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Alaska Native Allotments at Risk: Technological Strategies for Monitoring Erosion and Informing Solutions in Southwest Alaska

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Abstract: After the United States' purchase of Alaska from Russia in 1867, Alaska Native lands have existed in a legal state of aboriginal title, whereby the land rights of its traditional occupants could be extinguished by Congress at any time. With the passage of the Alaska Native Claims Settlement Act (ANCSA) in 1971, however, Alaska Native individuals were given the opportunity to select and secure a title to ancestral lands as federally administered ANCSA 14(c) allotments. Today, though, these allotments are threatened by climate-change-driven erosion. In response, our article provides an erosion monitoring tool to quantify the damage caused by coastal and riverine erosion. Using the Yup'ik (pl. Yupiit) community of Quinhagak as a case study, we employ high-precision measurement devices and archival spatial datasets to demonstrate the immense scale of the loss of cultural lands in this region. From 1976 to 2022, an average of 30.87 m of coastline were lost according to 9 ANCSA 14(c) case studies within Quinhagak's Traditional Land Use Area. In response, we present a free erosion monitoring tool and urge tribal entities in Alaska to replicate our methods for recording and quantifying erosion on their shareholders' ANCSA 14(c) properties. Doing so will foster urgent dialogue between Alaskan Native communities and lawmakers to determine what measures are needed to protect Alaska Native land rights in the face of new environmental challenges.

Keywords: unpiloted aerial vehicles (UAVs); remote sensing; Alaska high altitude photography (AHAP); satellites; erosion; climate justice; indigenous data sovereignty; archaeology; Alaskan Native; Yup'ik

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1. Introduction

1.1. Overview

The signing of the Alaska Native Claims Settlement Act (ANCSA) by President Richard M. Nixon on December 18, 1971 marked a pivotal moment in the history of Indigenous land rights in the United States. With its passage, ANCSA provided over 17,000 land parcels (i.e., ANCSA 14(c) allotments) to individual Alaskan Natives who could demonstrate claims to the land "under traditional use and occupancy." Today, however, many of these ANCSA 14(c) allotments are under threat from climate-change-driven erosion. In response, our article provides an erosion monitoring tool for ANCSA 14(c) allotment owners and village corporations to quantify the damage caused by coastal and riverine erosion. Using the Yup'ik (pl. Yupiit) community of Quinhagak as a case study, we employ high-precision measurement devices and archival spatial datasets to demonstrate the immense scale of the loss of cultural lands in this region. In conclusion, we call for tribal entities in Alaska to

replicate our methods for recording and quantifying erosion on their shareholders' ANCSA 14(c) properties. Our goal is to foster urgent dialogue between Alaskan Native communities and lawmakers to determine what measures are needed to protect Alaska Native land rights in the face of new environmental challenges.

1.2. A Recent History of Southwestern Alaska: Reclaiming Ancestral Lands, One Acre at a Time

The windswept islands and coasts of southwestern Alaska have been occupied by Indigenous cultures for millennia (Figure 1) [1]. According to most recent estimates, the first peoples to cross into modern-day Alaska arrived via the Beringia land mass circa 14,000 Before Present (BP) [2]. Since then, successive generations have developed the innovative technologies and ecological knowledge necessary to subsist and survive in this harsh climate [1,3,4]. In turn, the oral histories and archaeological records of these Alaskan Native communities—including the Unangan of the Aleutian Archipelago, the Sugpiaq of the Alaskan Peninsula and Kodiak Archipelago, and the Yup'ik (pl. Yupiit) of the Yukon–Kuskokwim Delta—all testify to the cultural importance and knowledge embedded within Indigenous subsistence sites, ancestral villages, and place names [5–8]. For these reasons, the relationships among place, people, and nonhuman species are central to all Alaskan Native cultures and cosmologies.

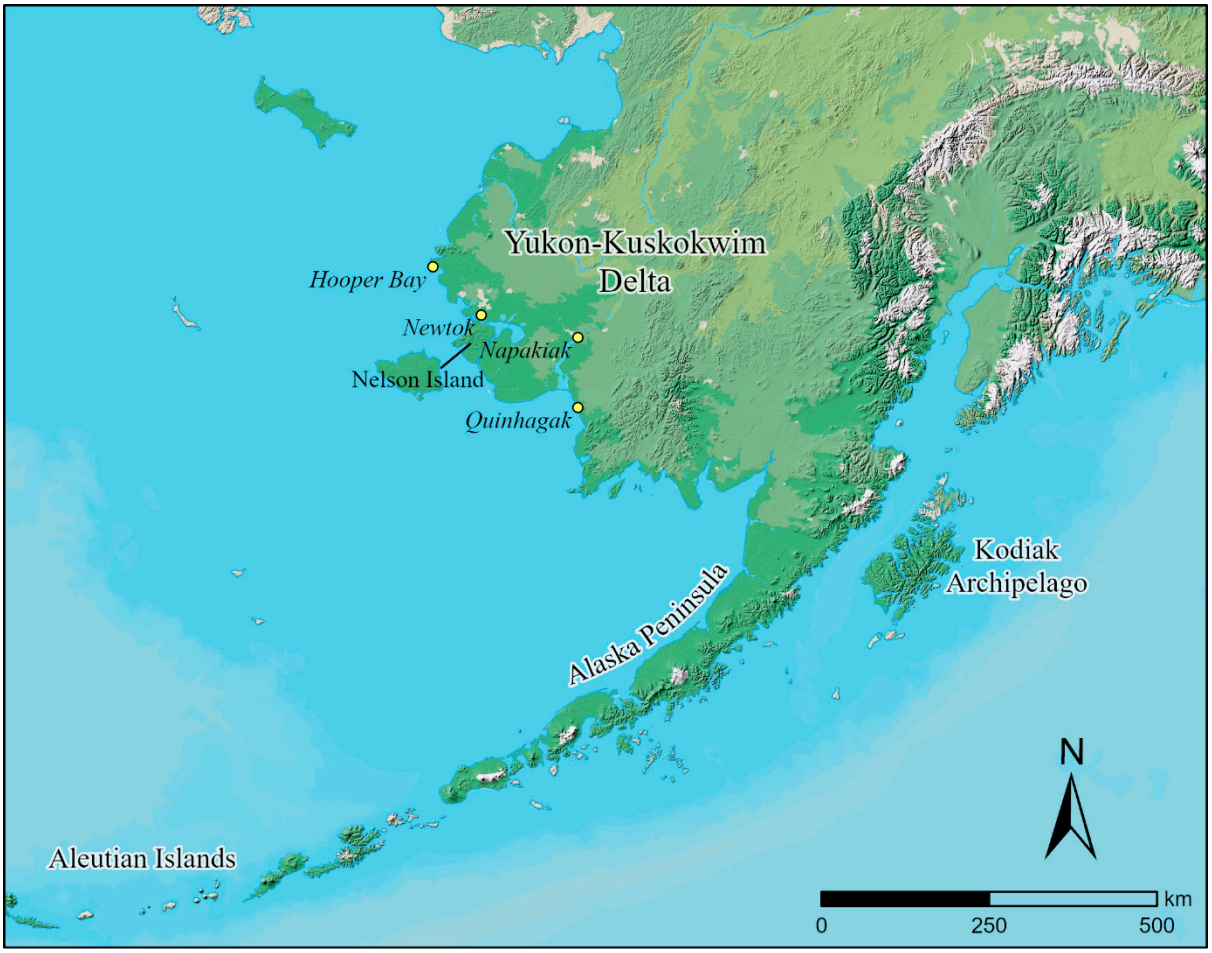

Figure 1. Southwest Alaska is home to many Alaska Native groups who must now contend with the devastating effects of climate change on their homes and heritage.

