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Bear Encounters with Seismic Stations in Alaska and Northwestern Canada

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ABSTRACT

A typical seismic experiment involves installing 10–50 seismometers for 2–3 yr to record distant and local earthquakes, along with Earth's ambient noise wavefield. The choice of the region is governed by scientific questions that may be addressed with newly recorded seismic data. In most experiments, not all stations record data for the full expected duration. Data loss may arise from defective equipment, improperly installed equipment, vandalism or theft, inadequate power sources, environmental disruptions (e.g., snow covering solar panels and causing power outage), and many other reasons. In remote regions of Alaska and northwestern Canada, bears are a particular threat to seismic stations. Here, we document three recent projects (Southern Alaska Lithosphere and Mantle Observation Network, Fault Locations and Alaska Tectonics from Seismicity, and Mackenzie Mountains EarthScope Project) in which bears were regular visitors to remote seismic stations. For these projects, there were documented bear encounters at 56 out of 88 remote stations and 6 out of 85 nonremote stations. Considering bear-disrupted sites—such as dug-up cables or outages—there were 29 cases at remote stations and one case at nonremote stations. We also compile bear encounters with permanent stations within the Alaska Seismic Network, as well as stations of the Alaska Transportable Array. For these two networks, the stations are designed with fiberglass huts that house and protect equipment. Data losses at these networks because of bears are minor (<5%), though evidence suggests they are regularly visited by bears, and data disruptions are exclusively at remote stations. The primary goal of this study is to formally document the impacts of bears on seismic stations in Alaska and northwestern Canada. We propose that the threat of damage from bears to a station increases with the remoteness of the site and the density of bears, and it decreases with the strength and security of materials used. We suggest that low-power electric fences be considered for seismic stations—especially for temporary experiments—to protect the equipment and to protect the bears. With the goal of 100% data returns, future seismic experiments in remote regions of bear country should carefully consider the impacts of bears.

Supplemental Content: Evidence of bear encounters with seismic stations.

INTRODUCTION

Alaska is one of the world's most seismically active regions. Its southern tectonic boundary is marked by the subduction of the Pacific plate under the North American plate. Toward southeastern Alaska, the plate boundary is marked by the Queen Charlotte and Fairweather strike-slip fault system. Over the past 100 yr, nearly the entire plate boundary has ruptured over the course of dozens of earthquakes, including the 1964 M_w 9.2 Prince William Sound subduction earthquake, the 1979 M_w 7.4 Wrangell St. Elias thrust earthquake, and the 1949 M_s 8.1 Queen Charlotte strike-slip earthquake.

Mainland Alaska and northwestern Canada—far from the plate boundary—exhibit broad crustal deformation evidenced from differential surface velocities, seismicity, and active faults (Page *et al.*, 1991; Freymueller *et al.*, 2008; Koehler and Carver, 2018). The subsurface structure comprises accreted terranes and, at deeper levels, is dominated by the subducting Pacific plate, which flattens under south-central Alaska in response to collision of the Yakutat block (Eberhart-Phillips *et al.*, 2006; Christeson *et al.*, 2010).

Alaska has been a prime target for seismic experiments seeking to understand the structure and dynamics of subduction zones, starting with the Broadband Experiment Across the Alaska Range (BEAAR) in 1999–2001. This experiment, as well as those that followed (Table 1, Fig. 1), exploited the logistical advantage of Alaska's limited road system. Recent experiments, such as Southern Alaska Lithosphere and Mantle Observation Network (SALMON) and Fault Locations and Alaska Tectonics from Seismicity (FLATS), ventured into remote regions of Alaska.

Bears can be found nearly everywhere in mainland Alaska (Fig. 2). In this study, we document recent bear encounters with seismic stations in Alaska and northwestern Canada. Our approach is to document disruption at sites and to classify bear encounters. We augment this documentation with motion-triggered video recordings of animal activity at one site. Seismic experimental designs that had previously performed well along the Alaska road system were not adequate in remote regions, due to data losses caused by bears. Future seismic

 doi: 10.1785/0220190081

Table 1
Summary of Bear-Caused Data Outages at Seismic Networks in Alaska and Northwestern Canada

Seismic Network		Duration		Stations		Bear-Caused Station Outages				
		Start (yyyy/mm)	End (yyyy/mm)	R1/R2	R3/R4	R1/R2	R3/R4	Other Outages	Percent of Station Outages Due to Bears	
BEAAR	XE	1999/06	2001/09	37	0	–	–	–	–	–
ARCTIC	XR	2004/06	2007/09	16	0	–	–	–	–	–
MOOS	YV	2006/06	2009/09	28	6	–	>0	–	–	–
Yahtse	XF	2009/06	2011/09	0	11	0	1	–	–	–
FLATS	XV	2014/09	2019/09	4	9	0	1	3	25	–
SALMON	ZE	2015/05	2017/07	9	19	1	12	0	100	–
MMEP	7C	2015/08	2018/08	27	13	0	9	31	23	5.2
WVF	YG	2016/06	2018/06	35	0	0	0	–	–	–
Subtotal				156	58	1	23			
Alaska TA	TA	2015/01	2019/01	61	131	0	9	–	–	2.2
AEC	AK	2013/01	2019/01	59	75	0	12	–	–	4.5
NTWC	AT	2013/01	2019/01	14	1	1	0	–	–	–
Subtotal				134	207	1	21			
Total				290	265	2	44			

See Figure 1 for locations of stations. Classifications of site remoteness (R1 to R4) are listed in the Methods section. The number of outages can potentially exceed the number of stations, because a single station could have outages in multiple years. In the final column, the first percentage is the fraction of stations whose outages were caused by bears, and the second column is the fraction of total network data loss from bear-caused outages. For the permanent networks, station and outage numbers apply to the date range shown under duration. Dash indicates that information was not available. AEC, Alaska Earthquake Center; ARCTIC, Alaska Receiving Cross-Transects for the Inner Core; BEAAR, Broadband Experiment Across the Alaska Range; FLATS, Fault Locations and Alaska Tectonics from Seismicity; MMEP, Mackenzie Mountains EarthScope Project; MOOS, Multidisciplinary Observations Of Subduction; NTWC, National Tsunami Warning Center; SALMON, Southern Alaska Lithosphere and Mantle Observation Network; TA, Transportable Array; WVF, Wrangell Volcanic Field.

experiments in remote regions of Alaska and Canada will need a strategy for deterring bears and reducing data losses.

