Participatory Science for Landslide Community Awareness: Development of a Protocol for Southeast Alaska

[1]A. Johnson, [2]J. Roering, [3]K. Prussian, [4]P. Wilcox, [5]R. Heintz, [6]L. Pierce, [7]D. Head, S. Tobey, [5]Z. Danielson, [8]C. Udell, [5]E. Neumann, [9]Q. Aboudara, [10]S. O'Neil, [11]A. Jacobs, [12]J. Isaacs, [13]A. Thoms, [5]L. Silva

[1]Community Collaborators, Juneau, Alaska, USA

[2]University of Oregon, Eugene, Oregon, USA

[3]USDA Forest Service, Sitka, Alaska, USA

[4]RAND Corporation, Anchorage, Alaska, USA

[5]Sitka Sound Science Center, Sitka Sound Science Center, Sitka, Alaska, USA

[6]Central Council of the Tlingit and Haida Indian Tribes of Alaska, Juneau, Alaska, USA

[7]Tlingit and Haida Master Weaver, Craig, Alaska, USA

[8]Oregon State University, Corvallis, Oregon, USA

[9]Shaan Seet Corporation, Craig, Alaska, USA

[10]USDA Forest Service, Thorne Bay District Office, Thorne Bay, Alaska, USA

[11]NOAA National Weather Service Forecast Office, Juneau, Alaska, USA

[12]Craig Tribal Association, Craig, Alaska, USA

[13] Sitka Conservation Society, Sitka, Alaska, USA

Abstract

Despite the abundance of steep slopes, heavy rainstorms known as atmospheric rivers, a long history of road building and timber harvest, and recent exacerbation of mass-wasting events and associated public safety concerns, there is a conspicuous lack of slope stability studies on Prince of Wales Island, the third largest island in the United States (2577 m^2, 6674 km^2) in Southeast Alaska. This project brought together academic scientists, federal scientists, and community members from Tribal and non-Tribal organizations, youth groups, educators, and local conservation organizations to collaboratively reduce geohazard risk on Prince of Wales Island.

Project results informed a four-step community science engagement protocol: (1) *Conduct community meetings, workshops, and potlucks* to summarize interconnected-island local concerns, develop unifying approaches for enhancing emergency management plans for road maintenance and response, and assess linkages among landslides, land use, infrastructure, bridges and culverts used for stream crossings, and salmon populations. (2) *Make relevant measurements,* including rainfall and soil saturation along elevation gradients, information enhancing weather forecasting and supporting community situational awareness for storms having the potential to trigger landslides. (3) *Involve local youth in meaningful and sustained education and workforce development*. Local Alaska Youth Stewards participants learned to identify landslide-prone terrain and consider management impacts, use field forms, install equipment, and verify a landslide runout model. (4) *Develop community tools,* including action plans and hazard maps. The study results highlight geophysical and human system interconnectedness, community and youth engagement relevance in local research, and continued protocol use and both in Southeast Alaska and elsewhere.

Key Words: Landslides, Community Resilience, coproduction, K̲utí Geohazards, STEM, Prince of Wales Island

1 Introduction

The mountainous terrain of Prince of Wales Island, in Southeast Alaska, is periodically inundated with heavy rainstorms, inducing landslides and causing significant impacts to human safety, community infrastructure, transportation routes, and aquatic habitats. The destructive impacts of landslides are steadily increasing due to extreme rainfall events called atmospheric rivers. Atmospheric rivers contribute up to 97% of annual extreme precipitation in Southeastern Alaska, with the highest amounts of precipitation, up to 82%, occurring during autumn (Sharma and Déry, 2020; Nash et al., 2024).

Integration of local knowledge with western science has been shown to increase the resilience of hazard-prone communities (e.g., Mercer et al., 2010; Walshe and Nunn, 2012). For this reason, citizen science, also called participatory science, along with other collaborative research by scientists and the concerned populations have been growing in popularity in both academic and public sectors (Bonney et al., 2014; McKinley et al., 2017; Yua et al., 2022)

A National Science Foundation-funded project known as K̲utí, the Tlingit word for weather, aims to build "partnerships between governments and communities to reduce the risks of landslides to the people and resources of Southeast Alaska through coordinated research, mitigation, communication, outreach, and response (Sitka Sound Science Center, 12/6/24)." K̲utí was initiated in 2022 and extends until 2027. K̲utí has forged partnerships with six communities across Southeast Alaska, including two on Prince of Wales Island, Craig and Kasaan. K̲utí attempts to co-produce research on landslides and other geohazards caused by extreme precipitation through partnering in the region with local Tribal governments who steer the work based on Tribal and community needs and concerns. Partnerships require meeting community members and holding listening sessions so that the K̲utí team can apply the development of risk reduction tools and knowledge to community needs and knowledge. To enhance K̲utí programming on Prince of Wales Islands, additional place-based STEM educational programs for youth such as the Alaska Youth Stewards program (AYS, eight high school students organized through the Central Council of Tlingit and Haida Tribes), have been heralded to foster relevant workforce development (e.g., Sustainable Southeast Partnership, https://sustainablesoutheast.net/).

This K̲utí project was bolstered with USDA Forest Service Participatory Science grant funding to develop a community engagement protocol by achieving four goals: (1) Facilitate community meetings to learn techniques from Prince of Wales communities to best strategize on landslide-related issues and concerns. (2) Make measurements to determine differences in rainfall along elevation gradients while supporting the US National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Juneau Forecast Office. (3) Facilitate relevant workforce development through local education programs. (4) Summarize ideas for co-produced action plans to build useful tools and guide science strategies for geohazard risk reduction.

1.1 Study Area

Prince of Wales Island, located 19 miles (30 km) from Ketchikan in Southeast Alaska, is in the southernmost extension of the Tongass National Forest and within the ancestral unceded territories homeland of the Tlingit and Haida Tribes, who have stewarded these lands since time immemorial and continue to do so today. Residents of Southeast Alaska depend on the forests, streams, coastlines, and oceans of Southeast Alaska to support food and cultural lifeways. Cultural species considered “very high priority areas of concern” include salmon, cedar, and shellfish (Kapp, 2018). For example, all five salmon species (*Oncorhynchus sp.*) present in Southeast Alaska depend on the maintenance of quality spawning and rearing habitats that are influenced by climate variation, habitat degradation, and management actions (Ratner et al., 2006, Kapp, 2018; Atlas et al., 2021).

Prince of Wales Island is dominated by rocks of the Alexander Terrain, a large accretionary fragment, consisting of granodiorites, greywackes, conglomerates, limestones, and sandstones (Gehrels and Berg, 1992). Most of the bedrock below 305 ft (1000 ft) elevation on Prince of Wales Island is covered by glacial deposits or till (Swanston, 1969). The steep forest lands are characterized by a broadly dissected drainage pattern with deep valleys, steep slopes, and narrow intervalley ridges, all strongly controlled by bedrock faulting and heavily modified by extensive glaciations (Harris et al., 1974).

A weather station located at the Klawock airport on western Prince of Wales Island indicates a mean annual temperature of 7.3° C (45.2° F) and a mean annual total precipitation of 2471 mm (89.2 inches) (U.S. Climate Normals NOAA 2023, 2006–2020 record). Southeast Alaska, considered a temperate rainforest, is dominated by western hemlock (*Tsuga heterophylla*), and Sitka spruce (*Picea sitchensis*), with lesser amounts of western red cedar (*Thuja plicata*), and Alaskan yellow cedar (*Chamaecyparis nootkatensis*), which become more scarce further north in the region (Harris et al.,1974). Shore pine (*Pinus contorta*) typically grows in open muskegs, and red and Sitka alder follow areas where soil has been previously disturbed by forest logging operations and landslides (Deal and Orlikowska, 2002). Yellow cedar decline, a natural mortality of old-growth forests has been associated with change in soil temperature, chemistry, and/or change in hydrology as opposed to an association with pests or pathogens (Hennon and Shaw, 1997) and yellow cedar sites on steep slopes are prone to greater landslide frequency (Johnson and Wilcock, 2002). Clearcutting of the old-growth forests has occurred primarily since the 1950s resulting in a mosaic of clearcuts, second growth, and old-growth patches.

Forest disturbances on Prince of Wales Island include wind, forest harvest, landslides, and flooding. Windthrow is the dominant forest disturbance (Harris et al., 1974; Nowacki, 1998, Buma and Johnson, 2015). Landslides in Southeast Alaska are often associated with windy and rainy conditions (Johnson et al., 2000; Buma and Johnson, 2015) and serve as a key mechanism for carbon transport (Vascik et al., 2021; Booth et al., 2023) and the generation of fluvial sediments influencing fish habitat (Bryant et al., 2007; Martin and Shelly, 2017). Landslides impact homes, infrastructure, and subsistence resources. For example, in November 2023, a landslide hit a power line resulting in a loss of power for the entire island (Alaska Public Media, 2023). Landslides both create and destroy fish habitat by introducing sediment and woody debris into ocean, lake, and river systems (e.g., Geertsema et al., 2009, Carlson, 2024). A model of landslide impacts on fish habitat on Prince of Wales Island illustrates how most landslides typically deposit on the base of U-shaped valleys before depositing whereas landslides more often deposit directly in V-shaped valleys (Miller, 2021). Forest harvest has resulted in a 2-to-4-fold increase in landslide frequency in Southeast Alaska (Swanston and Marion, 1991). The Tongass National Forest, with a comprehensive landslide inventory, provides a unique opportunity to characterize the effects of forest management actions on an array of relevant issues (Landwehr, USDA Forest Service, unpublished report).

In Southeast Alaska, increases in landslide occurrence are associated with atmospheric rain events, which generate extreme rainfall intensity and sometimes rain-on-snow events (Nash et al., 2024). The area southeast of Craig (Sunnahae Mountain) is considered an area of particular concern, given population density and prime location for orographic-enhanced precipitation often associated with atmospheric river events (Nash et al., 2024). The atmospheric rivers that impact Prince of Wales tend to be laden with moisture and approach from the south. The Port Saint Nicholas Road at the base of Sunnahae Mountain has been considered, "a disaster waiting to happen” (2009, unpublished Alaska Department of Natural Resources recorded landslitide expert panel discussions) owing to the recent prodigious construction of homes on several debris fans formed by the accumulation of debris flow deposits over millenia.