Unfortunately, for these groups, the past two centuries have been marked by colonial violence and intergenerational trauma. The arrival of Western powers during the 19th and 20th centuries—beginning with the first contact between Alaskan Natives and Russian

soldiers, traders, and missionaries—created calamitous societal upheavals in the form of displacement, violence, forced conversion, uncompensated labor, and disease [9–11]. For instance, "The Great Sickness" epidemic of 1900 killed between 25–50% of Indigenous communities in Western Alaska [12]. In addition, with the purchase of Alaska from Russia in 1867, the United States government introduced genocidal policies of systematic repression through the forced enrollment of Alaska Native youth to boarding schools run by the Bureau of Indian Affairs and missionaries. As a result, entire villages were forced to relocate to new settlements containing boarding schools, where locals were prevented from participating in subsistence activities, culture practices, and ceremonies [13].

Despite this legacy of colonialism, Alaska Natives have achieved meaningful victories since the start of the 20th century to regain control of ancestral lands. As a new territory of the United States at the turn of the 20th century, Alaska Native lands existed in a legal state of 'aboriginal title' that granted ownership to traditional occupants by virtue of their peoples' continuous use from 'time immemorial' [14]. However, these rights could be extinguished by Congress at any time without compensation, putting these groups on a precarious legal footing. With the passage of the Alaska Native Allotment Act of 1906, however, Alaska Native individuals were given the opportunity to select and secure a title to 160 acres of land as federally administered allotments. Frustratingly, very few applications were actually processed and conveyed under this program in the following decades: the initiative was poorly advertised, and labyrinthine bureaucratic practices placed insurmountable obstacles in the path for Alaska Natives to obtain their allotments [15]. However, after years of lobbying by Alaska Native groups, especially the Alaska Native Brotherhood, and other allied parties, US Congress passed the monumental Alaska Native Claims Settlement Act (ANCSA) in 1971 [15]. ANCSA extinguished all aboriginal titles in Alaska in exchange for USD 962.5 million and 44 million acres that were held in 'fee simple' titles by 12 newly formed Alaska Native corporations whose shareholders included all tribal members born before 1971. In addition, ANCSA and its subsequent amendments finalized the conveyance of more than 14,000 ANCSA 14(c) allotments to individual shareholders by the end of 1992.

In some ways, this granting of ANCSA 14(c) allotments to Alaskan Native shareholders was more generous and less culturally damaging than comparable measures in other parts of the country, such as the Dawes Act of 1887—a heavy-handed division of territory where Native Great Plains families were forced into a farming-based lifestyle by randomly allotted parcels that were not arable, nor compatible with traditional subsistence lifestyles [16]. Nevertheless, the ANCSA 14(c) allotments process was not without issues or restrictions: First, it is also no longer possible for Alaska Natives to be allocated such properties unless through inheritance, potentially disenfranchising future generations from the opportunity to hold ancestral land [17]. Second, the ANCSA 14(c) claim validity does not include land use that commenced after 18 December 1971, which restricts the inclusion of new, contemporary subsistence camps. In addition, individual allotments must meet a strict criteria of use as of 1971 that excludes any property or land use aside from an individual's primary place or residence, business, subsistence camp, or nonprofit location. Finally, ANCSA 14(c) individual allotments are 'restricted' (as opposed to 'fee simple') properties, meaning they cannot be sold without an arduous and expensive process of federal approval.

Such stipulations—alongside the fervent support of ANCSA by the oil and gas industry since it empowered tribal corporations to sell land for development—has led to criticism that the legislation has been largely inadequate for redressing the territorial injustices and intergenerational trauma of the colonial experience [15]. Nevertheless, Alaska Native individual allotments are highly treasured assets since they serve as symbolic and legal affirmations of their owners' ancestral connection to the land. Allotments may also be used to generate income from permits, leases, or purchases to third parties. Finally, many ANCSA 14(c) allotments include subsistence camps that have been in use for generations and, therefore, contain priceless material heritage in the form of archaeological remains and ancestral graves.

1.3. Permafrost Loss and Erosion in an Era of Change

Since ANCSA 14(c) allotments were granted as one-time, permanent conveyances, individuals are unable to select new allotments if their parcel can no longer serve as a primary residence, business location, or subsistence camp. Thus, recent years have seen the rise of another existential threat to Alaskan Native lands in the form of climate change: over the course of the 21st century, rising annual temperatures have dissipated offshore sea ice and melted the permafrost in soil, making its coastal regions particularly susceptible to erosion [18]. In turn, Alaskan Native communities have unfortunately become some of the first climate change refugees: a 2021 erosion forecast report by the State of Alaska's Department of Natural Resources concluded that of the 48 Yukon–Kuskokwim communities assessed, 33 are forecast to lose infrastructure and cultural sites due to erosion before the 2070s [19]. As a result, many villages have already made evacuation plans: The Yup'ik community of Newtok, for example, has recently relocated to the new village of Metarvik 14 km further inland [20]. In addition, Napakiak, a community on the Kuskokwim River, has lost approximately 80 m of its riverbank from 2016–2022 while a cursory inspection of cadastral records and modern satellite imagery shows that many nearby ANCSA 14(c) allotments are now reduced in size due to erosion [21,22]. In response to these threats, Napakiak tribal leadership has identified a safe location nearby to evacuate to at a projected cost of USD 100 million, of which only 10% of the funds have been secured [23].

1.4. Study Area Profile: Quinhagak, Alaska

Villages such as Napakiak and Newtok are not the only Alaskan Native communities who must contend with the consequences of a rapidly changing world [24–26]. One such village is Quinhagak, a coastal community of around 774 Yupiit (sing. Yup'ik) located along the Bering Sea coastline roughly 40 km south of the mouth of the Kuskokwim River. The village is nestled between two major salmon rivers [27]—the Qanirtuuq (var. Kanektok River) on whose mouth the village is situated, and the Agalig (var. Arolik River) 8 km to the south (Figure 2). Pursuant to ANCSA, the village corporation Qanirtuuq Inc (Q-Corp) has been allocated approximately 58,000 hectares of land, which enclose 86 private allotments consisting of 2597.7 hectares prior to erosion. In light of the community's favored subsistence resources, namely salmon, berries, and sea mammals, it is unsurprising that the majority of these allotments are on or at the mouths of the two major rivers and along the coast where these resources abound. However, the Traditional Land Use Area (TLUA) extends far beyond Q-Corp's land claims as demonstrated by the presence of ANCSA 14(c) allotments outside the corporation's boundaries. Quinhagak is also located near the archaeological site of Nunalleq (GDN-248), a 17th century 'winter village' composed of semisubterranean structures with walls made of sod blocks (known colloquially in Alaska as 'sod houses'). Sod houses were used widely in Yupik communities until the mid-20th century, and some families, such as those of late Quinhagak Elder Sam Carter, lived in them until the mid-1970's (John Smith pers comm.). Prior to the Western colonial era, the Yupiit lived a semisedentary lifestyle, moving throughout the year with skin tents to establish seasonal camps [11]. During the colder months, the Yupiit would reconvene in winter villages for shelter, and occasionally remote subsistence sites also contained isolated sod structures. For these reasons, sod houses and ancestral winter villages constitute two important features that were often claimed as "traditional use and occupancy" under ANCSA 14(c) conveyance.