STUDY AREAS, SEISMIC NETWORKS, AND STATION DESIGN

Starting in 1999, Alaska has hosted several regional seismic experiments funded by the National Science Foundation, as well as the state-wide EarthScope Transportable Array (TA) (Fig. 1). The three permanent monitoring networks in Alaska are Alaska Seismic Network (AK), Alaska Volcano Observatory (AVO) seismic network (AV), and the National Tsunami Warning Center Alaska Seismic Network (AT). There are also isolated stations in mainland Alaska that are part of global (II.KDAK, IU.COLA) and national networks (US.EGAK, US.WRAK).

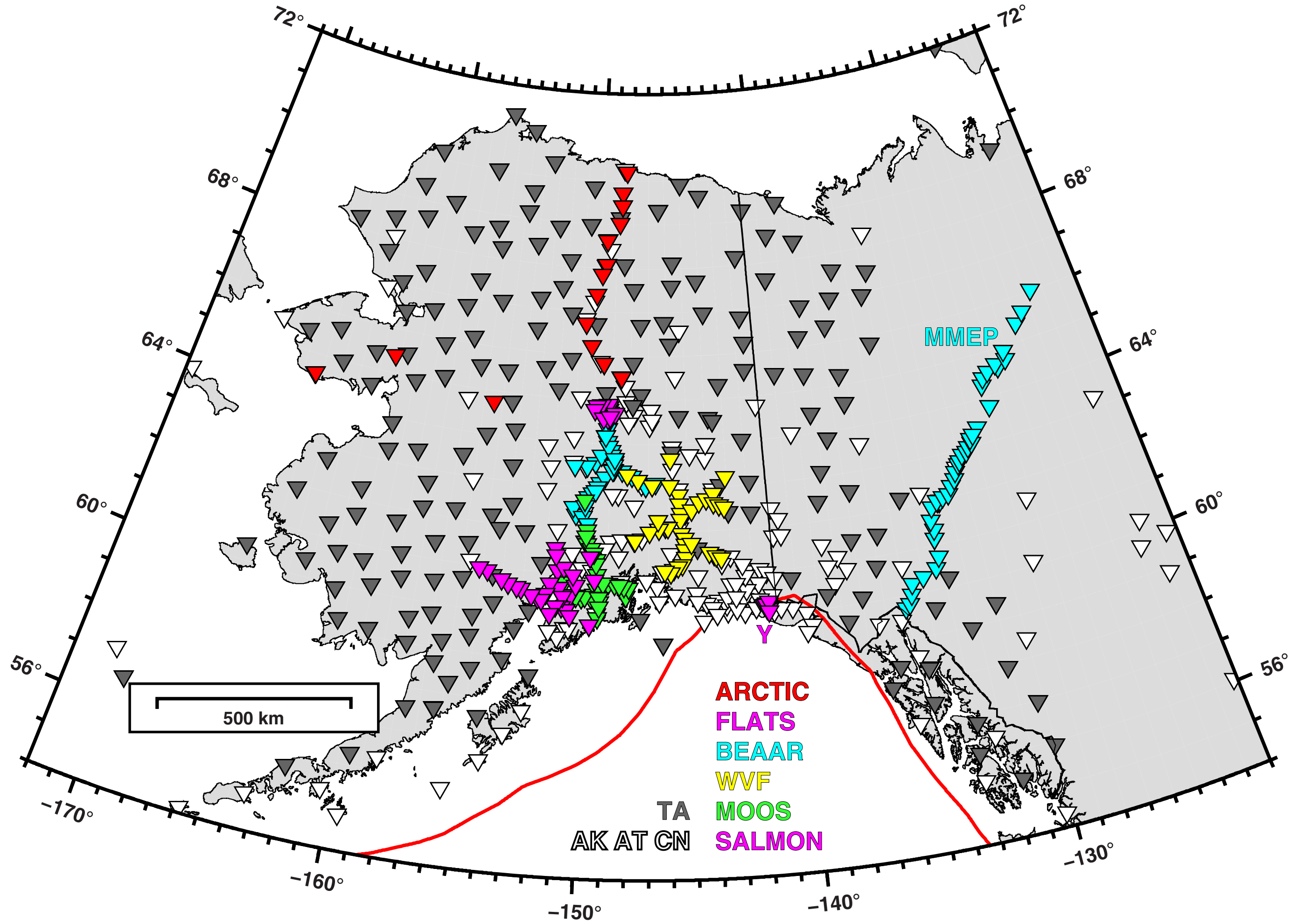
SALMON (ZE)

The SALMON experiment contained 28 stations in the Cook Inlet region of south-central Alaska. These stations required a range of approaches, including boat, float plane, all-terraine vehicle, and helicopter. The station design is described in Tape *et al.* (2017). Each station included a direct-burial Nanometrics T120 PH posthole sensor, powered by six Cegasa Celair 3V 1200 AH air alkaline batteries stored in a partially buried, 24 gal plastic box. No telemetry was used. The only adaptation following the first station servicing (in 2016) was to install all Global Positioning System (GPS) antennae inside the station box. In the first year, at least three GPS antenna cables (HLC1, HLC2, and BULG) were severed at sites where bears had caused station outages.

FLATS (XV)

The FLATS experiment contains 13 stations spanning the Minto Flats fault zone and Nenana basin, west of the town of Nenana in central Alaska (Tape, Silwal, *et al.*, 2015; Tape *et al.*, 2018). Most sites require boat access via the Tanana river.

The FLATS experiment started in the fall of 2014 with the installation of two stations, FPAP, adjacent to a house near Nenana, and F3TN, a site 20 km downriver from Nenana. Figure 3a shows a typical site for the FLATS experiment. The seismometer is directly buried and connected to the station box via a sensor cable. The station box is a 53 gal (0.2 m^3) Contico model 3725 Tuff-bin box. It contains twelve 3 V batteries, in two 18 V parallel sections, which power the sensor, a Kinemetrics Quanterra Q330 recording system, a GPS antenna, and a radio antenna. A key difference between FLATS and