2 Methods

The methods used for community engagement provide the basis for a protocol that could be applied in other communities in Southeast Alaska, and elsewhere. Study methods included meeting preparation and discussion summarization from meetings in four communities on Prince of Wales Island, rain gauge and piezometer installation and evaluation of measurements from Sunnahae Mountain, work with the Alaska Youth Stewards Program, and evaluation of tools and information to make communities safer.

2.1 Community meeting preparation and discussion summarization

Beginning in April 2024, we scheduled meetings in the communities of Craig, Klawock, Hydaburg, and Kasaan. These meetings were facilitated by a Sitka Sound Science Center contract with Adelaide Johnson, representing the organization “Community Collaborators,” to work with the Central Council of Tlingit and Haida Indian Tribes of Alaska, Sitka Sound Science Center educators, and Alaska Youth Stewards program. The extensive planning process included a series of e-mails, phone calls, and Zoom meetings to assess schedules, discuss community needs, evaluate study objectives, connect and present to Tribal Councils, reserve meeting rooms, work with the Forest Service for use of vehicles and bunkhouse space, and reserve lodging prior to community visits. Meeting logistics included preparation of potlucks with raffle prizes donated by the team members. Community meetings were organized to engage a wide range of organizations and community interests related to Tribes, knowledge bearers, elders, forest and city managers, youth organizations, and emergency services providers. Meetings were also organized to work directly with community members in the neighborhood along Port Saint Nicholas Road in the Sunnahae slide zone. During the K̲utí planning process, there was turnover in the community connectors roles. Community connectors are local Tribal contacts who help facilitate meetings, communication, and relevant work on the project. In the communities of Craig and Kasaan, the two Tribes that had originally supported the K̲utí proposal, the original connectors had taken new positions.

Meeting preparation included map creation by the US Forest Service, Southeast Watershed Coalition, and K̲utí team members. Maps showing road networks, landslides, and forest harvest were prepared. Maps showing predicted landslide initiation sites were printed by the Central Council of Tlingit and Haida Tribes of Alaska to facilitate discussion and knowledge sharing during community meetings. Posters created to advertise meetings were linked to Facebook pages of area Tribes, posted at public buildings, and tacked up at local grocery stores (Figure 1).

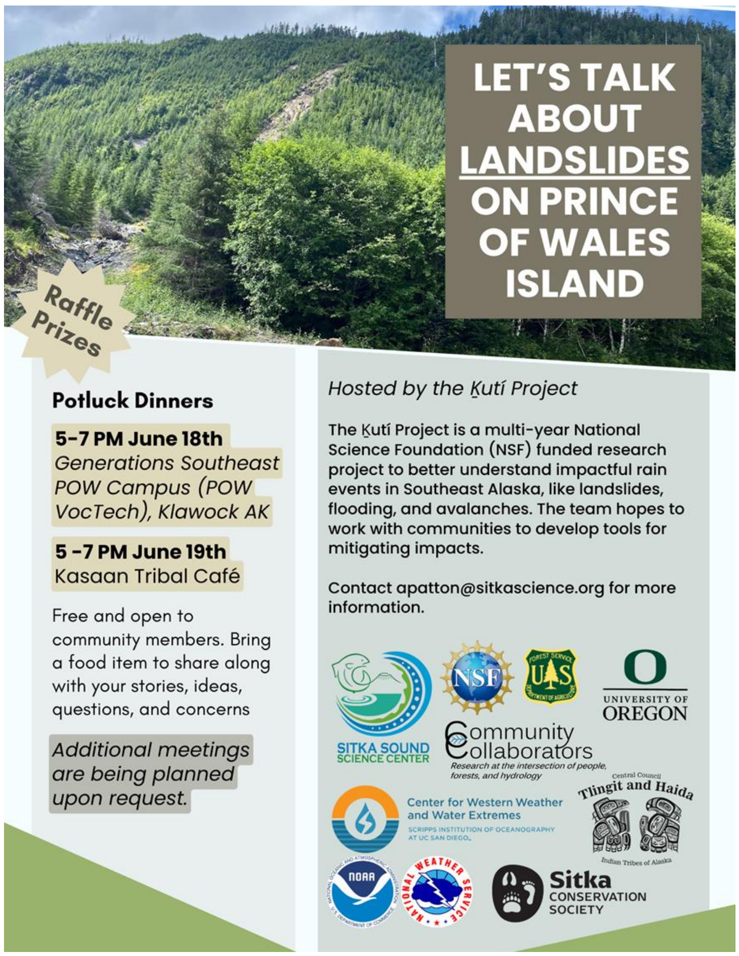

Figure 1. Poster to announce Prince of Wales Island meetings (Jacyn Schmidt, poster creator).

At meetings, the project was typically introduced by Ron Heintz, acting K̲utí principal investigator followed by the introduction of team members, and then, ideas were solicited, and questions were raised to community members to gain input on perspectives, ideas, and concerns related to geohazards. Following meetings, the five core K̲utí participants, namely Adelaide

Johnson, Josh Roering, Peggy Wilcox, Lindsey Pierce, and Ron Heintz gathered to examine their notes, synthesize top community meeting themes, and collaboratively write a summary (see Supplemental Information). In addition to the core team members, USDA Forest Service hydrologists Katherine Prussian and Skylar O'Neil attended selective meetings and assisted with field work.

2.2 Measurements

2.2.1 Rain Gauge Installation

Rain gauge installation, cellular transmission of rain data, and community involvement included seven key steps (see Supporting Information for more detail):

(1) Formalize agency, partner agreements, and contracts, plan Alaska Youth Stewards (AYS) work program, receive partner matching funding, order equipment.

(2) Prepare detailed topographic maps in collaboration with Forest Service specialists and Tribal partners to facilitate the choice of three precipitation measurement sites. Available Alaska Department of Natural Resources maps of landslide-prone areas were also compiled.

(3) Install precipitation gauges and piezometers with Forest Service and AYS (Figure 2), ensure that cellular data is being transmitted to forecasters within the NOAA's National Weather Service Forecast Office in Juneau, Alaska (Figure 3), engage with selected Community Connector to maintain/monitor rain gauges and piezometers during fall and winter months.

(4) Compile data, make graphs of cumulative rainfall over time and share project findings at high school and middle schools.

(5) Summarize protocol for precipitation measurements for review.

(6) Share protocol, project results at local and international conferences (e.g. Johnson et al. 2024).

(7) Maintain network with project partners including the AYS and NOAA's National Weather Service Forecast Office in Juneau, Alaska to sustain/continue the project in other communities.

Figure 2. Working with community partners (a) Skylar O'Neil, US Forest Service, and Jess Isaacs, Craig Tribal Association on rain gauge installation and (b) Laci Lowery, Alaska Youth Stewards program, and Casey Jacklyn, Oregon State University, on piezometer installation.

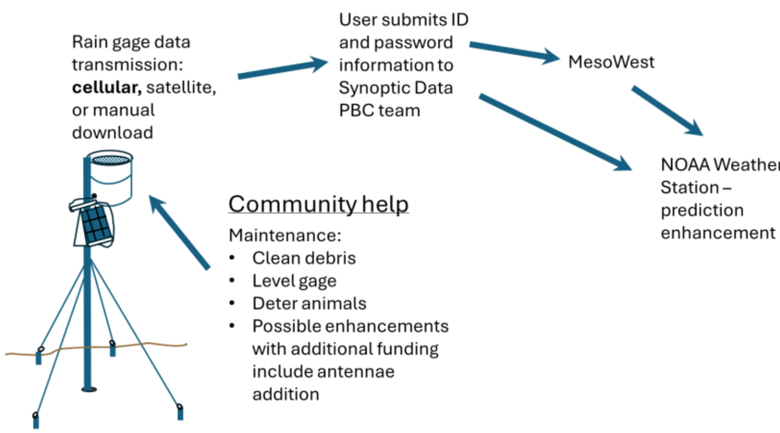

Figure 3. Method of transmitting precipitation data from Onset rain gauge station to the NOAA National Weather Service Forecast Office in Juneau, Alaska.

Four tipping bucket rain gauge sites were installed on Sunnahae Mountain following Shaan Seet Corporation's approval for use of their land and confirmation of cell coverage to the chosen sites (Figure 3, Figure 4). Two Onset S-RGA-M002 Rain Gauges (0.01 inch per tip) with 2m cable were set up (Low, 30.5 m, 100-ft elevation; Medium, 305 m, 1000-ft elevation) at open quarry site and on a recent landslide, respectively. The third rain gauge (High site, 853 m, 2800-ft elevation), a Texas Electronics, TE - 525 heated rain gauge (0.254mm, 0.01 inch per tip) was placed on a State of Alaska communications tower on a steep alpine meadow at the top of Sunnahae Mountain.