The excavation of Nunalleq, which has recovered almost 100,000 artifacts and ecofacts, is the most significant archaeological investigation of a precontact Yup'ik community [7]. Today the collection is housed locally in a purpose-built museum and cultural center, allowing the community to learn valuable lessons about their ancestors. For all the outstanding body of research carried out on the Nunalleq site though, relatively little has been performed to research the wider cultural landscape of the community: limited surveys were conducted in 2021 and 2022 to document nearby subsistence sites as an extension of 220 Yup'ik place names recorded in 1999 by former Qanirtuuq land manager Joseph

Pleasant [28,29]. For both surveys, qualitative data were collected during in situ interviews with Elders as well as community meetings. Site locations were recorded using a hand-held GPS, and a preliminary database was published for community use in July of 2022. Notably, the majority of these sites are located on or near ANCSA 14(c) allotments and contain important, intergenerational cultural knowledge about the landscape [30]. For example, place names such as *Neqlin Kuiga* (trans. "Fish processing lake.") are a record of important locations to obtain resources needed for survival. In other cases, place names in the Yup'ik language of Yugtun may help communicate how to best traverse the landscape. For instance, the Agalig river, which is nearly impossible to navigate for most of the year due to low water levels, has bends of the river named to warn travelers on the waterway (e.g., *Angyarrairyaraq*, "the place where boats can barely get through"). As such, the cultural significance of these place names (and their corresponding ANCSA 14(c) allotments) cannot be overstated, as they represent a tangible link to the past for many Yupiit in the Y-K Delta. Like many villages in the Y-K Delta, Quinhagak has lost vast swathes of corporation land, infrastructure, ANCSA 14(c) allotments, and cultural sites to erosion—a situation that is expected to worsen in the coming years [31]. Moreover, in order to qualify for government grants to mitigate this damage, Yup'ik coastal villages must pay external consultants to quantify and map the impact of recent erosion events. The costs associated with these environmental reports and surveys can be high, as evidenced by a recent 2018 erosion study commissioned in Quinhagak to estimate erosion damages caused by the Qanirtuuq river to the old airport runway near the Yup'ik placename *Meqsarturyaraq* (trans. "place where one gets freshwater"). This report—which included bathymetric and lidar surveys, hydrological data, and visible spectrum satellite imagery—provided the village of Quinhagak with potential river reroute plans alongside flood plains for 50, 75, and 100 flood events [32]. In total, the report cost Q-Corp USD 267,000, and the village was not provided digital copies of the underlying datasets.

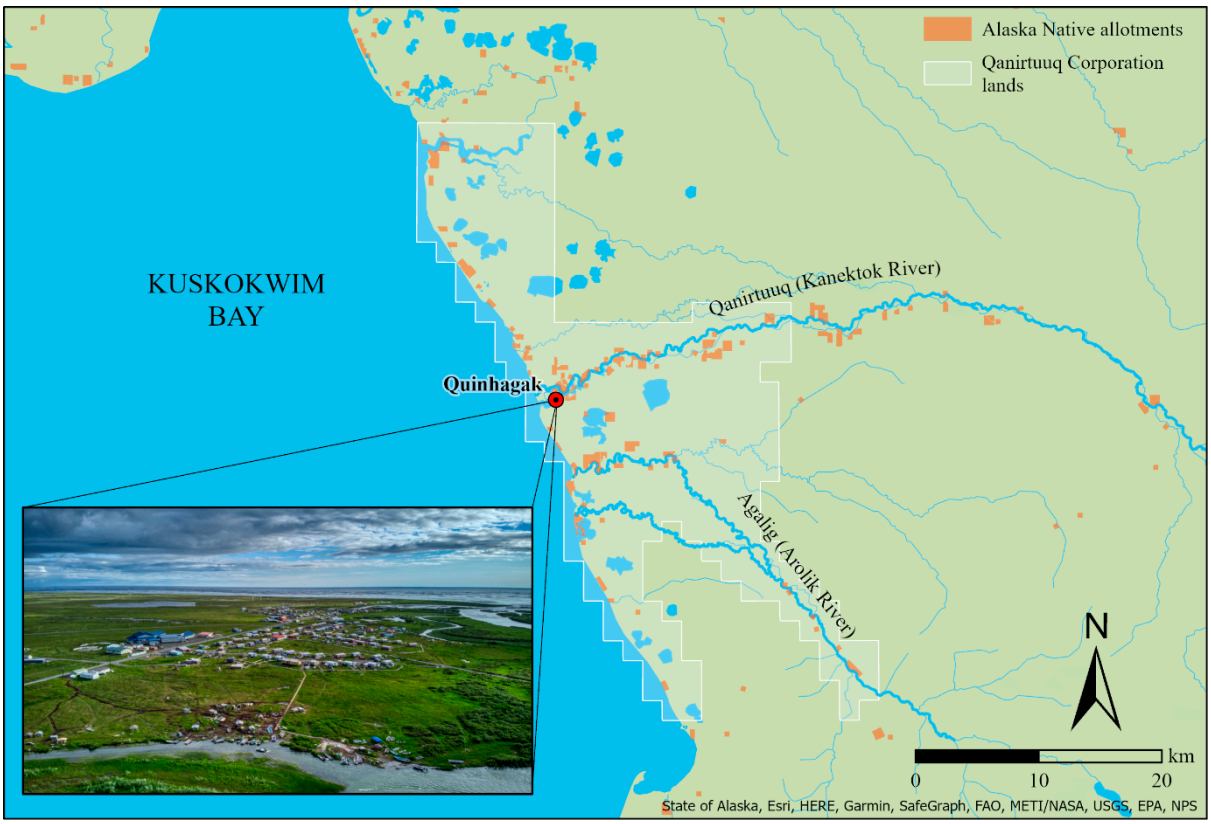

Figure 2. Quinhagak is a traditional Yup'ik village of around 700 people on the Bering Sea (see inset aerial photo). Exact sample area locations are not shown to protect archaeological site locations.

In response, our article proposes a new approach to quantifying erosion damage to ANCSA 14(c) allotments. Using the Traditional Land Use Area (TLUA) of Quinhagak as a case study, we use highly accurate and high-resolution geospatial datasets derived from archival satellite imagery and Unpiloted Aerial Vehicles (UAVs, a.k.a. "drones") surveys to demonstrate the extent to which coastal erosion has damaged nearby ANCSA 14(c) allotments. To do so, we introduce a novel Python script for use in geographic information systems (GIS) software to automate the interpretation of aerial imagery so that other communities requiring urgent documentation of erosion damage can conduct similar analyses.

2. Methodology

2.1. Surveying in Wetland Tundra

Conventional land surveys in the Y-K Delta are challenging due to the frequency of waterways and patches of marshy terrain. Furthermore, access to many sites is only possible by boat due to the absence of land transport infrastructure in rural Alaska [33]. In response, researchers working in this region increasingly rely on aerial imagery derived from satellites or UAVs [28,29]. UAV platforms are well suited for surveying since they can record large areas of terrain remotely at a higher resolution than satellite imagery provided that the aircraft remains within the pilot's line of sight in accordance with current US Federal Aviation Authority (FAA) laws. Moreover, photogrammetric methods have advanced to the degree that precise spatial measurements may be made from aerial photographs of an area, thereby reducing the necessity for obtaining measurements by hand in difficult terrain and environmental conditions [34].

2.2. Collecting and Processing Aerial Imagery of Erosion

Four regions within Quinhagak's TLUA were selected for survey and analysis (Table 1). Each region was located along an important waterway for Yup'ik subsistence and contained at least two significant erosion events on or near ANCSA 14(c) allotments. Finally, specific areas within each region were selected for UAV-based imaging in consultation with Q-Corp with feedback from local Yupiit during community meetings and interview sessions that occurred from 2019–2022.

Table 1. Regions measured using UAV surveys in 2022 and archival satellite imagery.

Region Name	Erosion Areas Measured	Cultural Significance
Uyak	2	An important creek used for subsistence. Contains significant archaeological remains and traditional Yup'ik placenames.
Agalig Mouth	2	A major salmon river used for subsistence. Contains significant archaeological remains and traditional Yup'ik placenames at its mouth.
Bessie Creek	2	A creek branching off on the Agalig. Possible archaeological sites near the confluence. Site of a proposed gravel pit, making it important for future village infrastructure.
Old airport	3	Many ANCSA 14(c) allotments, one of which is inhabited throughout the year. Important village infrastructure that is eroding.