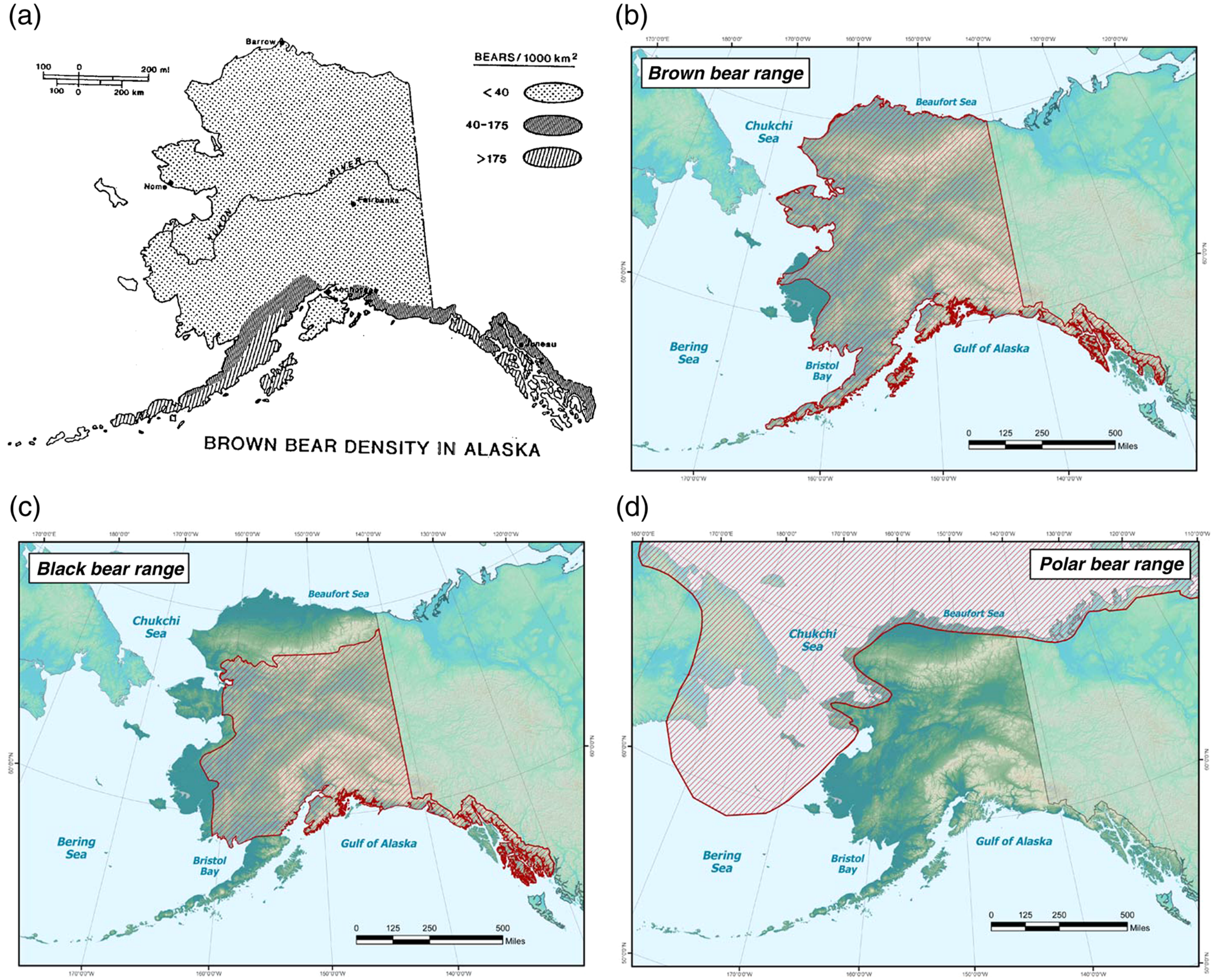


▲ **Figure 1.** Permanent broadband seismic stations in Alaska (white inverted triangles) as of January 2019. Two ongoing temporary experiments are also shown—EarthScope Transportable Array (TA) and Fault Locations and Alaska Tectonics from Seismicity (FLATS)—as well as previous temporary experiments—Alaska Receiving Cross-Transects for the Inner Core (ARCTIC), Broadband Experiment Across the Alaska Range (BEAAR), Wrangell Volcanic Field (WVF), Multidisciplinary Observations Of Subduction (MOOS), Southern Alaska Lithosphere and Mantle Observation Network (SALMON), and Mackenzie Mountains EarthScope Project (MMEP); Yahtse is labeled as Y (Table 1). The majority of the Alaska road system underlies ARCTIC, BEAAR, MOOS, and WVF. The remaining sites in Alaska are accessible by plane or helicopter. Not shown on this map are permanent short-period and intermediate-band stations, notably those within the AV network. The color version of this figure is available only in the electronic edition.

SALMON stations is that FLATS data are telemetered in real time using radios or cell modems. The telemetry requires more batteries (12 or 15 instead of six) and, in turn, larger station boxes. With each battery weighing 18 pounds (8.2 kg), a set of 12 is 216 pounds (98 kg).

Both FPAP and F3TN recorded data all winter long. Upon checking F3TN in June 2015, after the river ice had broken up, we discovered substantial disruption (Fig. 3b). Logs pinning down the tarp had been removed, the tarp had been removed, sod and dirt had been dug up around the station box, and the entire metal conduit (from station box to tree) containing the radio antenna cable had been dug up. Initially we were unsure about what could have disrupted the site. A bear seemed to be the obvious candidate, because we had seen ample evidence of bears during our reconnaissance work in 2013 and 2014, but we could not rule out other animals, such as fox or coyote, or even humans. Upon inspecting the station box, we discovered toothmarks on the edge of the hard plastic box (Fig. 3c), revealing the culprit.

FLATS stations were deployed for up to 5 yr, giving us opportunities to adapt the station design. The two main changes were: (1) burying the entry point for the sensor cable into the station box and (2) using concentrated Lysol on top of the station box. We installed a 3 inch bulkhead connector to the bottom side of a new station box. The sensor cable and radio antenna cable (if present) were fed through the bulkhead entrance. This way, there were no exposed cables or conduit, even if the tarp was removed from the station box. Plumbers putty was used to seal the opening around the cables; the seal was critical to keep water from entering into the buried box. The



▲ **Figure 2.** Ranges of brown, black, and polar bears in Alaska. Images used by permission from Alaska Department of Fish and Game. (a) Bear density map from figure 7 of Miller (1993) (see also fig. 8 of Miller *et al.*, 1997). The three density categories are <40, 40–175, and >175 bears per 1000 km^2. (b–d) Bear range maps from the Alaska Department of Fish and Game (see Data and Resources). The color version of this figure is available only in the electronic edition.

upgraded boxes were installed at F3TN, F4TN, FNN2, and F6TP.