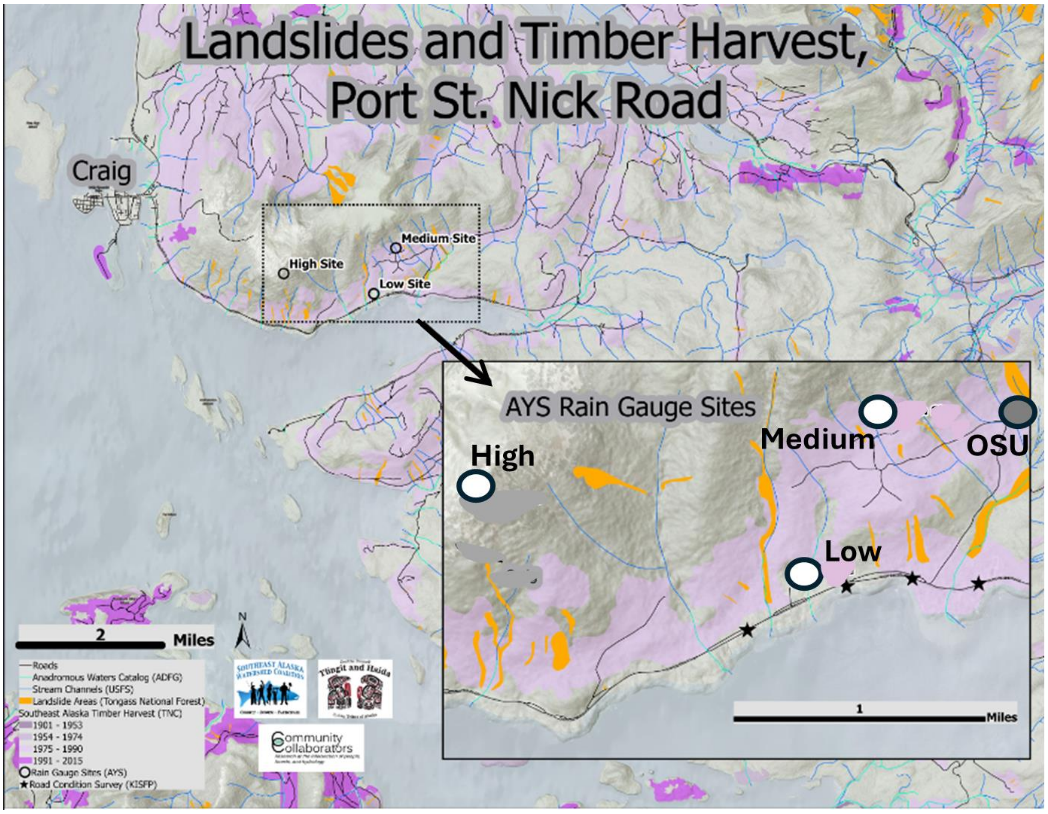

Figure 4. Rain gauge locations on Sunnahae Mountain. Forest harvest age is indicated by purple color and landslides are indicated by orange color (map was created by Khrystl Brouillette, Southeast Watershed Coalition).

Equipment was chosen based on moderate cost, technical support services, and ease of transmitting data (see Supplemental Information supporting information). The high-elevation (2800-ft above sea level) site required purchase of an Onset S-UCD-M001 Pulse Input Adapter - Contact Closure (note: this plus input adapter comes as part of the other rain gauges) to connect the rain gauge to the cellular transmission apparatus. All three rain gauges transmit cellular data using Onset RX2102 HOBO MicroRX Stations with solar panels using the cellular transmission plan, SP-812 BASIC, US service with connectivity to AT&T. Set up followed manufacturer guidelines. All three rain gauges followed standard procedures for site set up in areas with no trees or vegetation above a 45° angle from the horizon around the gauges. One additional rain gauge, built and operated by Chet Udell at Oregon State University (OSU) was set up at a site at 500 feet in elevation. The OSU site has a solar panel for power, required manual downloading, and was located on the bank of a stream along a logging road. The OSU site and the 1000-foot site were in areas harvested between 1975 and 1990 and situated on surfaces impacted by landslides (Figure 4).

Since rain was being collected to improve weather forecasting capability, steps were required to set up initial data transmission, submit cellular data to the cloud, and transit data to the NOAA National Weather Service Forecast Office in Juneau, Alaska (Figure 3). In this case, data was sent to the LICOR cloud for Onset Hobo rain data and made available to NOAA's National Weather Service Forecast Office in Juneau, Alaska following a few steps (see Supplemental Information for more detail):

(1) In the office, organize the rain gauge equipment and read manufacturer's instructions, set up a username, password, and location that links to the serial number of the rain gauge.
(2) Set up instruments in the field by following manufacturer instructions and test data transmission. In this study, it was ensured data that was being transmitted at the rain gauge site by calling technicians at Onset.
(3) Once back in the office after ensuring that the data is being transmitted, begin the process of transferring (ingesting) data by a second party (in this case, Synoptic Data

Maintenance of rain gauges include regular cleaning of debris, use of a hand level to make sure rain gauges were level, and addition of large wood at the base of rain gauges to deter curious animals. For the two lower rain gauge installations, levelling was facilitated with guy wires using adjustable screws. The 30.5 m (100-ft) site located at the Shaan Seet quarry uses an Onset M-TPB-KIT Complete 2M Tripod kit and the 305 m (1000-ft) site uses a pole with added guy wires.

2.2.2 Piezometer installation

A total of 10 handmade piezometers were installed in clusters of three or four, at three sites on 32° to 38° slopes in areas with documented landslide activity. Piezometers are geotechnical sensors used to measure pore water pressure in the ground. As pore water pressure increases, the soil becomes less stable. Each cluster included piezometers several feet from each other as follows: (1) four piezometers at the mid-elevation rain gauge site (305 m, 1000-ft elevation), (2) three piezometers at the OSU rain gauge site (152 m, 500-ft elevation), and (3) three piezometers at the base of on a community member's property on Port Saint Nicholas Road (about 30 m, 100-ft elevation, Figure 5).

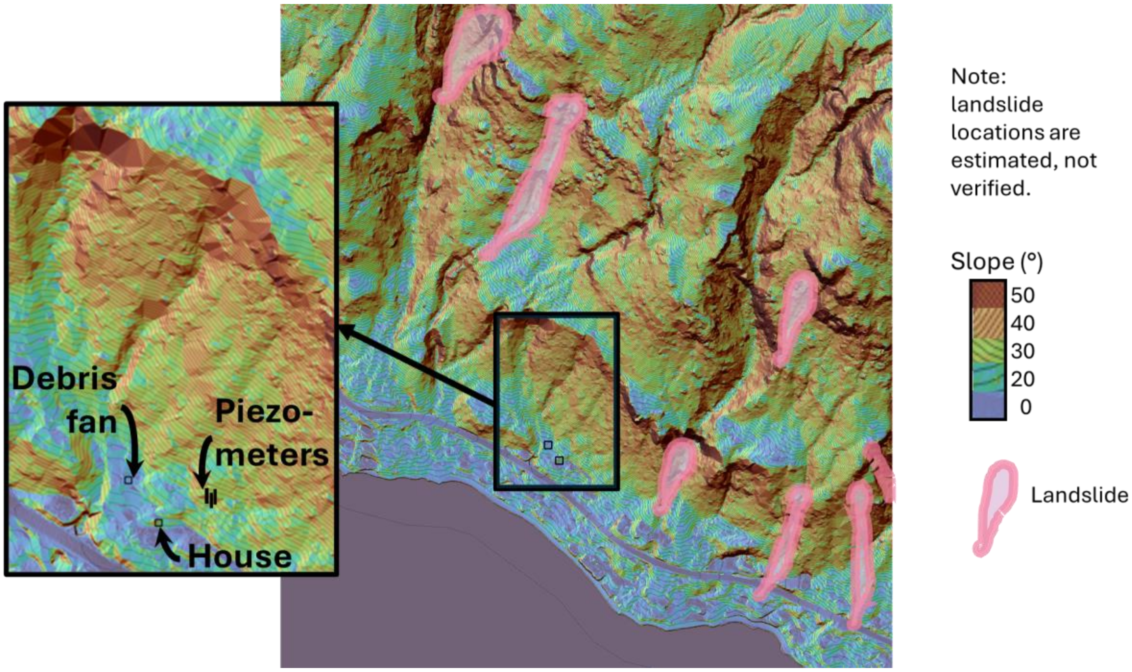

Figure 5. LiDAR coverage of a portion of Saint Nicholas Road at the base of Sunnahae Mountain indicating approximate locations of landslides and an inset map with piezometer locations (Note: LiDAR coverage from Department of Geological & Geophysical Surveys).

The handmade pipes were constructed of one-inch PVC pipe. The pipes were about 1.0 m long originally and were cut down once soil depth was known. The bottom 10 cm of each piezometer were drilled with 4 mm holes (about 50 holes) and surrounded by Teflon screen (glued on) and caps were glued on the bottom. Ground cork was inserted into one-half inch acrylic tubes that were inserted into the PVC pipes. A loose cap was placed on top of each piezometer. Given increases in soil saturation, water moved up from the bottom of piezometer the cork floated higher in the acrylic tube leaving a ring that could be read to determine maximum soil-water height. This method was used previously with community volunteers in three locations including Prince of Wales, Sitka, and Kupreanof Island to assess ground saturation on landslide prone terrain along using the equations: $p = h \cos^2 \alpha$ and $M = h/Z$. Here p is the height of the cork, α is slope, Z is soil depth, and M is maximum degree of soil saturation (Johnson and Wilcock 2002).

2.3 Youth Engagement

A plan for field work with the Alaska Youth Stewards program was facilitated through meetings with three professional educators at the Sitka Sound Science Center (Sarah Tobey, Zofia Danielson, and Janet Clarke) in the spring and early summer of 2024. This Alaska Youth Steward engagement process involved six steps: (1) discussion of slope stability fundamentals, including slope gradient, landform, hydrologic input, soil depth, and impervious layers below the soil, including rock and glacial deposits (till). Key features associated with identification of unstable slopes were also discussed including cracks in roads, pistol butted trees (recurved), jack-strawed trees (trees tilted in various directions) (British Columbia, Ministry of Forests 1999), (2) discussion of how landslides have historically affected community members by blocking roads and island power supply, affected subsistence resources such as salmon habitats; (3) training for skills with tools including rain gauges, clinometers, compasses, piezometers, (4) practice using field forms and Forest Service Landform Guide to document characteristics and assess road effects on site hydrology (See Supplemental Information for the form used), (5) assistance installing rain gauges and piezometers, (6) training on data acquisition and discussion of precipitation and rainfall measurement.

Along with work with the Klawock Alaska Youth Stewards program, additional classroom lectures and field work were conducted with Craig High School and Klawock Middle School at the beginning and end of the 2025 school year. These engagements summarized work that was conducted during the summer and enabled discussions with community members, including high school science instructors who live on the Port Saint Nicholas Road.

2.4 Developing Tools to enhance public safety

Local knowledge gathered in community engagements was summarized to provide background for developing scientific tools, including: (1) Online tools to promote community safety and landslide understanding. (2) Plans for development of products, including an early warning system like in Sitka, Alaska (Sitka Science Center 2022); creation of predicted landslide runout paths; sharing construction, slope, and runoff maintenance guidelines; and sharing available information on landslide impacts on fisheries. (3) Possible use of this strategy to assess microclimate impacts in other Southeast Alaska communities with Alaska Youth Stewards.