From July until August 2022, a precision landscape measurement of each region was completed using an DJI M300 RTK UAV outfitted with a DJI P1 35 mm full-frame 48 MP RGB optical sensor. The M300 has real-time kinematic (RTK) capabilities, allowing it to receive coordinate information from a stationary base station to improve image spatial accuracy [35]. The horizontal and vertical spatial accuracy of this UAV when combined with the DJI D-RTK2 base station configuration was advertised as 1 cm–2 cm according to the DJI user manual. However, from our own independent measurements of control points from each region with an Emlid RS+ GNSS unit, the D-RTK2's accuracy appears closer to ~10 cm and ~5 cm.

Automated flights for data collection were planned and implemented using the DJI's proprietary Pilot 2 software and smart controller. The UAV was programmed to fly cross

grid patterns, capturing imagery at automated intervals to achieve an 80% forward and 70% side overlap to ensure the ease of constructing georeferenced orthomosaics. Flights were performed at an altitude of less than 400 feet to ensure a ground sampling distance (GSD) of <4 cm. Before each flight, a DJI D-RTK2 High Precision GNSS Mobile Station was allowed to self-calibrate for over two hours to improve the spatial accuracy of the final image.

2.3. Software and Archival Data Sources

Archival Very High Resolution (VHR) satellite imagery was utilized alongside current UAV imagery to measure the comparative levels of erosion at specific ANCSA 14(c) allotments over time. The primary VHR dataset included declassified 1976 military intelligence photographs (Keyhole satellite system) with a <1 m GSD. This imagery was then georeferenced using extant geological features alongside pre-georeferenced DigitalGlobe (WV02) imagery (dated 9 May 2015). Finally, authoritative Native allotment and corporation property boundaries hosted by Callista Corporation were utilized to determine the location of specific ANCSA 14(c) allotments [36,37].

ArcGIS Pro 3.0.2 was used to view and manipulate the imagery and to take precise spatial measurements. This is a powerful and versatile GIS software package that all Alaska Native groups have access to under an agreement with the US Bureau of Indian affairs. The workflows and scripts described in this article may thus be easily replicated in other communities if they have a computer available to run the software. In addition, Agisoft Metashape Professional 1.8.2 was used to create georeferenced orthomosaics from the UAV imagery.

2.4. Community Engagement: Interviews and Meetings

Community meetings were held at the project's onset to determine the spatial extents and regions for inquiry. From 2018–2022, 20 GIS-based interviews were also conducted about individual ANCSA 14(c) allotments within Quinhagak's TLUA. During these interviews, individuals had the opportunity to review GIS layers, composite orthomosaics, and UAV footage of specific subsistence sites under threat from erosion. UAV footage for these interviews was compiled in Davinci Resolve 17.2.0., and Adobe audition was used to edit .wav files of recorded interviews. Finally, researchers held ad hoc meetings with community leadership during this time period to present preliminary findings and gather additional feedback.

Ethnographic interviewing was also conducted during on-site visits to each of the four proposed regions. During interviews, Yup'ik familiar with each site were asked nondirective and directive questions about a location's importance, usage, and history. Relevant GIS coordinates were logged with a Garmin handheld GPS and an Emlid DGNSS RS+ base station/rover unit. Interviews were recorded using a Zoom Fn2 Lavalier microphone (32 bit, .wav) and a BMPCC 6 K camera (6144 × 3456 pixels, .braw). Video captured from UAV flights using a DJI Mavic Mini 2 (3840 × 2160 pixels, .mp4) were also collected to provide a bird's eye view of erosion for interviewees. At the request of Q-Corp, select portions of recorded interviews were published as ESRI Story Maps to highlight the erosion damage at particular subsistence sites (e.g., link).

2.5. Measuring Erosion

A custom ArcPy geoprocessing script—the Waterway Erosion Tool (WET)—was written in ArcGIS Pro to automate the measurement of erosion change between two images of the same area. The script utilizes user-defined inputs in order to produce a table showing minimum, maximum, mean, and median change for a specified area with erosion damage. It is available for download here (https://github.com/Nalaquq/WET) [Accessed 5 January 2023]. As an open-access tool, this script will allow communities to measure erosion in their wider cultural landscape, not just the limited places covered in the recent

2021 State of Alaska erosion survey. The process for its implementation is summarized in Figure 3 below:

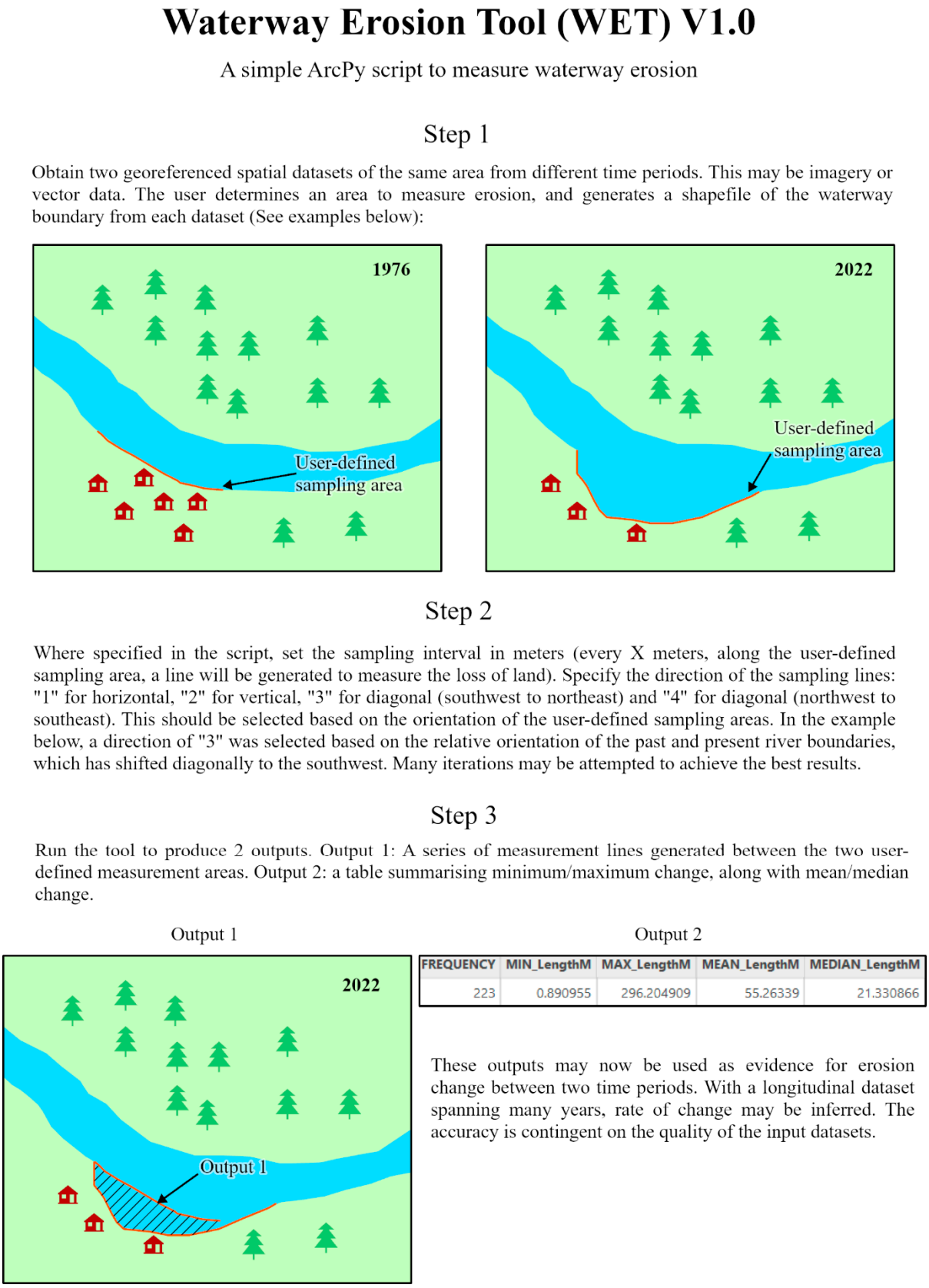

Figure 3. The open-access tool used in this study to measure erosion was developed by the authors for use in ESRI ArcGIS Pro, which every Alaska Native community has access to via the BIA.