We were motivated to try a bear deterrent after repeated bear disruptions at our FLATS sites. We installed F3TN in September 2014. Our first site visit showed major disruption (Fig. 3b), and we felt fortunate that seismic data were still being recorded. In June 2015 we staged boxes and batteries at two other sites (F1TN and F2TN). In August we discovered that bears had disrupted F3TN by again digging up the conduit; they had also disrupted F1TN. These incidents did not bode well for the FLATS project, and we decided to consider untested (at least by us) bear deterrents. Our boat captain, Daniel Ketzler, said his family had long used concentrated Lysol to try to keep bears away from their property along the Tanana and Kantishna rivers, where his family had lived for generations. Starting in September 2015, we poured a 12 ounce (355 mL) bottle of Lysol on top of each station box, prior to covering the box with the tarp.

Mackenzie Mountain EarthScope Project (7C)

The Mackenzie Mountains EarthScope Project (MMEP) seismic array was 40 temporary stations spanning the Yukon and Northwestern Territories in northwestern Canada (Fig. 1). The stations were distributed in a linear array approximately 850 km long, originating near Fraser, British Columbia, and terminating at Great Bear Lake in the Northwest Territories. Twenty-eight stations (MM01–MM27, MM41), primarily located in the Yukon, were accessible via the Canol Road, an historic oil supply road. The other 12 stations in the Northwest Territories (MM28–MM40, excluding

▲ **Figure 3.** Bear encounters with FLATS stations. These photographs are associated with the following labels in Ⓔ Table S1: F3TN/14-1 (B4), F6TP/16-1 (B3), and FNN1/15-2 (B5). (a) Example of an undisturbed site (F3TN). The tree in the background, at center, holds the radio antenna, which faces toward the river, and also the camera, which points toward the station and records videos of animal activity (Figs. 8 and 9). (b,c) F3TN on 2015-06-02. Tarp removed, box partly dug out, radio antenna conduit dug up, toothmarks in box. (d) F6TP on 2017-06-03. Tarp removed, toothmarks, significant holes in station box. (e) FNN2 on 2016-09-13. The station outage occurred on 2016-08-01, six days after annual servicing. The outage was caused by a bear pulling the sensor cable from the box, then mangling the cable. The color version of this figure is available only in the electronic edition.

MM37, which was not deployed) were only accessible via plane. For details of the MMEP project and preliminary results, see Baker *et al.* (2019).

MMEP stations were equipped with Güralp 3T seismometers, a Q330 recording system, and a Quanterra PB14F low-temperature baler. For all stations the sensor was mounted on a 6 inch (0.15 m) diameter concrete pier inside a partially buried vault. The vault was constructed with an upright 55 gal (0.21 m^3) trash can with a sawed-off bottom. It also additionally housed an inverted 10 gal (0.04 m^3) trash can strapped around the sensor to function as a positive-pressure bell jar. Station boxes were 35 gal (0.13 m^3) Rubbermaid ActionPackers. Primary power was supplied by three 6 V, 600 Ah air alkaline batteries; secondary power was supplied by a 12 V, 100 Ah dry cell battery charged by two south facing 12 V solar panels. Conduit for the the sensor cable and the solar panels and GPS antenna cables were constructed from rubber-lined fire hose and buried in 0.1 m deep trenches. No telemetry was used. Both the vault and the station box were waterproofed with tarps strapped around the lids.

Alaska Volcano Observatory (AV)

In the late 1990s, the Alaska Volcano Observatory (AVO) designed a new environmental station enclosure for housing power, recording, and communications systems at remote field sites. The enclosure, or hut, is made of fiberglass, is both strong and lightweight (about 400 pounds), and is transparent to radio waves, allowing the radio antenna to be placed inside the hut. Solar panels are mounted to one face of the hut. The impetus of this design was to address and counter many of the environmental factors that cause station failure: physical damage due to snow and ice loads and the more creative and destructive efforts of bears (John Paskievitch, e-comm., 2019). The hut is strong enough to withstand extreme snowloads that occasionally crushed some of the pre-existing station enclosures. It is large enough to accommodate all current and foreseeable equipment packages, and provide ample room and shelter for a field technician to work during servicing. Having as much critical equipment inside and protected from extreme conditions and bear molestation has greatly increased chances and rate of station survival.

The AVO huts—or slightly modified versions of the them —are also used by the AK network, by the Alaska TA, and by University NAVSTAR Consortium (UNAVCO) for its continuous GPS stations.

Alaska Seismic Network (AK)

The Alaska Seismic Network (AK) is operated by the Alaska Earthquake Center (AEC) and consists of approximately 130 stations. These stations are distributed across the state and include strong-motion networks in Anchorage and Fairbanks, road-accessible sites on the highway system, hosted sensors in villages, public facilities, telecommunication sites, and stand-alone battery-powered remote stations. This last category includes 70 of the most remote sites that share common design features and are of the most interest to this study.

The power and communication systems at a remote AK station is typically housed in a plywood reinforced fiberglass enclosure. Power and data cabling lead from this enclosure to the seismic sensor and Q330 recording system in a nearby surface vault, a 90 gal overpack drum embedded in concrete in a shallow hole with its lid protruding above grade.