Summarized project results include four key interacting themes: (1) key community meeting topics including interconnectivity of communities, climate change impacts, land use history, communication, partnerships, and education; (2) instrumentation to assess differences in rainfall and soil saturation depending upon location, (3) Alaska Youth Stewards involvement and workforce development, and (4) means to enhance public awareness and safety including brochures, refrigerator magnets, and online tools.

3 Results

3.1 Community meetings

The comments from 13 meetings conducted in the four communities of Craig, Klawock, Hydaburg, and Kasaan the week of June 17th to 21st 2024 fell under five main themes: (1) Interconnected communities, (2) climate change and weather recognition, (3) landslide occurrence in association with landscape and land use recognition, (4) communication, (5) partnerships, and (6) education and workforce development (see Appendix C for a summary of meeting notes).

(1) Interconnected communities**:** Communities are inter-dependent, inter-connected and inter-reliant on a road system that is vulnerable to landslides. During the meetings, the majority of community members described a situation whereby a landslide greatly affected their transportation for hours and often longer. Key issues discussed in association with roads included: (a) issues associated with multiple ownership entities (USFS, State, municipalities, ANCSA) with responsibility for road maintenance often unclear (e.g., road clean up and culvert maintenance). (b) Power connection along the roads in areas of landslide activity (e.g., Black Bear Hydro Power, Figure 6). (c) Management activities such as forest harvest along roads (e.g., timber harvest). (d) The water supply line for the city of Craig, located under Port Saint Nicholas Road, is a residential area with chronic landslide activity. (e) Reduction in Forest Service roads due to closures and landslides result in reduced access to hunting and fishing areas. These impacts vary by community. Community members identified that local initiatives are well-equipped to facilitate regional support, given their understanding of the magnitude of local impacts. Food security is an issue due to road closures and the Forest Service roads that are being closed reduce the ability to hunt and gather rather than rely on access to grocery stores. Roads are being put in storage by USFS because of budget cuts (e.g., reduction of road funding from $1M to $480k in the last eight years and infrastructure built up during logging and now less supported.)

Figure 6. A Klawock Middle School field trip where students visited and discussed the November 2023 landslide (largely a rock fall) that knocked down power lines providing power to the island. Note: scale of landslide as indicated by the white car located in mid-right portion of photo. (photo A. Johnson).

(2) Climate change and weather recognition - Although differing opinions were expressed, the consensus among community members was that the intensity of storms is increasing leading to an increase in landslide occurrence. It was noted that as part of the Forest Service Participatory Science Grant engagement, rain gauges were installed in June 2024 at sea level (100 feet), 1000 feet, and 2,800 feet along Sunnahae Mountain to better understand rain distribution southeast of Craig. It was shared that the data was to be sent by cell to Synoptic Data, a database used by the NOAA National Weather Service Juneau Forecast Office to better predict atmospheric river events. Community observed changes in weather included decreases in snowpack, variable wind impacts, notable microclimates, with major rain events occurring that are not universally felt over the island. Considering the size of the island, recommendations were made for the placement of additional rain gauges to better understand the distribution of rainfall patterns.

Community members also discussed the timing of landslides that occurred when droughts were followed by heavy rainstorms. Two ideas about landslides following dry periods include:

(1) Possible soil shrinkage away from underlying rock occurring with droughts leading to increases subsurface tunnels where water could flow (e.g. Beven and Germann, 1982) and/or (2) occurrence of hydrophobic surface soil attributes following droughts leading to increased runoff in some contributing areas with higher volumes of water leading to landslide initiation sites.

(3) Landscape and land use history/management – Community members were interested in learning where landslides were likely to occur, where landslides were likely to flow and deposit, and implications of land management practices (forest harvest, road building) on landslide occurrence and landslide runout. Road closures, currently being implemented according to the Forest Service Road Access Travel and Management Plans, were developed for each district. It was clear that community members did not support the road closures given road use for harvesting, hunting, and recreation. Community members recognized the implications of forest harvest on landslide occurrence including changes in soil root cohesion, changes in drainage due to roads, possible hydrologic effects of remaining decayed logs, and implications of drainage ditches created by dragging logs. Specific changes in hydrologic contributing area associated with road building were documented at some sites in the field by the Alaska Youth Stewards program attendees. Further studies to ascertain forest harvesting impacts and effects of roads were discussed at meetings. Specifically, maps of predicted landslide runout paths were requested.

(4) Communication - Demographics of the island were discussed and was uncertain whether Native presence is growing in communities. In addition, the possible presence of non-Native older people was noted (e.g., more retirement homes on Port Saint Nicholas Road). Future work includes checking the census for answers to these questions.

(5) Partnerships - Tribal organizations and western governments agree that unified approaches are needed**.** While there is a lack of emergency management plans in most communities, one community (Craig) described an informal collaboration with the local Native Corporation to stage earth-moving equipment prior to the arrival of big storms. Such activities highlight potential contributions, partnerships, response measures, and unexplored opportunities such as multiple entity agreements to enhance road maintenance and landslide response.

6) Education and workforce development – Community suggestions include outreach and door-to-door information sharing to improve public safety. Social media sharing suggestions include the use of Facebook and newspaper articles for expansion of Ḵutí project objectives and communication of weather warnings. At meetings, the upcoming work with the Alaska Youth Stewards with Adelaide Johnson and Sitka Sound Science Center Educators Sarah Tobey and Zofia Danielson on July 16-18, 2024, was discussed and there was plenty of community enthusiasm. It was clear that the planned field work including learning to identify slope stability features, impacts of roads on hydrology and stability, along with the use, and maintenance of rain gauges and piezometers was considered useful.

3.2 Measurements

3.2.1 Rain gauge measurements

Data from three rain gauges, now online, is being used by the NOAA National Weather Service Juneau Forecasting Office to improve forecasting (Synoptic Data, https://viewer.synopticdata.com/map/data/202504291845/volt?layers=#map=11.24/55.4261/-132.979&networks=293).

The total cumulative rainfall from the end of June 26 to October 9, 2024, was 56.24 cm (22.14 in), 73.73 (29.03 in), 29.69 (11.69 in), respectively for low, medium, and high rain gauge sites (Figure 7). Overall, the mean cumulative rain at the medium elevation 305 m (1000 ft) was 39% more rain than the low elevation 30.5 m (100 ft.) site for the time period of measurement. This information is now being received by the United States National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), Juneau Forecast Office. An additional project result was engagement with Jess Isaacs, the new Craig Community Connector and Cultural Coordinator,

The OSU 152 m (500-ft) elevation weather station indicates a similar amount of cumulative rain falling at 305 m (1000 ft). Comparisons of OSU rainfall with the other locations were difficult because the OSU data needed to be downloaded manually and was collected at different time increments.

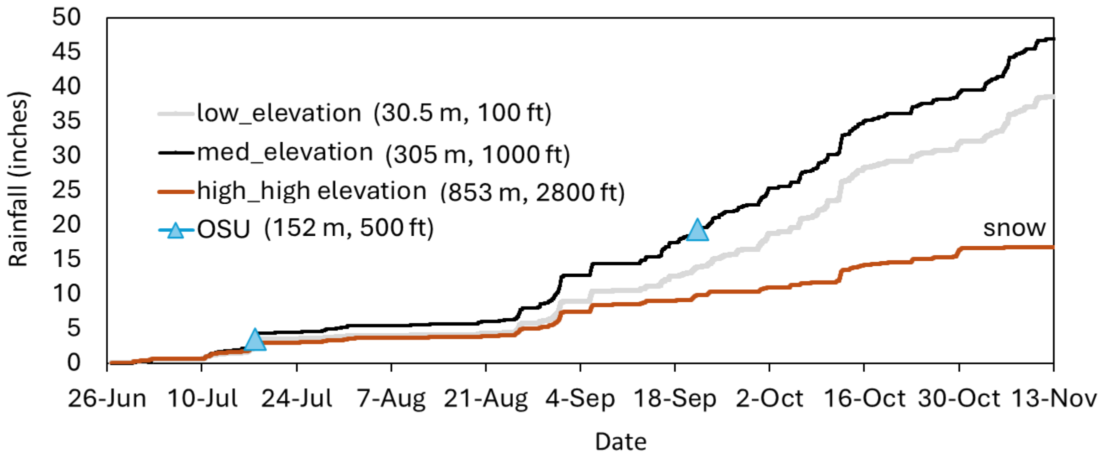

Figure 7. Comparison of cumulative precipitation from three rain gauges on Sunnahae Mountain near Craig, Alaska.

3.2.2 Piezometer measurements

Piezometers indicated that the toe slope on Port Saint Nicholous Road was consistently more saturated than the mid-valley and high slope locations following rainstorms (Figure 8).

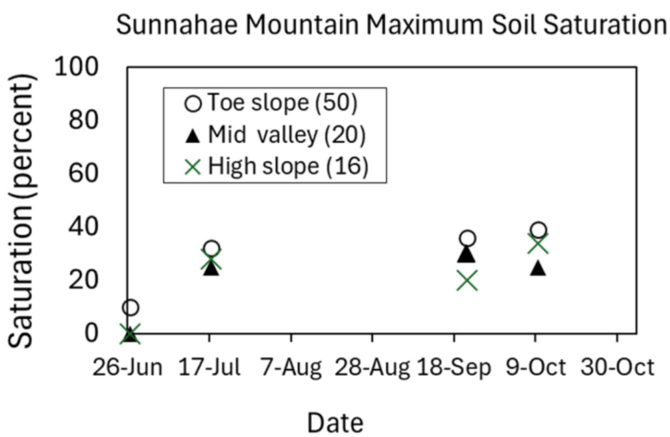

Figure 8. Comparison of maximum soil saturation calculated from piezometers.

3.3 Create Opportunities with Local Youth

Relevant local experiences with the Alaska Youth Stewards program helped to foster greater public safety and build workforce development. Fieldwork, training, and classroom discussions resulted in at least six youth opportunities including: (1) Training to identify slope stability features and learn how landslides can affect roads and island power supply, (2) Acquiring skills with tools including clinometers and compasses, (3) Practicing using field forms, using the Forest Service Landform Guide, making descriptions of slope characteristics, assessing road effects on site hydrology, (4) Helping install rain gauges and piezometers (Figure 9), and (5) measuring, downloading, and discussing cumulative precipitation.