3. Results

3.1. Erosion

At each of the nine selected sample areas, each chosen for their cultural significance, large amounts of land have been lost since 1976 (Table 2).

Table 2. A list of sample areas measured across four regions near Quinhagak.

Sample Area	Region	Native Allotment ID	Sampling Lines	Min. Length	Max Length	Mean	Median	Erosion Period
1	Uyak	Lot 11, USS 9532	15	1.87	6.9	3.89	3.62	Since 1976
2	Uyak	Lot 4, USS 9532	64	7.42	109.81	70.07	72.11	Since 1976
3	Agalig Mouth	Lot 2, USS 9568	28	1.27	22.58	12.35	13.40	Since 1976
4	Agalig Mouth	Lot 1, USS 9680	60	0.33	25.87	11.77	7.03	Since 1976
5	Bessie Creek	Lot 4, USS 9688	21	0.37	29.56	13.00	9.90	Since 1976
6	Bessie Creek	Lot 1, USS 9688	26	3.47	28.51	13.39	21.75	Since 1976
7	Old Airport	Lot 5, USS 9672	223	0.89	296.20	55.26	21.33	Since 1976
8	Old Airport	Lot 1, USS 9672	10	64.00	75.45	67.28	66.14	Since 1976
9	Old Airport	None, village infrastructure	51	6.01	61.87	30.48	25.30	Since 2015

3.2. Uyak Creek

Uyak Creek is a narrow waterway north of Quinhagak. Near its mouth is the archaeological winter village site of Uyakmiut (trans. "People of Uyak"), a collection of at least four precontact sod houses dated to Cal AD 1450 to 1640 within a Native allotment (Figure 4). Non-Yup'ik researchers were initially perplexed at the choice of location since it is unusual for a winter village to be sited on a waterway that has no immediate access to the salmon runs [38]. However, ethnographic data collected in 2021 during interviews with former Quinhagak mayor Willard Church indicated that this creek is indeed frequented by anadromous fish species such as salmon and smelt. The bank adjacent to the structures at the site (Sample area 1) has been eroding for decades, with a mean of 3.89 m (median 3.62 m) of erosion since 1976. Church recalls how, as a child, his brother would obtain artifacts from the erosion face, including ornate wooden masks and stone bowls. Finally, as noted in ethnographic interviews with local hunters (n = 3), Uyakmiut has been long utilized for subsistence hunting since it is an optimal place to intercept birds on their annual migration routes.

Near Uyakmiut, at the mouth of Uyak creek, is a partially eroded narrow spit known as *Legenret*, which is located on an ANCSA 14(c) Native allotment (Sample area 2). As noted during on-site interviews in 2021, *Legenret* has long been an important place to hunt ducks and gather edible greens, wood, and grass for weaving baskets. However, it has also suffered some of the worst erosion in Quinhagak's TLUA with a mean land loss of 70 m (median 72.11 m) since 1976. As a result, the former peninsula became an island in 2019. Due to this topographic shift, local Yup'ik have raised concern that further erosion will increase the volume of water flowing into the creek at high tide, something that may, in the future, increase the rate of erosion at nearby allotments including the nearby Uyakmiut site.

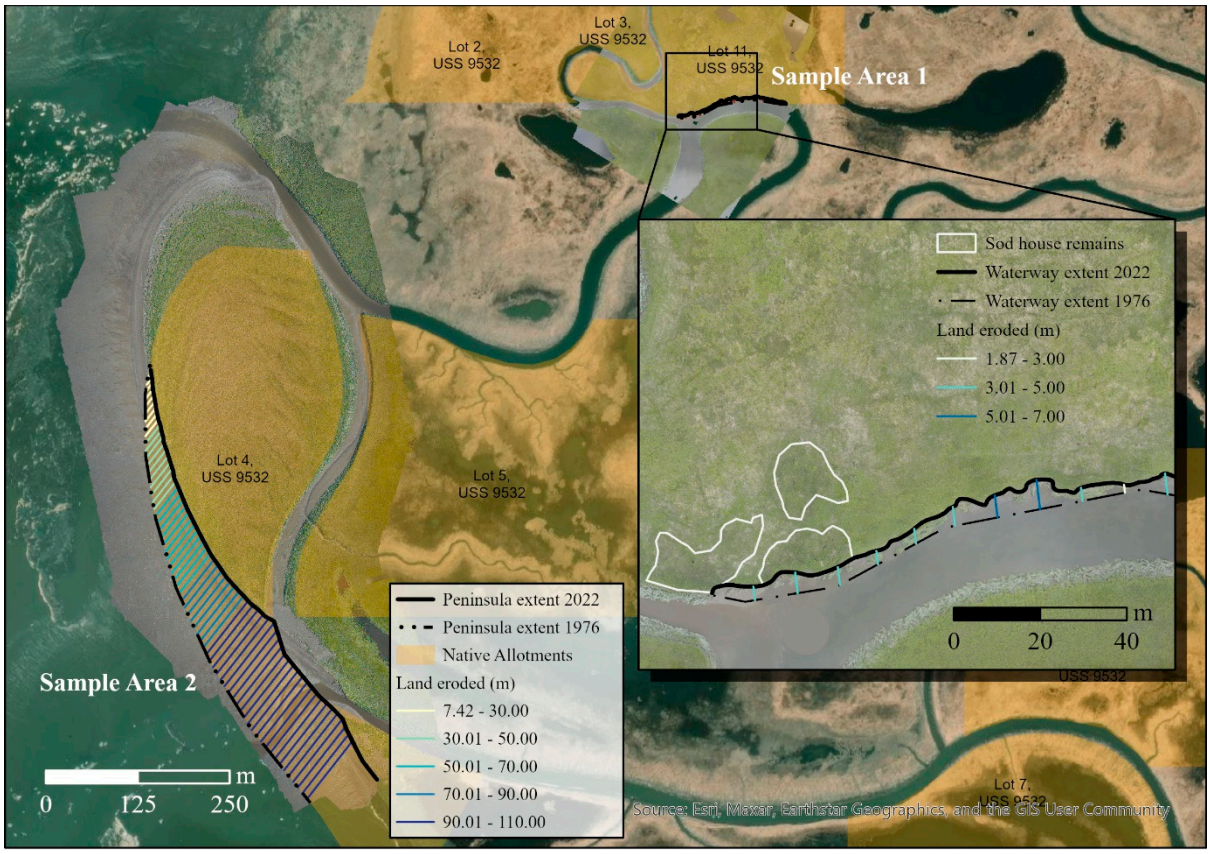

Figure 4. Erosion at Uyak Creek. Aerial orthomosaics by authors (2022), basemap by ESRI.

3.3. Agalig Mouth

The Agalig (Arolik River) is the most important subsistence waterway in the Quinhagak area. It is extremely difficult to navigate, as it is dangerously shallow. As such, there is a high concentration of archaeological sites and Native allotments near the mouth of the river where less navigation is required. Furthermore, salmon are funneled into this area as there are fewer tributaries, making it a very good area for fishing [38]. Sample area 3 represents what may be an undocumented cluster of three small sod houses on a ANCSA 14(c) allotment on the south bank of the river, which has lost a mean of 12.35 m (median 13.40 m) of land since 1976 (Figure 5). Artifacts have been recently recovered from this erosion edge, including an intricate wooden spoon and bow.