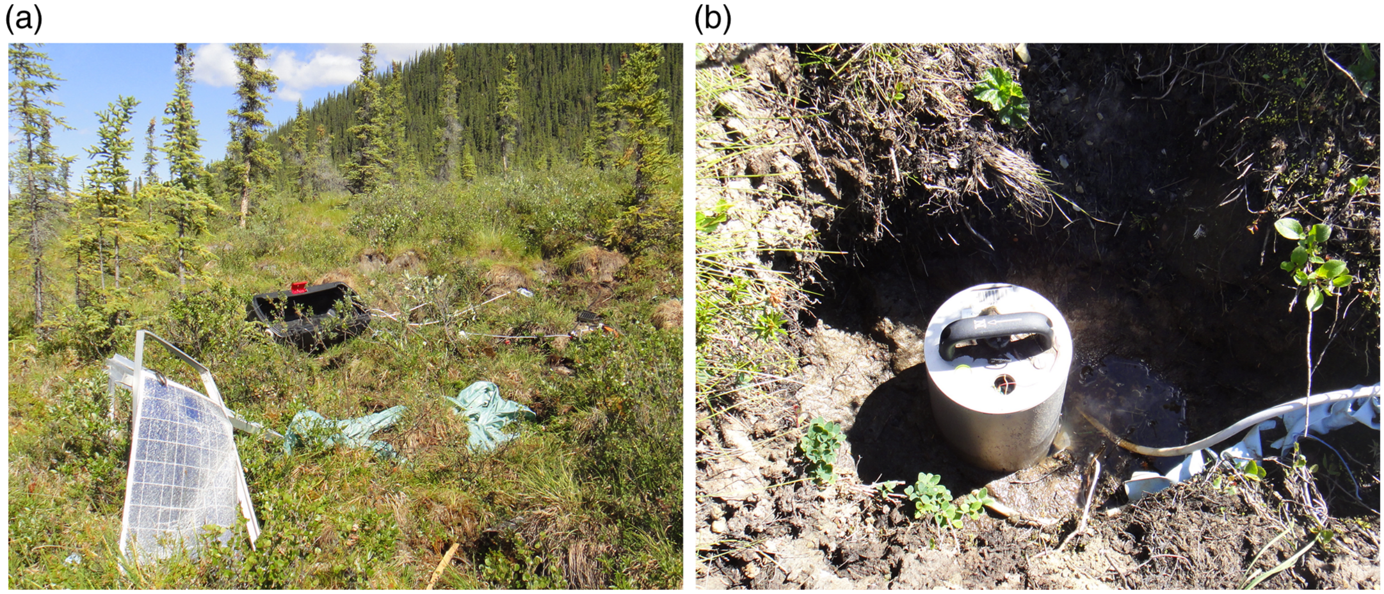
Data are acquired from these stations in real time through a number of methods, with the majority of the remote sites relying on 902–928 MHz ultra high frequency radios. Radio networks are extended into remote regions by utilizing strategically placed stations as repeaters at which multiple radios communicate up and down the chain. This communication topology leads to station interdependence—an outage at one station can cause corresponding outages of all stations distal to it in the radio network. This topology also causes variability in load across the network, and the power systems at repeater sites are sized to support the power consumption of multiple radios and increased data throughput. Typical loads range between 3 and 10 W. Valve-regulated lead-acid batteries are wired in parallel in banks ranging between 15 and 40 kWh nominal capacity. The south-facing surface of the enclosure is typically used to mount a solar array with a nominal rating of 150 W. Stations with high-power requirements are augmented with extra solar arrays mounted on frames that stand apart from their enclosures.

Alaska Transportable Array (TA)

The Alaska Transportable Array (TA) is operated by the Incorporated Research Institutions for Seismology (IRIS) as part of the National Science Foundation funded EarthScope program. The intended research target of the Alaska TA is to image the structure of the North American continent using earthquake tomography, which requires a uniform and dense spacing of high quality, telemetered seismic stations operated continuously for at least two years. The Alaska TA leveraged existing seismic networks to complete the grid, upgrading a subset of stations but focusing primarily on new installations far from the road system and in remote areas that had not been previously monitored. Apart from 13 initial stations installed between 2011 and 2014, the bulk of construction was accomplished in three field seasons: 2015 (30 stations), 2016 (71 stations), and 2017 (79 stations plus two strong-motion only sites) for a total of 193 new seismic stations.

The Alaska TA station design was developed on the foundation of previous seismic and geodetic networks operated in this region and utilized a plywood reinforced fiberglass enclosure, also referred to as a station hut. Site locations are remote and far from any infrastructure, hence most Alaska TA stations are autonomous with power sustained by solar and a combination of lithium iron phosphate and lead acid batteries. Near-real-time telemetry is enabled by satellite, cellular, or direct radio links. Communication and GPS antennas are mounted on the top of the station hut with cabling threaded through the steel pipe mounts and minimally exposed. Alaska TA stations use Q330 recording systems and incorporate broadband posthole seismometers (Nanometrics T120 PH and Streckeisen STS-5A) emplaced in a 6 inch diameter steel casing at a depth of ~2–3 m for improved noise performance and durability. Sensor cables are threaded through jacketed flexible

▲ **Figure 4.** SALMON station outages caused by bears. These photographs are associated with the following labels in Table 3: LTUW/15 (B6), HLC2/15 (B6), HLC1/16 (B6), HLC3/16 (B5), HOPE/16 (B5). (a) LTUW on 2016-05-18. The outage occurred on 2015-07-15, 12 days after installing the station. (b) HLC2 on 2016-07-19 (outage 2015-10-03). The sensor cable had a single, deep bite mark and the Q330 recording system was short circuited. (c) HLC1 on 2017-07-12 (outage 2016-09-30). The box is tethered by the sensor cable; one battery had been removed from the box. (d) HLC3 on 2017-07-12 (outage 2017-05-19). (e) HOPE on 2017-07-16. Removal of tarp and deformation of the box allowed water to fill the box, causing a power outage on 2017-06-12, >12 months after servicing. The box top had tooth holes. The color version of this figure is available only in the electronic edition.



▲ **Figure 5.** Remains of MMEP station MM31, at Cache Lake in Northwest Territories, Canada. The station was installed on 2016-08-15 and stopped collecting data on 2016-08-27. This bear encounter appears as MM31/16 in the R4 and B6 box in Ⓔ Table S2. (a) View of site on 2017-07-17. (b) View of partially unburied sensor. Because of time constraints and marshy substrate, the 3T seismometer was placed before the pier was fully cured, resulting in the sensor feet becoming mired in concrete. The cable port on the 3T consequentially broke off during the bear attack, exposing the internal electronics and destroying the sensor. The color version of this figure is available only in the electronic edition.

steel conduit that is coupled to the station hut and well cap. This conduit is cut to fit on site with minimal slack, buried in a shallow trench, and covered with rocks and other local materials. The station hut as installed with all batteries and equipment weighs at least 1200 pounds and is secured to the ground with stakes in four corners.

National Tsunami Warning Center Alaska Seismic Network (AT)

The National Tsunami Warning Center operates 14 stations in Alaska. All of the stations utilize commercial power with a battery backup. The equipment is typically housed in metal National Electrical Manufacturers Association enclosures at the base of a satellite dish or other communications infrastructure (Scott Langley, e-comm., 2019).

METHODS

Our methods are (1) to document station damage with notes and photographs and (2) to classify bear encounters at each station. Documentation is particularly important to avoid double-counting episodes of station damage as bear encounters. For example, toothmarks in a station box will be present for future site visits. Having a complete set of photographs and notes allows us to discern the most recent damage.

