to Indigenous sovereignty if they are designed, owned, and controlled by local communities. Any material—whether it be a dance mask, snowmachine, or drone—is only a "real" or "genuine thing" within the Yup'ik cosmology if it is inscribed within the larger actions, knowledge, and performances of *yuuyaraq*. Alternatively, materials lacking this cosmological orientation are susceptible to misuse through the logic of settler colonialism: A dance mask may be stolen, sold, shipped across the world, and misinterpreted just as a drone may operate in the Y–K Delta in ways that undermine Yup'ik territorial sovereignty. Accordingly, our goal is never to replace or validate old technologies or knowledge systems. Rather we strive to bring old and new ways of knowing together to learn more about *ellavut* (trans. "our land and weather"). In this sense, our sensor toolkits would be useless if they ignored Yup'ik cosmologies, since, in the Y–K Delta, these cosmologies lay at the heart of environmental communication.

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Conflicts of interest: The authors declare that there is no conflict of interest.

Data availability

Data are available on request due to restrictions (e.g., privacy or ethical). Data presented in this study are available on request from the corresponding author (sgleason@nalaquq.com), with additional prior permission from Lynn Marie Church (lchurch@nalaquq.com) of Nalaquq, LLC. The data are not publicly available due to being owned by the community of Quinhagak, as represented by Qanirtuuq Incorporated and Nalaquq, LLC.

Note

1. For example, GPS sensors may be referred to by village Elders as *angalkucuaraat* (lit. "little shamans") (Cusack-McVeigh, 2017).

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Appendix A

Table A1. Our core toolkit consists of UAV, GIS, audio, and optical sensors for recording Yup'ik place names

Sensor type	Model	IoT	Weather proof	Cost (USD)	Core Kit
GIS	Garmin 700i	Yes	IPX7	700	Yes
GIS	Reach RS2+ RTK	Yes	IP67	4,000	No
GIS	DJI D-RTK Base Station	Yes	IP65	4,600	No
Audio	Zoom Fn2	No	No	149	Yes
Audio	Sony XLR-K3M	No	No	500	Yes
UAV	DI Mavic Mini 3 Pro	Yes	No	900	Yes
UAV	DJI M300 RTK	Yes	IP45	13,000	No
Optical (RGB)	Sony A7 IV	No	No	2,600	Yes
Optical (RGB)	Zenmuse P1	No	IP4X	6,000	No
Optical (Multispectral)	Parrot Sequoia +	No	No	3,500	No
Processing	MSI Codex R	No	No	2,400	Yes

Note. UAV = unmanned aerial vehicle; GIS: Geographic Information System.

Nalaquq's sensor and software toolkits

Table A2. Our software development kit also includes a blend of commercial and FOSS products available to Alaskan Native communities.

Software type	Name	Version	Use	FOSS	Cost	Core kit
GIS	QGIS	3.26.3	Mapping	Yes	Free	No
GIS	ESRI ArcGIS Online	2.9.0	Mapping	No	Free[1]	Yes
GIS	ESRI ArcGIS Pro	2.8.7	Mapping	No	Free[1]	Yes
UAV	Aeroscientific DJI Flight Planner	4.45	Automated UAV Flights	No	100	Yes
UAV	VC Technology Ltd Litchi Flight App	2.9.0	Automated UAV flights	No	30	Yes
Modeling	Agisoft Metashape Pro	1.8.4	Photogrammetry	No	149	Yes
Python module	PyTorch	1.12.0	Deep learning	Yes	Free	No
Python module	OpenCV	4.6.0	Computer vision	Yes	Free	No
Python module	Kivy	2.1.0	Mobile app development	Yes	Free	No
Python framework	Django	4.1.1	Web app development	Yes	Free	No
Database	MongoDb	6.0	Database management	Yes	Free	Yes
Audio visual	Adobe creative cloud	5.6	Data visualization	No	Varies	No
Audio visual	Davinci resolve	18.2.1	Video editing	No	295	Yes

Note. UAV = unmanned aerial vehicle; GIS: Geographic Information System.
[1] Denotes software that is free to registered ANCSA 14(h) corporations and their subsidiaries.