The abandoned village near Sample area 4 was known as Agaligamiut. In the late 19th century, it was a larger settlement than Quinhagak, according to the US census. However, by 1910, it was totally abandoned. There are no obvious surface indications of structures, but structures appear on an old USGS map from 1954. Furthermore, UAV surveys conducted in 2022 were able to clearly delineate these structures using elevation and multispectral data. A mean of 11.77 m (median 7.03 m) of land has eroded since 1976, almost encroaching on the structures.

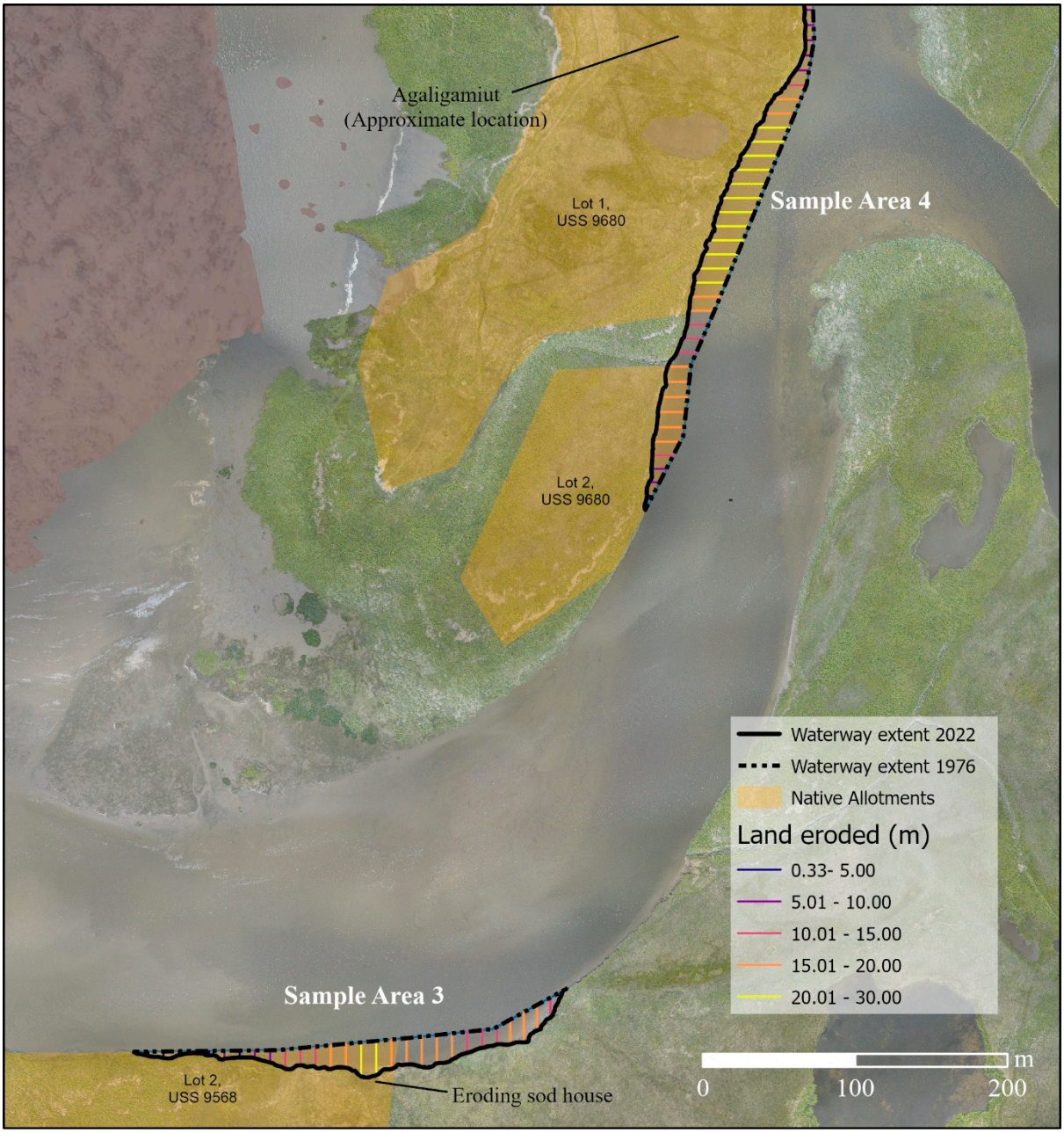

Figure 5. Erosion at the mouth of the Agalig. Aerial orthomosaic by authors (2022).

3.4. Bessie Creek

Bessie Creek is a tributary of the Agalig (Figure 6). There are many traditional place names in this area, indicating that this is an important place to obtain salmon, small mammals, berries, and waterfowl. In 2019, the authors carried out test pits at Sample area 5: it was suspected to be an undocumented cultural site due to its elevated position and the presence of fireweed—an indicator of past human activity in this particular environment [29]. No structures were immediately evident, but test pits revealed the presence of a dense layer of faunal remains just below the topsoil, along with 20th century waste including candy wrappers. This suggests there was a historic hunting camp in the area. There is a high amount of erosion threatening this site, with a mean of 13 m (median 9.9 m) lost since 1976.

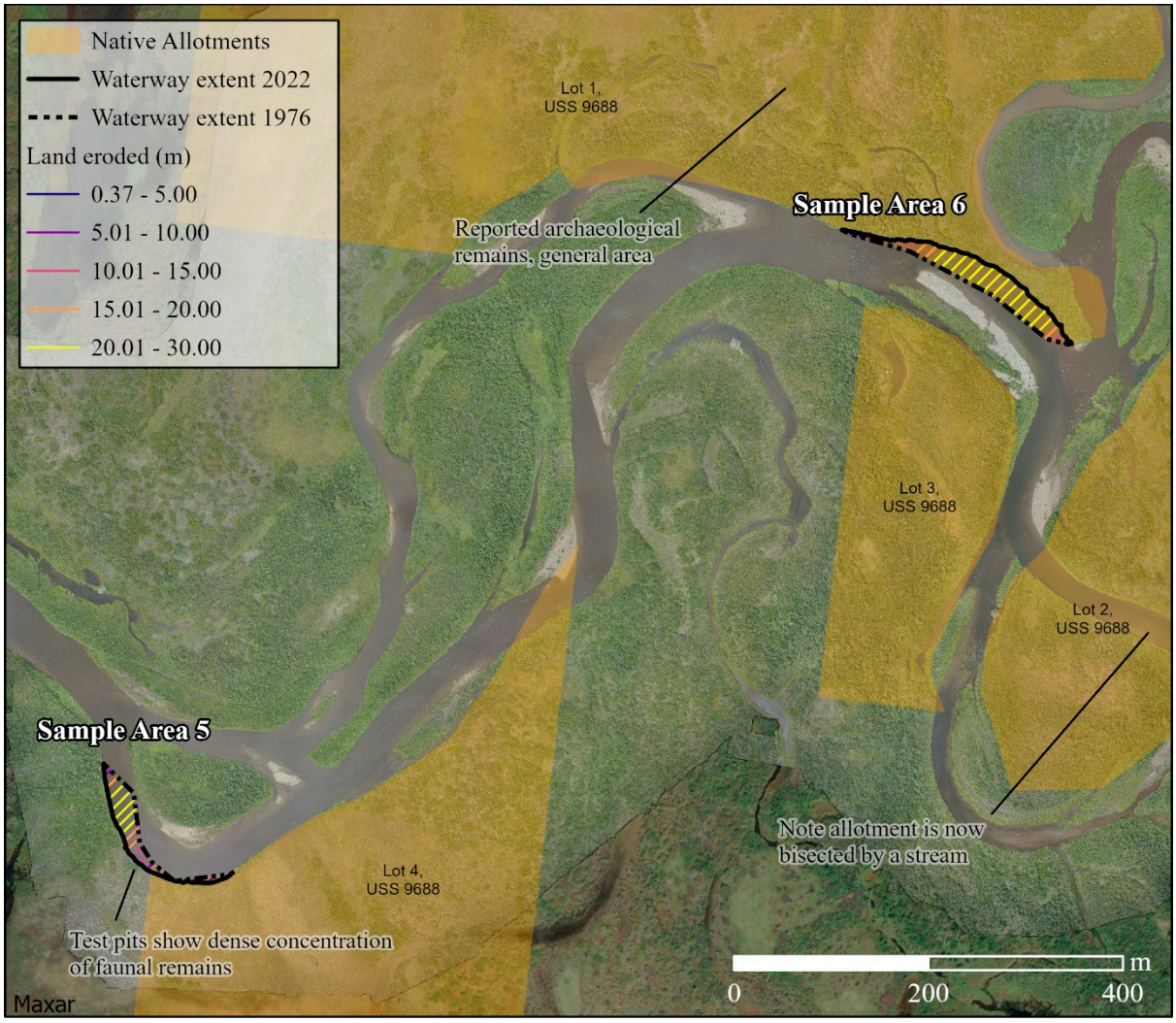

Figure 6. Erosion at the confluence of Bessie Creek and the Agalig. Aerial orthomosaic by authors (2022), basemap by ESRI.