At two FLATS stations (F3TN and F8KN), motion-trigger cameras (Moultrie M-550; less than $100 each) were installed to document and examine how animals interact with the stations. The camera at F3TN recorded for four winters, from September 2015 to June 2019. The camera had infrared night mode as well, so it provided a complete record of all animal activity (squirrel, birds, and larger animals) within the sensor view of the camera. The camera at F8KN recorded for only two months, from 2018-08-04 to 2018-10-06. Its infrared light was faulty, so it did not record night activity; it died for unknown reasons.

Classification for Site Remoteness and Bear Encounters with Seismic Stations

We classify each seismic station according to its remoteness, and then we classify each time period of station activity according to whether there was evidence for a bear encountering the station.

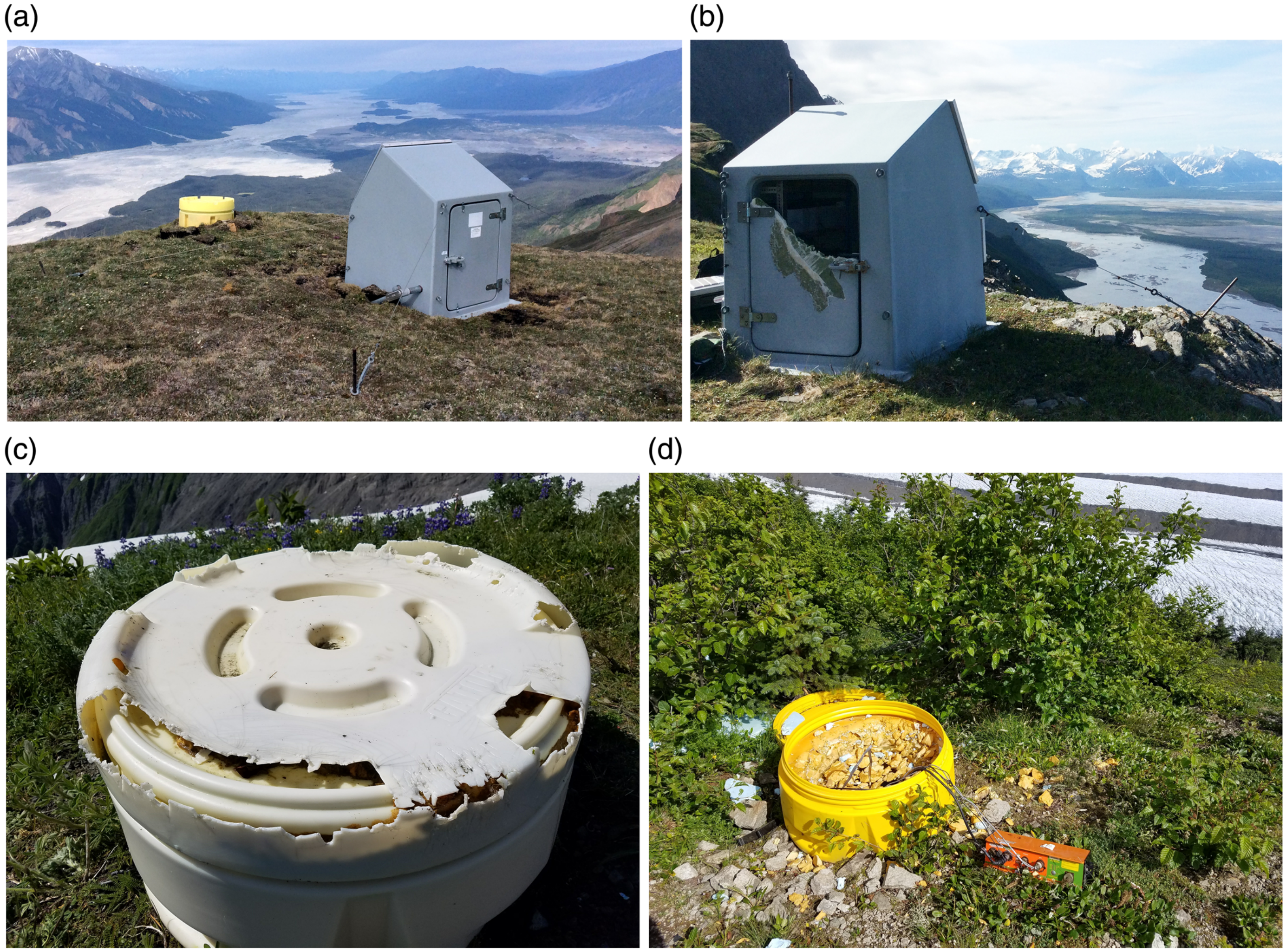
Classification for site remoteness is as follows:

- R1 road access: significant presence of human activity;
- R2 landing strip or road access: some presence of human activity;
- R3 no road access: some presence of human activity; and
- R4 no road access: no presence of human activity.

By road access, we mean a road that connects the site to a permanent population, whether it be an isolated village (accessible by plane) or any town on the main road system (e.g., Fairbanks, Nenana, Anchorage). Two FLATS stations help illustrate these classifications. FTGH is close (~200 m) to the Parks Highway, but it is accessed via a gated, former logging road. F5MN is in the Old Minto Cultural Heritage Camp, which is occasionally used in summer; it is near the seasonally populated Old Minto Recovery Camp, which is accessible by landing strip (as well as by river). Both FTGH and F5MN are classified as R2.

Classification for bear encounters with stations is as follows:

- B1 no sign of bears at site or in vicinity;
- B2 no damage, but signs of bear at site or in vicinity (tracks or damage nearby);



▲ **Figure 6.** Permanent Alaska Seismic Network sites. (a) AK.BARN is a typical remote station with an equipment enclosure and a surface vault (yellow). (b) AK.BMR, pictured on 2017-06-19, was damaged by a bear that destroyed the enclosure door and damaged electronics and cabling, causing an outage that lasted for more than six months. (c) The vault at AK.SAMH as seen in 2017, showing evidence of chronic chewing that did not cause a station outage. (d) The vault as it was found at AK.BERG on 2018-06-20, flooded and full of foam fragments. A bear removed the lid, pulled the Q330 recording system from the vault, and spent some time chewing on the vault insulation. The resulting outage lasted approximately 10 weeks. A black bear was seen nearby by the technicians sent to repair this damage. The color version of this figure is available only in the electronic edition.