Figure 9. Tia Christopherson, Alaska Youth Steward program participant and a life-long Prince of Wales Island resident, shows a rim of cork indicating maximum height of soil water following a rainstorm (photo: A. Johnson).

3.4 Developing Tools to Enhance Prediction and Community Resilience

Study results include plans to interconnect geophysical and human systems to include local perspectives on the transfer of technical data about landslide occurrence to communities to support resilience. Plans for tool development include: (1) On-line tools to share causes of landslides, historic landslide maps, what to look for, and make emergency plans (Wilcox et al., in prep, Figure 10). (4) Development of an early warning system like Sitka, Alaska's (Sitka Sound Science Center 2022). (3) Plans for development of landslide initiation and runout maps through the University of Oregon with verification by the Alaska Youth Stewards program. (4) Plans for possible use of this strategy in other Southeast AK communities with possible involvement with the Alaska Youth Stewards program.

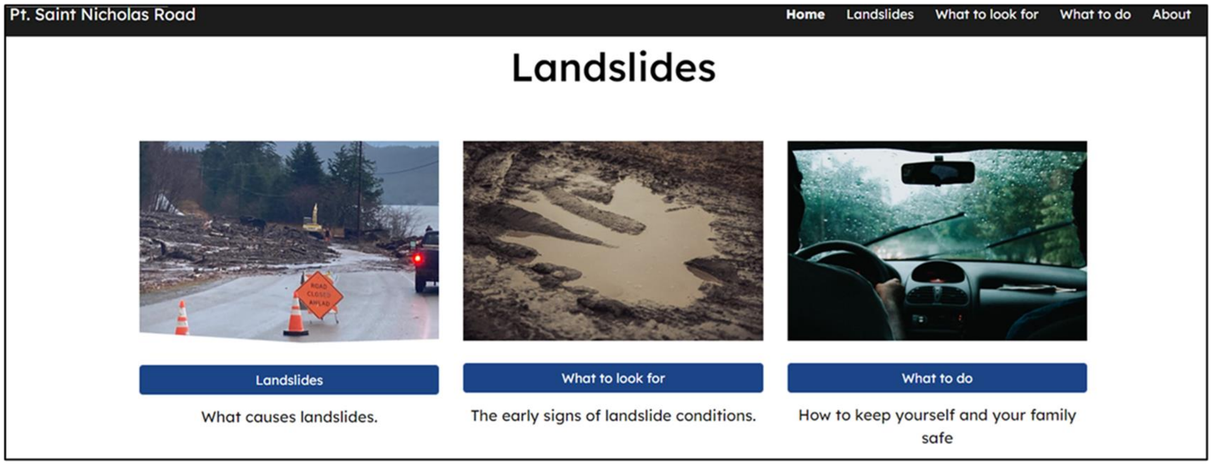

Figure 10. An on-line tool to promote public safety in landslide prone terrain (Wilcox, in preparation)

3.5 Protocol

Our engagement with community members, installment of scientific equipment, work with youth organizations, and recommendations of tools for enhancing safety serve as basis for a protocol for community engagement that can be applied elsewhere. The protocol summary includes a four-step co-designed process of engagement and research with process including: (1) community gatherings, (2) improving rain predictions with local measurements, (3) creation of youth opportunities, and (4) building community tools (Figure 11).

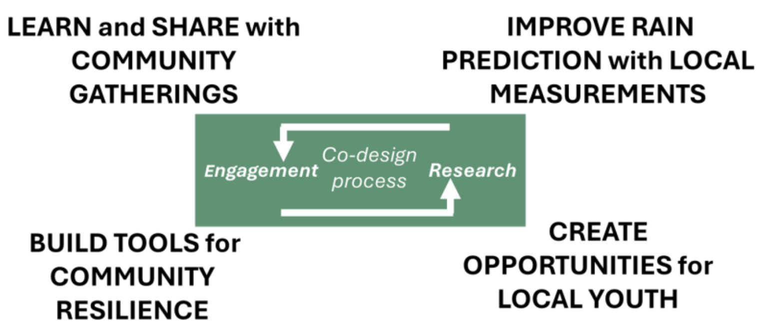

Figure 11. An interactive approach to conduct research while engaging community members enhances public awareness and safety.

3.5.1 Community Engagement, Repeat Interactive Cycle

Our interactive community participatory approach to engage and enhance community safety continues by sharing results and cycling back. Initial results were shared online with community members and at the American Geophysical Union Conference December 13, 2024 (Johnson, 2024). Continuation of the community engagement process is facilitated with Community Connectors partnerships in Craig and Kasaan. There are key components for project continuation through communication of research findings, use and strengthening of rain prediction measurements, expansion of youth opportunities (AYS future work in POW and outreach in other communities), and continuing to co-design relevant tools to enhance community understanding of geohazards to increase community resilience.

4 Discussion

To increase resilience in an area regularly impacted by landslides, this study engaged a wide array of community members including support services, environmental leaders, teachers, students, elders, and Native artisans who depend on forest resources. Further, the project fostered relevant workforce development by enlisting the existing Alaska Youth Stewards program (high school students and recent graduates) to aid in the collection of precipitation and ground saturation measurements. We learned that keeping people informed and safe in landslide-prone terrain is facilitated through a collaborative approach requiring partnerships, funding, educational outreach opportunities, and adaptation to new information.

This K̲utí-related participatory science geohazards project both supports and was benefitted by other geohazard research in Southeast Alaska and throughout the world. The on-going K̲utí projects in Yakutat, Hoonah, Haines, Skagway, and Klukwan foster place-based strategies involving meetings and relevant tools and gaining interest in youth engagement and involvement of communities in making relevant measurements. Researchers and community members in Puerto Rico, with over 100 times the population and three times the size Prince of Wales Island (>3 million versus approximately 6,000 people, respectively; Wordometer 2025), have installed an observational network and determined that landslide densities tended to be exponentially higher in areas with the highest rainfall totals, sites with igneous intrusive and other non-limestone sedimentary geologic terranes, with maximum densities occurring on relatively moderate slopes of 35–50% (24–27°), and not on the steepest hillslopes (Ramos-Scharrón et al. 2022). At these Puerto Rico sites, community members are made safer through communication networks (Hughes and Torres 2025). The rainfall measurements collected, like those in Puerto Rico, indicate occurrence of landslides occur at higher elevations with higher levels of precipitation, but in contrast, Prince of Wales Island landslides initiate on some of the steepest slopes 47–143% (25–55°, mean slope 72%, 36°) (Johnson et al. 2000) at sites generally high above transportation corridors within multiple community jurisdictions. Being in multiple jurisdictions complicates interagency communication and the road cleanup process. In Nepal, social science was used to determine that local adaptation and mitigation practices included demographic shifts and patterns, land use changes, and occupational diversification indicating how people living in landslide sites have the potential to build on local knowledge base and strengthen their adaptive capacities (Cieslik et al., 2019). In this study, the community meetings, measurements, youth engagement, and tool development provide information to enhance the next cycle of community engagements to furthering community resilience capacity.

4.1 Community meetings

Our meetings in the various Prince of Wales Island communities were conducted in a range of venues and the demographics of attendees was also highly variable. Being introduced by locally known community leaders enhanced the level of community input and fostered trust. Meeting attendance and level of engagement depended, at least partially, on previously committed seasonal subsistence-related activities. The use of promotions, such as raffles, provided additional incentives for community participation. The concerns and priorities raised by participants varied by factors including degree of urbanization, positions people held, length of time in the community, and whether community members had children.

4.2 Local measurements

One benefit of this project was the observation of differences in cumulative rainfall along an elevation gradient highlighting strong orographic rainfall. The high elevation alpine site (2800 feet), having high winds, was expected to have the most rain, but was found to have less rain than the 1000 and 100 ft sites. These measurements and continued rain gauge data submission, support NOAA National Weather Service Juneau, Alaska Forecast Office's efforts, especially because by far, most rain gauges are at sea level. Given the need for microclimate research in other locations discussed previously (Nash et al., 2024), future plans will include installation of a rain gauge at 1,500 feet in a less windy location. Considering local knowledge of risks and issues, it is recommended that future work includes information on landslide density by location, landform, and land use.

The chosen community connector in Craig, along with coordinating meetings, will help to maintain rain gauges and piezometers, send field information collected from piezometers, and help by giving updates on local weather. In Kasaan, students at the high school have shown an interest in helping to install and maintain a rain gauge in their community.

4.3 Youth Engagement

Community members at all meetings were supportive of engaging young people to gain an understanding of issues of local importance, foster workforce development opportunities, and facilitate interest in forest-related careers. The Alaska Youth Stewards program provides an excellent option for study expansion. For example, given community interest in understanding landslide initiation and runout, the Alaska Youth Steward program will verify a landslide model currently being developed by Nicolas Mathews in the summer of 2024.

Through this youth engagement work, it was learned that it was important to schedule the Alaska Youth Stewards program early in the season and provide opportunities for local youth to get involved in all aspects of the four-step protocol. Such participation in local activities provides a basis for involving student information sharing at community meetings and provides students to present at local environmental conferences. In this way, students have opportunities to become local community ambassadors.

4.4 Development of Tools

Prince of Wales Island rainfall collection (3 gauges, 5 total by summer 2025), support the NOAA National Weather Station Forecast Office in Juneau along with on-going atmospheric river research (Deanna Nash). The Kuti team is addressing community interest in a landslide early warning system by analyzing high-resolution weather research models in conjunction with a new landslide inventory that includes constraints on the timing of slope instability. Preliminary results suggest that landslides can be triggered via intense, short (several hr) duration rainfall events as well as long duration (1 to 2 day) storms with slightly lower intensity. By combining these statistical analyses with NWS forecasts that generate rainfall predictions up to 3 days in the future, we anticipate being able to provide actionable information and warning levels that are tailored to specific locations on Prince of Wales.

This summer, potential relationships of landslides with road impacts are planned (facilitated by Alaska Youth Stewards activities) by using detailed maps to facilitate community road cleanup efforts. This summer, as recommended by community members, information packets will be hand-delivered to all residents along Port Saint Nicholas Road. Information will include a general safety message, poster for summer community meetings, and links for people to access further information.