The ANCSA 14(c) allotment around Sample area 6 is of particular interest, as many people have expressed that there might have been a winter village there (Church pers. Comm). This area is also important for the future development of Quinhagak. It is known to have very firm ground due to extensive gravel deposits. However, a high degree of erosion has occurred at this site with a mean change of 13.9 m (median 21.75 m) lost since 1976.

3.5. Old Airport

Quinhagak's abandoned old airport is where some of the worst erosion is taking place (Figure 7). Although there are no recorded archaeological features in the vicinity, it is culturally important. The area is an important subsistence region traditionally known as *Meqsarturyaraq* (trans. 'place where we get fresh water'). The ANCSA 14(c) allotment at Sample area 7, an important subsistence place near modern fishing camps, has seen a staggering loss of land at almost 300 m in places, with a mean loss of 55.26 m (median 22.33 m). On a similar vein, the allotment at Sample area 8 is permanently occupied throughout the year by members of the Cleveland family. However, it has also lost a lot of land since 1976, a mean value of 67.28 m (median 66.14 m). The most alarming damage of all is taking place just south of this allotment, on the runway of the abandoned airport. Until recently, it was used as a gravel road to access fishing areas and gravel harvesting

pits to the east [39]. In the last 7 years alone, since 2015, this area has seen a mean loss of 30.48 m (median 25.30 m).

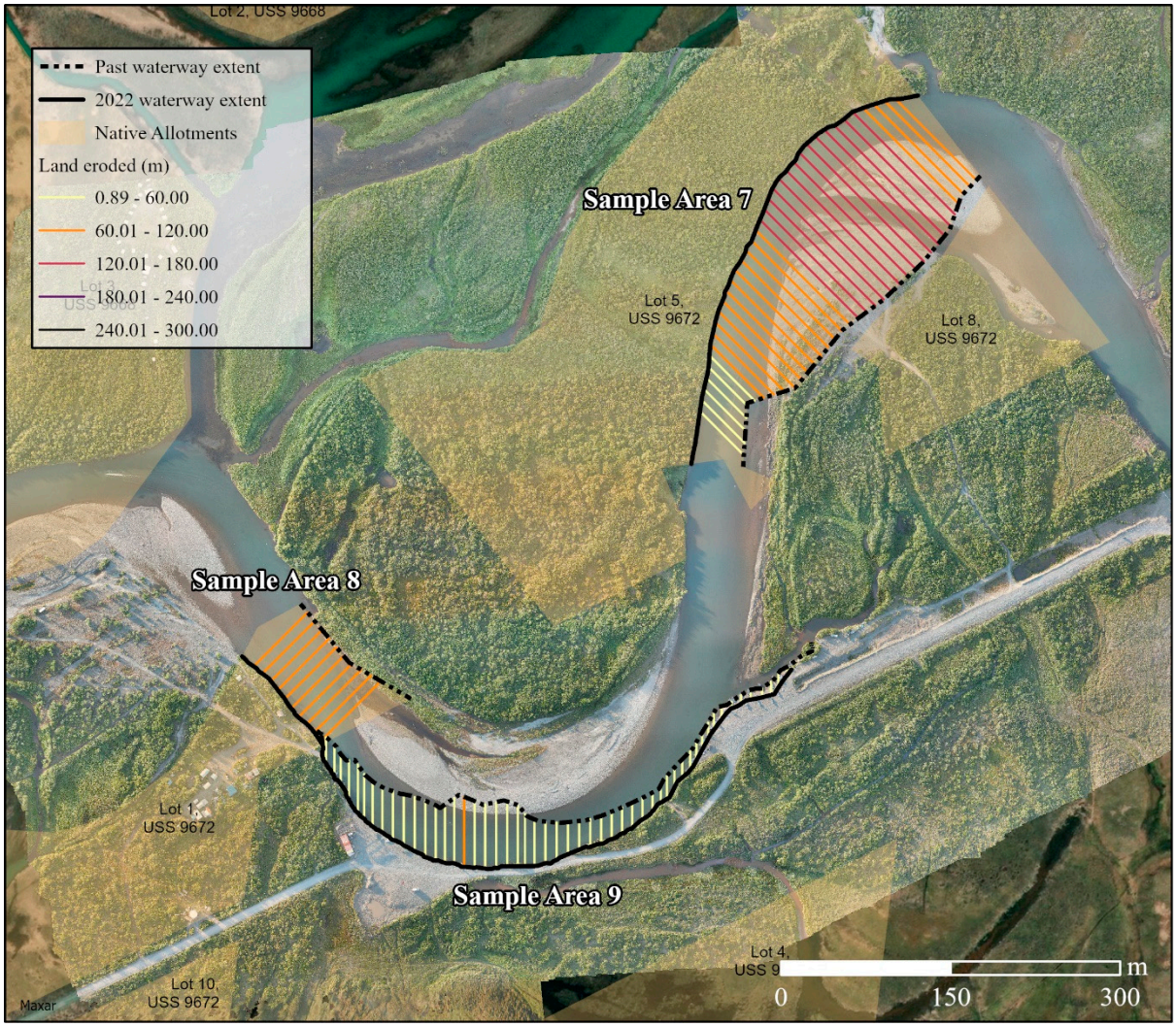

Figure 7. Erosion at Quinhagak's old airport. Aerial orthomosaic by authors (2022), basemap by ESRI.

4. Discussion: The Economic and Cultural Significance of Native Allotments

> " . . . *most villages began as winter settlements for a nomadic population whose members consumed goods and services that were locally produced in a subsistence hunting, fishing, and gathering economy. Today most villages continue to be well sited for participation in the subsistence economy, but they are not locations at which human beings would reside if they wished to participate in the wage economy that produces the goods and services that village residents, and particularly young Natives, now want to consume.*" (Mitchell 2001, 535) [40]

Debate exists as to whether ANCSA 14(c) allotments are compatible with the traditional Yup'ik subsistence lifestyles. After all, as evidenced by ethnographic accounts from Nelson Island, there was no concept of private property in precontact Yup'ik society, and it was common for multiple families to subsist together without consideration of boundaries or territorial restrictions [41]. However, the world that contemporary Yupiit occupy is drastically different from that of their ancestors. Today, Alaska Natives must navigate a wage-based economy, and many feel that ANCSA 14(c) allotments provide a bulwark against uncertain times, especially in the context of the United States' history of forced relocation of Native peoples.

To an extent, ANCSA 14(c) allotments provide financial security as some owners use their land as a source of income by renting land to outside companies: for instance, although there was a well-documented, historical animosity between local Yup'ik and guided sport fishing companies, sport fishing is now tolerated on the Qanirtuuq river, despite the disruptions it causes to daily community life [31]. As a result, some allotment owners allow recreational fishing camps to be situated on their properties for a fee. In addition, Native allotments are 'restricted' property, meaning any change to its status (e.g., transferring, mortgaging, or selling) is subject to the approval of the US Bureau of Indian Affairs (BIA). As imperfect as this arrangement is, the 'restricted' status provides allotment owners with a degree of legal certainty that their land is protected, since ANCSA 14(c) allotments are "inalienable and nontaxable", meaning that the land cannot be taken from the owner by force and is not subject to local or state property tax [42].