- B3 light damage: definite or possible bear encounter; station still running;
- B4 significant bear disruption, and station still running;
- B5 significant bear disruption, and station is out; data loss <6 months (postwinter outage); and
- B6 significant bear disruption, and station is out; data loss >6 months (prewinter outage).

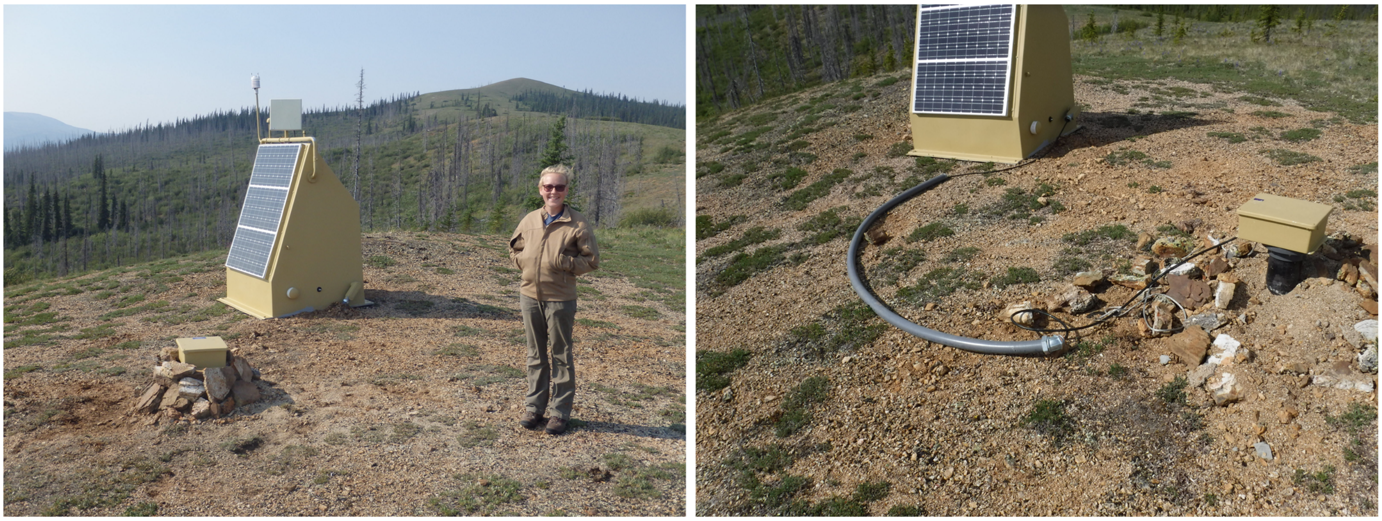
Significant bear disruption (B4–B6) means that the box has been moved or deformed, the box top has been removed, cables have been dug up, or sensor has been dug up. For our purposes, B2–B6 is considered a bear encounter, B3–B6 is a bear-damaged site, B4–B6 is a bear-disrupted site, and B5/B6 a bear-caused outage. For the telemetered AEC and Alaska TA stations, data loss includes periods when communication systems were down even when data were later recovered on site or through a regained telemetry connection.

RESULTS

From field notes and photographs, we tabulate bear encounters evidenced from each station site visit. A summary of seismic networks considered is shown in Table 1. This includes both temporary seismic experiments as well as permanent monitoring networks. In this study, we focus on three experiments (SALMON, FLATS, and MMEP) for which the field teams were carefully documenting evidence of bears; these results are summarized in Table 2.

There are three permanent networks in Alaska: Alaska Seismic Network (AK), AVO seismic network (AV), and the

(a) (b)



▲ **Figure 7.** Alaska TA station F26K. This station was (a) installed on 2016-07-15 and (b) serviced on 2017-06-19. The conduit had been pulled out of the station hut and well cap, exposing the sensor cable. This bear encounter appears as F26K/17 in the R4 and B4 box of Ⓔ Table S5. The sensor cable had been chewed but seismic data were not compromised or lost. Photos provided by Ryan Bierma and Doug Bloomquist. The color version of this figure is available only in the electronic edition.

National Tsunami Warning Center Alaska Seismic Network (AT). For the AV network, we did not have access to field records of bear encounters with seismic stations, but we note that bear encounters prior to the 1990s were partly the motivation for designing the huts. For the purposes of this study, the Alaska TA is categorized with the permanent network (AK) based on its similarity in station design.

For each of the seismic networks, we tabulate bear encounters with seismic stations in the form of Table 3, whereby each time interval between site visits is classified according to the type

Table 2
Bear Encounters with SALMON (Table 3), FLATS (Ⓔ Table S1), and MMEP (Ⓔ Table S2)

Network, Year [Number of Stations]		Nonremote R1/R2			Remote R3/R4		
		B1	B2/B3	B4–B6	B1	B2/B3	B4–B6
SALMON, 2015–2016	[24]	7	0	0	4	2	11
SALMON, 2016–2017	[23]	6	0	1	5	4	7
SALMON total	[47]	13	0	1	9	6	18
FLATS, 2014–2015	[2]	1	0	0	0	0	1
FLATS, 2015–2016	[13]	3	1	0	5	3	1
FLATS, 2016–2017	[13]	4	0	0	3	6	0
FLATS, 2017–2018	[13]	4	0	0	3	6	0
FLATS, 2018–2019	[11]	4	0	0	3	4	0
FLATS total	[52]	16	1	0	14	19	2
MMEP, 2015–2016	[4]	4	0	0	0	0	0
MMEP, 2016–2017	[36]	22	2	0	6	0	6
MMEP, 2017–2018	[38]	24	2	0	7	2	3
MMEP total	[78]	50	4	0	13	2	9
Total	[177]	79	5	1	36	27	29
		79	6		36	56	

Each station is classified as nonremote (R1/R2) or remote (R3/R4), and each station-year is classified as a bear encounter (B2/B3 or B4–B6) or not (B1) (see the Methods section). For stations with multiple site visits in a year, only the highest *B*-value is used. Some stations are not accessible to bears and are excluded from the compilation. The bottom row tallies the total number of nonbear encounters (B1) and bear encounters (B2–B6).