4.5 Future Work Needed

Future work, facilitated by Luka Silva, K̲utí project manager, including a mix of community knowledge, physical science, and social science, will be synthesized to develop an on-line tool for community members that will give landslide background, indicators of instability, and a method on making emergency plans (Wilcox et al., in preparation), along with development of a model to predict landslide runout (K̲utí post-doc work for summer 2025, possible comparison with previous work, Miller, 2021), development of an early warning system, and recommendations for construction and maintenance. Like elsewhere, Prince of Wales Island community members can aim to minimize landslide risk by adhering to recommended safety actions. Safety practices include better understanding of landslide susceptibility, including the likely impacts of abandoned old forest harvesting roads on slope hydrology. In addition, better understanding of the likely debris flow pathways is needed to assess possible impacts to houses, roads, and other infrastructure (e.g., USGS, on- line story map tool, accessed 1/10/2024, listed in references, see reducing risk) as follows:

(1) Is your location in a potential flow pathway? (*Note: this information is currently planned for Prince of Wales Island in the summer of 2025, Nicolas Mathews, in preparation*)
If yes, follow construction, slope, and runoff guidance, AND have an emergency plan. If no, follow guidelines for slope and runoff maintenance.
(2) Is your location in a high or moderate landslide susceptibility zone? (*Note: this information is currently planned for Prince of Wales Island in the summer of 2025, Nicolas Mathews, in preparation*)
If yes, follow construction, slope, and runoff guidance, AND have an emergency plan. If no, follow guidelines for slope and runoff maintenance.
(3) Is your location in or near a landslide deposit? (*Note: this information is currently planned for Prince of Wales Island in the summer of 2025, Nicolas Mathews, in preparation*)

If yes, follow construction, slope, and runoff guidance, AND have an emergency plan. If no, follow guidelines for slope and runoff maintenance.

Priority needs for Prince of Wales Island's future research include drafting maps of potential debris flow pathways and maps of landslide deposits along with providing guidelines for slope and runoff maintenance. In addition, construction guidance for new dwellings is suggested. These objectives can involve further work with communities, including the Alaska Youth Stewards program.

Construction Guidance (USGS, online story map tool, https://experience.arcgis.com/experience/b55c8497d115400aa09d9cb7a27f5dc8/page/Home/ accessed 10/1/2024).

a. Avoid building near steep slopes, close to mountain edges, near drainage ways, and along natural erosion valleys. Contact a qualified geologist or engineer before building.
b. Seat foundations on stable soil or rock materials in accordance with building codes (e.g., not on unstable or uncompacted soil).
c. Construct cut/fill slopes and nearby drainage measures properly, preferably with the help of a geotechnical engineer. Ensure that downspouts do not flow onto fill slopes.
d. Contact a qualified, licensed geologist or engineer to determine if a slope is stable, especially if the following are observed:
    - Cracks along driveway edges, fill slope tops, retaining walls, or foundations.
    - Bending/leaning of deck posts, tension cracks where the land pulls away from a hillside.
    - Trees growing at bent angles (pistol-butted trees),
    - Damage from past landslides.

Runoff and Slope Maintenance (USGS, online story map tool, accessed 10/1/2024).

a. Help stabilize slopes by preventing erosion using straw and wood chips to hold soil in place and by supporting natural vegetation and mature trees.
b. Ensure that water flows in natural drainages and does not back up behind culverts and ponds, in ditches, or flow onto fill slopes.
c. Make sure house downspouts do not flow onto any fill slopes.

d. Minimize slope instability by managing surface water runoff: note increasing flow over soil-covered slopes and where runoff converges.

5 Conclusion

Through the project's scientific engagement initiatives, community participants shared perspectives and contributed to research that allowed the team to come to three key takeaways: (1) coproduced community science fostering community resilience is iterative, supported by trust-building activities including potluck dinners and youth engagements, (2) although many aspects of landslides remain unknown and cannot be predicted at time scales deemed useful, areas prone to landslides should be delineated, storms associated with landslide occurrence should be determined, warning systems should be developed, and plans should be made in advance to help clean up and prepare, and (3) community member safety is considered personal – with varying levels of concern and fear regarding safety and various levels of concern regarding possible changes in the value of land and property. In summary, both understanding and managing landslide-prone terrain is difficult considering that it requires evaluation of multiple fields including science, philosophy, and psychology (Benda, 2023).

A team consisting of community members, educators, and youth leaders worked with visiting physical, biological and social scientists to build resilience in Southeast Alaskan communities facing increasing landslide impacts. We learned that all community members were influenced by landslides, especially impacts due to road closures and loss of power. A protocol for community engagement was built using a four-step process including meetings, measurements, youth engagements, and development of tools to support community resilience. The protocol is currently being used to continue community engagements and refine the process to facilitate greater attempts at coproduction. It is important to emphasize that the protocol is iterative in nature. Relationships between community members and scientists must be built by frequent interaction under formal and informal circumstances. Measurements of rain indicated significant differences in rainfall by elevation, information that can be used to enhance weather forecasting and warning systems. By using the protocol presented in this report, co-designed community research to engage communities can be enhanced to support increased public safety. Moreover, acceptance of the work depends on the community's support. We found that trust and community interest in the project increased with the amount of time spent on Prince of Wales Island.

Participants who engaged in project activities not only allowed for sound research, but importantly, supported community cultural health and sustainability by advancing the practice of giving back and enhancing "the path to reciprocity" (Kimmerer 2012). Future work efforts by the Ḵutí team in the summer of 2025 will increase restorative action by planting cedar seedlings, a practice suggested by community members previously (Johnson et al., 2021). Finally, given the importance of salmon, it is suggested that available databases on landslide impacts on anadromous fish channels on Prince of Wales Island be utilized to help support possible restoration actions (TerrainWorks, 2021, note application to Prince of Wales is about 2/3 of the way through a story map https://arcg.is/CazaG) to better understand the interplay of sediment, wood, and fish (Carlson, 2024; Benda, 2023).

Acknowledgements

Funding for this study was supported by a National Science Foundation grant (#2052972) and from a USDA Forest Service National Participatory Science Grant. Additional support was provided by the Sealaska Corporation for two class engagements at Craig High School and two days of field work with the Klawock Middle and High School organized by Robert Girt and Gary Lawton. We appreciate the Alaska Youth Stewards program interest and coordination facilitated by Robert Girt, Cheyenne Thompson, and Gabrielle Sjoberg. We are thankful for the initial written project support from the Craig Tribal Association and the Organized Village of Kasaan, indicating interest in collaborating on this geohazard project to facilitate community safety and continued involvement. Thanks to GIS specialists Michael Waylen, US Forest Service, and Khrystl Brouillette, Southeast Watershed Coalition for the creation of maps used in community meetings. We are grateful to Malcolm Cross, US Forest Service Hydrologist to a "Frank," a US Forest Service volunteer, for assistance with field logistics and to the USDA Forest Service for bunkhouse space and vehicle use during portions of our time on Prince of Wales Island. The paper was enhanced by discussions and reviews by Nicolas Mathews, Deanna Nash, Kenneth Weitzel, James Refuerzo, and three Community Science reviewers.

Data Availability Statement

Datasets used for this research are available through the Sitka Sound Science Center at: https://www.kutiproject.org/materials/publications/publication-data-statements.

References

Alaska Public Media, 2023. Storm that hit Wrangell brought wider Southeast Alaska damage, (accessed online November 2024)

Atlas, W.I., Ban, N.C., Moore, J.W., Tuohy, A.M., Greening, S., Reid, A.J., Morven, N., White, E., Housty, W.G., Housty, J.A. and Service, C.N., 2021. Indigenous systems of management for culturally and ecologically resilient Pacific salmon (Oncorhynchus spp.) fisheries. *BioScience*, *71*(2), pp.186-204.Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK (2014) Next steps for citizen science. Science 343(6178):1436–1437.

Benda, L. 2023. The Watershed Three-Body Problem, A Natural History Terra Incognita Where Science, Philosophy, and Psychology Collide and Fuse into a New Spectrum. ISBN: 979-8-9885051-0-5. 273pp.

Beven, K., and Germann, P. 1982. Macropores and Water Flow in Soils. *Water Resources Research* 18, no. 5: 1311–25. https://doi.org/10.1029/WR018i005p01311.

Bonney R, Shirk JL, Phillips TB, Wiggins A, Ballard HL, Miller-Rushing AJ, Parrish JK (2014) Next steps for citizen science. Science 343(6178):1436–1437

Booth, A.M., Buma, B. and Nagorski, S., 2023. Effects of Landslides on Terrestrial Carbon Stocks with a Coupled Geomorphic-Biologic Model: Southeast Alaska, United States. *Journal of Geophysical Research: Biogeosciences*, *128*(6).

Bryant, M.D., Gomi, T. and Piccolo, J.J., 2007. Structures linking physical and biological processes in headwater streams of the Maybeso Watershed, southeast Alaska. *Forest Science*, *53*(2), pp.371-383.

British Columbia. Ministry of Forests. 1999. Hazard assessment keys for evaluating site sensitivity to soil degrading processes guidebook. 2nd ed., Version 2.1. For. Prac. Br., B.C. Min. For., Victoria, B.C. Forest Practices Code of British Columbia Guidebook.

Carlson, L.D., 2024. Estimating full potential and protected potential large wood recruitment to fish-bearing streams attributable to stream-adjacent and debris flow sources in the Oregon Coast Range.

Cieslik, K., Shakya, P., Uprety, M., Dewulf, A., Russell, C., Clark, J., Dhital, M.R. and Dhakal, A., 2019. Building resilience to chronic landslide hazard through citizen science. *Frontiers in Earth Science*, *7*, p.278.

Deal, R.L. and Orlikowska, E.H., 2002. Development of mixed red alder-conifer stands in southeast Alaska. *UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE GENERAL TECHNICAL REPORT PNW*, pp.127-134.