Yet, the importance of ANCSA 14(c) allotments is not solely restricted to monetary considerations: as multigenerational use areas, Native allotments are very likely to contain the material remains of ancestral Yupiit in the form of archaeological remains. Moreover, all ANCSA 14(c) allotments are culturally significant places, since they were selected according to the importance to its owner and their family as a "traditional use and occupancy." As Q-Corp land manager Carl Nicolai Jr. noted in a 2022 interview, "Native allotments were chosen where people grew up, and places that are good for subsisting." In this sense, ANCSA 14(c) allotments hold intrinsic cultural value as places that are central to a family's history or important subsistence locations. Indeed, the majority of ANCSA 14(c) allotments within Quinhagak's TLUA are still regularly used by their owners for hunting, fishing, gathering, and camping. Besides serving as resource collection hubs, subsistence camps are places where families and friends can spend quality time with one another, away from the hectic setting of their home village—in other words, an opportunity to reinforce and establish social ties [30].

The profound sense of persistent cultural continuity, where every traditional place is imbued with societal memory and lessons for survival, is very much present in Quinhagak as it is in other Yup'ik communities in the Y-K Delta. [41,43]. The spiritual toll of allotment loss must, therefore, also be considered: traditional Yup'ik belief subscribes to the notion of *Ellam Yua*, a sentient universe that reacts and changes based on the actions of its inhabitants [44]. This belief is still prevalent throughout the Y-K Delta: for instance, the Yup'ik residents of Hooper Bay equate the degradation of treasured archaeological sites (most notably, the grave of a renowned shaman) with their people 'losing their way' in the modern world [43]. On Nelson Island, Elders contend that the lack of prey animals is a direct consequence of ill feeling and squabbling over land, triggered by the imposition of the ANCSA 14(c) allotment system [41]. However, as a community that has had longer exposure to missionary influence, the concept of *Ellam Yua* is not commonly discussed in explicit terms in Quinhagak [30]. However, traditional beliefs still endure in the cultural consciousness of the community. As longtime Nunalleq project collaborator Michael Smith says in the short film Children of the Dig, "We are seeing what the Elders were saying: When people change, the weather will too" [45]. Thus, as if the financial and symbolic consequences of Native allotment loss were not enough, the loss of Native allotments risks compounding social anxiety, derived from almost two centuries of generational trauma and the notion that Yup'ik society is on the wrong path.

5. Conclusion: New Solutions for a Changing World

Historically, Yupiit chose ANCSA 14(c) allotments that included place names near coastlines and in-land waterways. Yet, although these allotments constitute important cultural locations for subsistence and daily travel, they are, nonetheless, vulnerable to increased erosion due to climate change. In response, the US government has finally begun to take action with federal programs designed to mitigate climate change and rectify historical injustices: on 20 January 2021, the Biden–Harris administration issued Executive Order 13985, empowering Federal agencies to address systemic barriers to opportunity

facing historically underserved communities. Similarly, the US Department of the Interior (DOI) has adopted a Climate Adaptation and Resilience Plan, which seeks to champion climate justice to groups that are disproportionately affected by climate change, including Native Alaskan peoples. These goals are admirable, and it is in the spirit of these initiatives that we call for urgent measures to address the issue of Native allotment loss.

When the Alaska Native Allotment Act of 1906 was first conceived, the impending climate consequences of a rapidly industrializing world were impossible to predict. However, by the time ANCSA was enacted, there was sufficient evidence that climate change would disproportionately impact arctic communities, and that fossil fuels were a contributing factor [46,47]. Yet ANCSA was passed in large part due to support from oil and gas industries since it facilitated the purchase and leasing of oil-rich territories [15]. As a result, Alaskan Natives have been forced to pay the price for a catastrophe perpetrated by colonial powers.

As demonstrated through our analysis of satellite and UAV imagery, ANCSA 14(c) allotments within Quinhagak's TLUA have suffered increased rates of erosion since 1976. Such displacements, when coupled with the loss of traditional cultural and ecological knowledge, have had a significant impact on the health and safety of Alaskan Native communities. For instance, since ANCSA 14(c) allotments were selected relative to Yugtun place names, they often include important traditional knowledge and landmarks meant to help Yupiit navigate the tundra. Warren Jones' Native allotment on the Qanirtuuq, for example, was passed down to him from his late father and contains a single, prominent sod structure of indeterminate age that has been used as a landmark and shelter for Yupiit traveling upriver to the mountains over many generations. If, as Yup'ik Elder Paul Charles of Nelson Island notes, "[Yugtun] place names were like street signs", then the roadmaps needed to safely traverse the Y-K Delta are currently under threat [48]. Not surprisingly, this loss of intergenerational knowledge when coupled with the unpredictable freeze/thaw cycles have resulted in a notable increase in Search and Rescue (SAR) missions throughout the arctic [49].

Despite these challenges, Alaska Natives have displayed remarkable resilience in the face of colonial structures. Grassroots-level programs and Native-owned heritage organizations such as the Alaska Native Heritage Center and the Nunalleq Museum have worked tirelessly to record Elder teachings and to communicate traditional knowledge to new generations [7,50,51]. Moreover, the transition from subsistence to cash economies created undue hardships that have shaped traditional Alaskan Native communities to this day [52]. The economic cost of importing consumables necessary for survival to rural Alaskan communities with no road access—such as fuel and ammunition—is considerable and causes significant hardship [44]. In turn, the majority of Yup'ik families in the Y-K Delta still rely on subsistence activities to offset the high cost of food, building supplies, and heating fuel. Here, the erosion of ANCSA 14(c) allotments has a two-fold impact on the health, safety, and economic vitality of Yup'ik coastal villages. First, the loss of intergenerational Yugtun placenames means that families must work harder to gather the requisite supplies to subsist. Second, coastal and riverine erosion have made it more difficult for commercial barge vessels to bring necessary supplies into villages. In Quinhagak, for instance, riverine erosion along the Qanirtuuq river has forced barges to navigate shallower shipping channels at the risk of running aground (Figure 8).

The impact of ANCSA 14(c) allotment erosion has significant material, if not always visible, impacts on Alaskan Native communities. Thus, given the cultural and financial significance of these properties, we call for urgent dialogue and swift action between Alaska Native communities and lawmakers to compensate Native allotment owners for the loss of their lands. Ideally, this should take the form of allowing them to redefine the boundaries of their allotments, taking the effects of erosion into account. Perhaps these definitions may be informed through datasets generated by communities utilizing the methodology we have outlined in this article. The use of UAV data is crucial, as UAVs can produce higher quality data than satellite imagery. Furthermore, from a data sovereignty standpoint, there are no restrictions placed on the use of UAV imagery, allowing communities to publish and

monetize the data as they see fit. Regular surveys of areas at high risk of erosion, conducted at quarterly intervals throughout the year, will go a long way towards building a robust model for predicting how the landscape will change in the future. Other measures should also be used in conjunction with this, such as more funding for archaeological intervention and rescue excavations where erosion poses an immediate threat to material culture.

Figure 8. A UAV still image of a grounded barge at the mouth of the Qanirtuuq river in fall of 2022. Image courtesy of Bryan Jones, Quinhagak AK.

In these uncertain times, it is difficult to foresee the perfect solution for the myriad of challenges facing communities such as Quinhagak in Southwest Alaska. However, one thing is for certain: inaction is likely to lead to more damage to the culture and way of life of the Native inhabitants of Southwest Alaska. Only swift dialogue and decisive action can have a hope of forestalling the coming crisis.

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