Geertsema, M., Highland, L. and Vaugeouis, L., 2009. Environmental impact of landslides. *Landslides–disaster risk reduction*, pp.589-607.Geertsema, M. and Pojar, J.J., 2007. Influence of landslides on biophysical diversity—a perspective from British Columbia. *Geomorphology*, *89*(1-2), pp.55-69.

Gehrels, G.E. and Berg, H.C., 1992, Geologic map of southeastern Alaska: US Geological Survey Miscellaneous Investigations Series Map I-1867.

Harris, A. S., Hutchinson, O. K., Meehan, W. R., Swanston, D. N., Helmers, A. E., Hindee, J. C., & Collins, T. M., 1974, 1. The Setting. In The Forest ecosystem of southeast Alaska. Portland, OR: Pacific Northwest Forest and Range Experiment Station.

Hennon, P. E. and Shaw, C. G. 111. 1997. The enigma of yellow-cedar decline: what is killing these long-lived, defensive trees? J. For. 95:4-10.

Hughes, S. and Torres, I. C. 2025. Puerto Rico Landslide Mitigation Office, 03.27.25 - Puerto Rico Landslide Hazard Mitigation Office: Stephen Hughes and Isabella Cámara Torres on-line recording accessed, March 2025).

Johnson, A.C., P. Wilcock, 2002, Association between cedar decline and hillslope stability in mountainous regions of southeast Alaska, *Journal of Geomorphology*. 46: 129-142.

Johnson, A.C., Swanston, D.N. and McGee, K.E., 2000. LANDSLIDE INITIATION, RUNOUT, AND DEPOSITION WITHIN CLEARCUTS AND OLD-GROWTH FORESTS OF ALASKA 1. *JAWRA Journal of the American Water Resources Association*, *36*(1), pp.17-30.

Johnson, A., Clavijo, A., Hamar, G., Head, D.-A., Thoms, A., Price, W., Lapke, A., Crotteau, J., Cerveny, L., Hailey Wilmer, H., Petershoare, L., Cook, A., and Reid, S. 2021, Wood Products for Cultural Uses: Sustaining Native Resilience and Vital Lifeways in Southeast Alaska, USA. *Forests*, 12:90.

Johnson, A., Roering, J., Prussian, K., Wilcox, P., Heintz, R., Pierce, L., Tobey, S., Danielson, Z. Udall, C. Aboudara, Q., Thoms, O'Neil, S., Jacobs, A. 2024, American Geophysical Union Conference Abstract ID-1615790

Kapp, A., 2018. The Central Council of the Tlingit & Haida Indian Tribes of Alaska, August, 2019. Climate Change Program. *Institute for Tribal Environmental Professionals,* *Northern Arizona University. Available at: www7. nau. edu/itep/main/tcc/Tribes/ak_tlingit*.

Kimmerer, R. W. (2012). Searching for synergy: Integrating traditional and scientific ecological knowledge in environmental science education. Journal of Environmental Studies and Sciences, 2(4), 317–323.

Landwehr, D., unpublished report. USDA Forest Service, Ketchikan, Alaska.

Martin, D.J. and Shelly, A., 2017. Temporal trends in stream habitat on managed forestlands in coastal Southeast Alaska. *North American Journal of Fisheries Management*, *37*(4), pp.882-902.

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., CookPatton, S. C., et al. 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. Biol. Conserv. 208, 15–28.

Mercer, J., Kelman, I., Taranis, L., and Suchet-Pearson, S. (2010). Framework for integrating indigenous and scientific knowledge for disaster risk reduction. Disasters 34, 214–239. doi: 10.1111/j.1467-7717.2009.01126.x

Miller, D. 2021. Landslide initiation susceptibility, Prince of Wales Island, unpublished report accessed through, TerrainWorks story map https://terrainworks.sharefile.com/share/view/sa3c59824b9344558aec3925b34aedf0c (accessed online March 2, 2025).

Newing, H., Brittain, S., Buchadas, A., del Giorgio, O., Grasham, C.F., Ferritto, R., Marquez, J.R.G., Khanyari, M., König, B., Kulkarni, A. and Murali, R., 2024. 'Participatory'conservation research involving indigenous peoples and local communities: Fourteen principles for good practice. *Biological Conservation*, *296*, p.110708.

Moos, Christine, Peter Bebi, Massimiliano Schwarz, Markus Stoffel, Karen Sudmeier-Rieux, and Luuk Dorren. "Ecosystem-based disaster risk reduction in mountains." *Earth-science reviews* 177 (2018): 497-513. (*THIS is not cited, but might be useful).*

Nash et al. 2024. Atmospheric Rivers in Alaska: J. Geophysical Research 29. https://doi.org/10.1029/2023JD039294

Nowacki, G.J., 1998. *The effects of wind disturbance on temperate rain forest structure and dynamics of southeast Alaska* (Vol. 421). US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Ramos-Scharrón, C.E., Arima, E.Y. and Hughes, K.S., 2022. An assessment of the spatial distribution of shallow landslides induced by Hurricane María in Puerto Rico. *Physical Geography*, *43*(2), pp.163-191.

Ratner, N.C., Brown, P., Rowan, J., Yates, D., Smith, M., Dizard, J.A., Paige, A. and Turek, M.F., 2006. Local Knowledge, customary practices, and harvest of sockeye salmon from the Klawock and Sarkar Rivers, Prince of Wales Island, Alaska. *Juneau: Alaska Department of Fish and Game, Division of Subsistence*.

Sharma, A.R. and Déry, S.J., 2020. Contribution of atmospheric rivers to annual, seasonal, and extreme precipitation across British Columbia and southeastern Alaska. *Journal of Geophysical Research: Atmospheres*, *125*(9).

Sitka Sound Science Center. 2022. Landslide Warning System. https://sitkascience.org/research-projects/landslide-research/landslide-warning-system/, accessed 10/11/2024.

Southeast Sustainable Partnership. https://sustainablesoutheast.net/, accessed 4/10/2025.

State of Alaska, Department of Natural Resources 2009, unpublished Alaska Department of Natural Resources recorded landslide expert panel discussions - needed

Swanston, D. N. and D. A. Marion, 1991. Landslide Response to Timber Harvest in Southeast Alaska. In: Proceedings of the Fifth Interagency Sedimentation Conference, Federal Energy Regulatory Commission, Las Vegas, Nevada.

TerrainWorks, 2021, Mapping Landslide and Debris Flow Risk in Southeast Alaska, Story Map https://arcg.is/CazaG, accessed online March 2025.

Vascik, B.A., Booth, A.M., Buma, B. and Berti, M., 2021. Estimated amounts and rates of carbon mobilized by landsliding in old-growth temperate forests of SE Alaska. *Journal of Geophysical Research: Biogeosciences*, *126*(11), p.e2021JG006321.

Walshe, R. A., and Nunn, P. D. (2012). Integration of indigenous knowledge and disaster risk reduction: a case study from baie martelli, pentecost Island, Vanuatu. Int. J. Disaster Risk Sci. 3, 185–194. doi: 10.1007/s13753-012-0019-x

Worldometers, 2025, https://www.worldometers.info/world-population/puerto-rico-population/#:~:text=Puerto%20Rico%202025%20population%20is%20estimated%20at%203%2C235%2C289,the%20list%20of%20countries%20%28and%20dependencies%29%20by%20population (accessed on line April 11, 2025)

"U.S. Climate Normals Quick Access – Station: Klawock AP, AK". National Oceanic and Atmospheric Administration. Retrieved March 7, 2023.

USGS, North Carolina Geological Survey, Landslides in Western North Carolina (https://experience.arcgis.com/experience/b55c8497d115400aa09d9cb7a27f5dc8/page/Home/,), accessed on-line 10/1/2024.

Yua, Ellam, Julie Raymond-Yakoubian, Raychelle Aluaq Daniel, and Carolina Behe. “A Framework for Co-Production of Knowledge in the Context of Arctic Research.” *Ecology and Society* 27, no. 1 (March 26, 2022). https://doi.org/10.5751/ES-12960-270134.

Supporting Information for

Participatory Science for Landslide Community Awareness: Development of a Protocol for Southeast Alaska

[1]A. Johnson, [2]J. Roering, [3]K. Prussian, [4]P. Wilcox, [5]R. Heintz, [6]L. Pierce, [7]D. Head, S. Tobey, [5]Z. Danielson, [8]C. Udell, [5]E. Neumann, [9]Q. Aboudara, [10]S. O'Neil, [11]A. Jacobs, [12]J. Isaacs, [13]A. Thoms, [5]L. Silva

[1]Community Collaborators, Juneau, Alaska, USA; [2]University of Oregon, Eugene, Oregon, USA; [3]USDA Forest Service Alaska Region, Sitka, Alaska, USA; [4]RAND Corporation, Anchorage, Alaska, USA; [5]Sitka Sound Science Center; [6]Central Council of the Tlingit and Haida Indian Tribes of Alaska, Juneau, Alaska, USA; [7]Tlingit and Haida Master Weaver, Craig, Alaska, USA; [8]Oregon State University, Corvallis, Oregon, USA; [9]Shaan Seet Corporation, Craig, Alaska, USA; [10]USDA Forest Service, Thorne Bay Ranger Station, Thorne Bay, Alaska, USA; [11]NOAA National Weather Service Forecast Office, Juneau, Alaska, USA; [12]Craig Tribal Association, Craig, Alaska, USA; [13] Sitka Conservation Society, Sitka, USA.

Contents of this file:

A. Summary of Community Meetings on Prince of Wales Island

Multiple themes:

1. Inter-connected communities: Communities are inter-dependent (interconnected and inter-reliant) with reliance on a road system that is vulnerable to landslides
    - Road system has multiple ownership entities: USFS, State, municipalities, ANCSA
        - Responsibility for road maintenance is often unclear (e.g., road clean up and culvert maintenance)

                - Power connection is primarily along the roads in area of landslide activity (e.g., Black Bear Hydro Power)
                - Management can be focused along roads (e.g., timber harvest)
                - Impacts vary by community
                    - Local knowledge of risks and issues are well known
                    - Future work could increase knowledge of landslide density by location, landform, and land use
                - Food security is an opportunity to bolster food reserves when access is an issue
                    - Local initiatives with some regional support
                - Roads being put in storage by USFS because of budget cuts (e.g., reduction of road funding from $1M to $480k in the last eight years.
                - Infrastructure built up during logging and now this infrastructure is less supported.
        - Other infrastructure
            - Water supply line for the city of Craig, located under Port Saint Nicholas Road, is a residential area with chronic landslide activity
2. Climate change and weather recognition. There are differing opinions, but the consensus is as follows:
    - Intensity of storms increasing (Note: as part of participatory Forest Service engagement, rain gauges were installed in June 2024 at sea level, 1000 feet, and 2,800 feet along Sunnahae Mountain to better understand rain distribution southeast of Craig. Data will be sent by cell to MesoWest, a database used by the NOAA Weather Station to better predict atmospheric river events).
    - Snowpack decreasing
    - Microclimates on the island, major rain events are not universally felt over the island.
    - Variable wind impacts
3. Landscape and land use history/management
    - Putting roads in storage, USFS budget reduction, nobody wants to see the road closures

    - Harvesting impacts on landslides: roots, drainage/roads, possible hydrologic effects of remaining logs, and drainage ditches created by dragging logs
4. Communication
    - Demographics of the island
        - Is Native presence growing in communities? Is the non-Native presence getting older (e.g., more retirement homes on Port Saint Nicholas Road?
    - Check the census
5. Partnerships
    - Tribal organizations and western governments agree that a unified approach is needed
    - Lack of emergency management plans in most communities
    - Opportunity for road maintenance and response
6. Education and workforce development suggestions include:
    - Outreach and door-to-door information sharing
    - Social media sharing suggestions include the use of Facebook and newspaper articles for the expansion of K̲utí project objectives and communication of weather warnings
    - Note: Alaska Youth Stewards will work with Adelaide Johnson and Sitka Sound Science Educators Sarah Tobey and Zofia Danielson July 16-18, 2024. Field exercises will include identification of unstable slopes, impacts of roads on hydrology and stability, and use and maintenance of rain gauges and piezometers.
7. Meeting dates and attendance
    - 17-June-2024
        - Hydaburg Cooperative Association
            - Tony Christenson, Mayor; Cody Karl, Environmental specialist; Gail Deblous, Tribal administrator on loan from Central Council of the Tlingit and Haida Tribes of Alaska
            - 1h30min
        - Klawock Cooperative Association
            - Ann Wyatt, Environmental Coordinator; Tylo Reynolds, Environmental Assistant; Jannelle, Tribal Administrator
            - 1h

- 18-June-2024
  - Interagency Landslide Working Group (online)
  - Klawock Senior Center
    - Deb Head introduction
    - James (Jimmy) Williams, Donna, Director of facility, Ernestine and several other elders.
  - Klawock potluck and raffle at Generations SE VoTech Center
    - James (Jimmy) Willams, Ann Wyatt, Kecia Weatherwaso, Wilfred Lane; Joe Yates, Central Council of the Tlingit and Haida Tribes of Alaska filming; Larry James; Michelle James; Meganne Clarke; approximately 30 AYS interns/leaders making about 50 participants total.
- 19-June-2024
  - Kasaan potluck event
    - Kris Kain, Mike Karr, Luke Breiniga (sp.?), Della Cobara, Rose Ruel, Tom Tonella, Heather Ruel, Jeane Brey, Mike Jones (Mayor, KaviCo), Stormy Hamer, Bonnie Hamer, Stephanie Hamer, Eric Hamer
- 20-June-204
  - Kassan City Hall
    - Carol Fletcher, OVK Environmental Coordinator; Diesel James, Environmental Assistant; Angela Jones, City Clerk; Della Coburn, OVK
  - Stormy Hamar and daughter, Stephanie. Tour of house/museum/carving shed
  - Craig City Hall
    - Brian Templin, City Manager; Casey, Major; Jess Isaacs, Craig Tribal Association Environmental Specialist
- 21-June-2024
  - Shaan Seet Corporation
    - Quinn Aboudara, Environmental Coordinator

- Deborah Head
    - Tour of personal museum and Port St Nick landslide impacts
- USDA Forest Service District office, Craig
    - Mark Pentecost, District Ranger; Skyler Oneil, Hydrology Technician; Hannah Harris, Fish Biologist; Bill Brown, Deputy Ranger; Malcolm Cross, Hydrologist
- Craig Fire Dept
    - Tim O'Connor, Fire Chief and former mayor, James England, Fire responder, EMT.

B. Alaska Youth Stewards field form

A portion of the field form used to document hillslope characteristics used by the Klawock Alaska Youth Stewards program (Form was improved by Sarah Tobey, Sitka Sound Science Center education team).

Slope Stability Assessment type (circle): mostly old growth mostly young growth mostly naturally disturbed

Team member names:

Date and weather conditions:

100 m transect start latitude, longitude, elevation:

Distance (ft)	Slope (%)	Aspect ()	Landform	Vegetation	Indications of instability	Soil moisture (%)	Soil characteristics

C. Rain gauge instrument set up

Rain gauge installation, cellular transmission of rain data, and community involvement included seven key steps:

(1) Formalize agency, partner agreements, and contracts, plan Alaska Youth Stewards (AYS) work program, receive partner matching funding, order equipment (see equipment specifications in following paragraph), and prepare field logistics including travel (March to May 2024).
(2) Prepare detailed topographic maps in collaboration with Forest Service specialists and Tribal partners to facilitate the choice of three precipitation measurement sites. Available Alaska Department of Natural Resources maps of landslide-prone areas were also compiled (April to June 2024).
(3) Install precipitation gauges and piezometers with Forest Service (Skylar O'Neil assistance) and Alaska Youth Stewards (June and July 2024, Figure 2), ensure that cellular data is being transmitted to forecasters within the NOAA's National Weather Service Forecast Office in Juneau, Alaska (Figure 3), engage with selected Community Connector to maintain/monitor rain gauges and piezometers during fall and winter months (no engagement until September 2024).
(4) Compile data, make graphs of cumulative rainfall over time and share project findings at high school and middle schools (September 2024, May 2025).
(5) Summarize protocol for precipitation measurements for review (review of this report, fall 2024; additional community input winter 2025).
(6) Share protocol, project results at conferences (American Geophysical Union Annual Meeting, December 2024 and Alaska Forum on the Environment, February 2025) and share results on Tribal webpages (spring 2025).
(7) Maintain network with project partners including the Alaska Youth Stewards and NOAA's National Weather Service Forecast Office in Juneau, Alaska (fall and winter 2024-25) to sustain/continue the project in other communities.

Since rain was being collected to improve weather forecasting capability, steps were required to set up initial data transmission, submit cellular data to the cloud, and transit data to the NOAA National Weather Service Forecast Office in Juneau, Alaska (Figure 3). In this case, data was sent to the LICOR cloud for Onset Hobo rain data and made available to NOAA's National Weather Service Forecast Office in Juneau, Alaska following five steps.

(1) In the office, organize the rain gauge equipment and read manufacturer's instructions, set up a username, password, and location that links to the serial number of the rain gauge.
(2) Set up instruments in the field by following manufacturer instructions and test data transmission. In this study, it was ensured data that was being transmitted at the rain gauge site by calling technicians at Onset Hobo (508-759-9500, extension-4, post-sale

help; extension-1, technician support). Expect to share the serial number for devices with the help desk.

(3) Once back in the office after ensuring that the data is being transmitted, begin the process of transferring (ingesting) data by a second party (in this case, Synoptic Data), a group that can share data with a local weather forecasting office. You may need help from the Onset Hobo staff to set this transfer up. By logging in to the LICOR.cloud account with your username and password, create an API Token. A Token is created by logging into LICOR.cloud, getting in Data, and selecting, ADD TOKEN. Once a token has been made, add the e-mail of the appropriate contact at Synoptic Data. Go into account, select user, and add the e-mail address. An invitation will be sent to your Synoptic Data contact (James Simkins: james.simkins@synopticdata.com). Connect with your contact to give the contact your username and login credentials. The Synoptic data contact will set up a connection to your data by writing the appropriate computer code.

(4) To confirm that data is being collected correctly over time, set up weekly transfers of data from LICOR.cloud to your own e-mail account. Hobo technicians can help set this up.

(5) Make graphs of data over time to evaluate trends that you can share with communities. This is an important step because it will help determine where additional rain gauges could be helpful.

D. Rain gauge purchase information

Specifications for all requirements for installation of non-heated rain gauges on Prince of Wales Island (quotes are from December 2024). Contact for purchasing and technical help is available Monday through Friday from 8am to 5 pm Eastern Time, 1-508-759-9500, https://www.onsetcomp.com/contact,

Product	***Description***	***Unit price***
S-RGA-M002, Rain Gauge (0.01") with 2m Cabl	Tipping bucket rain gauge	529.00
RX2102, HOBO MicroRX Station with solar	Control and energy supply	770.00
SP-812 BASIC, US 1 hr. 20 sensors	Cellular transmission within the United States	199.00
M-TPB-KIT, Complete 2M Tripod kit	Tripod, appropriate for fairly flat slopes, only	259.00
Hand level, screwdriver, wire cutter, extra cable, poles for mounting along with hose clamps and other materials for sites where the tripod kit does not work	Miscellaneous tools are needed	200.00 (approx.)

Specifications for all requirements for installation of the heated rain gauge on Prince of Wales Island (quotes are from March 2024). Contact for purchasing and technical help for the first two line items is Texas Electronics (214-631-2490) for the heated rain gauge components. Onset Hobo is the distributor for the remaining products, listed in Appendix A.

Product	***Description***	***Unit price***
TR-525-U-01-H gauge, 0.01" per tip, install heater Note: need to work with Hobo Onset technician to make sure that units are clarified on transmission	Tipping bucket rain gauge with installation of heater	567.53
HT-525 part that is installed in rain gauge	Heater, 525 series	424.64
RX2102, HOBO MicroRX Station with solar	Control and energy supply	770.00
SP-812 BASIC, US 1 hr. 20 sensors	Cellular transmission within the United States	199.00
S-UCD-M001, to be used with heated rain gauge	Pulse Input Adapter - Contact Closure	99.00
Cold weather extension cords, conduit for extension cords, hose clamps, and other tools	Miscellaneous parts for very cold set up	500.00 (approx.)