Table 3
Bear Encounters with SALMON Stations

	B1 (Undisturbed by Bears)	B2	B3	B4	B5	B6 (Most Disturbed by Bears)
R1 [7] (least remote site) BING, CLAM, GOOS, MPEN+, NNIL, NSKI, SOLD	BING/15, BING/16, CLAM/15, CLAM/16, GOOS/15, GOOS/16, NNIL/15, NNIL/16, NSKI/15, NSKI/16, SOLD/15, SOLD/16					
R2 [2] HOPE, KALS+	HOPE/15				HOPE/16	
R3 [7] BULG, CONG, HOLG, SALA, WHIP, JUDD, JOES	CONG/15, CONG/16, BULG/16, WHIP/16, JUDD/15, JOES/16			SALA/15, WHIP/15		HOLG/15*, BULG/15, **SALA/16***
R4 [12] (most remote site) LTUW, LTUX, LTUY, KALN+, HARR, HLC1, HLC2, HLC3, HLC4, HLC5, WFLS, WFLW	LTUX/15, LTUY/15, LTUY/16	**HLC5/16**, WFLW/16	**LTUW/16**, **HLC4/16**, HLC5/15, WFLW/15	**HLC2/16**, HLC3/15, WFLS/15, **WFLS/16**	**HLC3/16**	LTUW/15, LTUX/16, HARR/15, **HARR/16***, HLC1/15*, **HLC1/16**, HLC2/15*, HLC4/15*

Classifications of site remoteness (R1 to R4) and bear encounter (B1 to B6) are listed in the Methods section. Each entry in the table corresponds to a station-year, for example, BING/15 is for station BING for the time period summer-2015 to summer-2016. Three stations are omitted from the table for sites where there are no bears, on Kalgin island (KALS+, KALN+) and inside a 2 km^2 gated moose pen (MPEN+). HOLG and JUDD were installed for 2015–2016 only; JOES was installed for 2016–2017 only. Bold entries denote stations where Lysol was used as bear deterrent.
*A site where the sensor cable was ruined (which leads to an automatic B5/B6 category).

of bear encounter (B1 to B6) and the remoteness of the site (R1 to R4). These tables are listed in the Ⓔ supplemental content to this article for FLATS (Ⓔ Table S1), MMEP (Ⓔ Table S2), Yahtse (Ⓔ Table S3), AK (Ⓔ Table S4), and TA (Ⓔ Table S5).

Temporary Seismic Stations (SALMON, FLATS, and MMEP)

The SALMON project suffered significant damage and data loss because of bears, as documented in Table 3. Of the 17 remote (R3/R4) SALMON stations over the two-year period, there were 24 bear encounters, including 18 disruptions, 12 of which were outages. By comparison, among the 7 nonremote (R1/R2) stations, there was one bear encounter: a postwinter outage (B5) at HOPE was caused by a station box deformed by a bear that had removed the tarp and bit into the box top.

Examples of bear-caused outages (B5/B6) from the SALMON experiment are shown in Figure 4. Other bear-disrupted sites—that were fortunately still running (B4)—are shown in Ⓔ Figure S1. The primary cause of disrupted sites was bears damaging or removing station boxes from the ground. Once the station box was opened, further damage occurred to sensor cables and other equipment.

For FLATS there has been only a single outage caused by a bear (Ⓔ Table S1): a pulled and severed sensor cable at FNN2 (Fig. 3e). This does not mean that bears are not visiting FLATS stations. There have been 32 bear encounters at FLATS stations, as indicated by the B2–B6 columns in Ⓔ Table S1. All but one of these encounters occurred at remote sites. (The exception is bear scat at R2 station F5MN, photographed on 2016-09-10.) Figure 3b is an example of a B4 bear-disrupted station. The majority of bear encounters with FLATS stations fall into the B3 category and look such as Figure 3d (or Ⓔ Fig. S2): minimal damage evidenced by torn or removed tarp or toothmarks in the station box.

A compilation of MMEP bear encounters is presented in Ⓔ Table S2. During the July 2017 service visits, stations MM30, MM31, MM35, MM36, and MM39 were found to have suffered extensive damage attributed to bears. Damage to MM39 was limited to the solar panels and aluminum frame. Damage to the other four stations included excavation and evisceration of the station box: this generally proved fatal. For these stations, failure is attributed to battery discharge caused by flooding of the exposed station box by rain or snowmelt, potentially days or weeks after the initial attack. At MM35, the station box was completely exhumed and rolled over, disconnecting the solar panel cables and the GPS antenna cable and thereby allowing for identification of the bear attack on the seismic traces (Ⓔ Fig. S3). Spare parts were available to fully restore all stations except for MM31 (Fig. 5), which was instead removed from service. MM36 was further concealed with plywood sheeting scavenged from the wreckage of a cabin. During demobilization (August 2018), MM30, MM34, and MM35 were found to have suffered damage similar to the first year. Notably, MM36 did not suffer a second bear attack, possibly because of the additional concealment provided by the cabin debris.

Table 2 summarizes the results from SALMON (Table 3), FLATS (Ⓔ Table S1), and MMEP (Ⓔ Table S2). The results support the key finding of this study: Bear encounters, including outages, are more likely at remote stations. Of the least remote stations (R1), there was no evidence of bears at any SALMON, FLATS, or MMEP site. There were 30 stations disrupted (B4–B6) by bears, and 29 of these were at remote (R3/R4) stations. (The one exception was R2 station HOPE, discussed earlier.)

Alaska Seismic Network

The bear-caused outages at AK sites noted by AEC and shown in Table 1 were counted for calendar years 2013–2018. Maintenance records from before this time are incomplete but incidents of bear damage prior to 2013 follow the trends seen in the data described here. All AK station outages caused by bears occurred at remote sites (R3/R4). No bear disturbances were noted at any nonremote (R1/R2) site.

Because the definition of a station outage is subjective (consider intermittent solar power, or a sensor with just a single misbehaving channel), instead of comparing bear-caused versus total outages, we count bear-caused versus total station-days of data lost. We calculate that AEC lost 1767 station-days of data to bear damage among 39,715 station-days of data lost to all causes from 2013 to 2018, or about 4.5%. These numbers do account for data lost at stations remote from where the bear damage occurred in instances when a bear damaged a repeater. For example, the loss of communication equipment damaged by a bear at GLB in 2016 caused the outage of four stations repeated by GLB (BAL, BARN, KIAG, and VRDI) whereas data from GLB continued to be acquired due to the nature of the damage. This outage lasted 56 days and accounts for 224 of the 1767 station-days of data lost to bear damage.

Bear damage at AK sites is categorized by remoteness and severity in Ⓔ Table S4. The most prevalent type of bear damage noted at AK sites is chew marks on the lid of the plastic surface vault, as shown in Figure 6c. The multilayer design of these vault lids prevents most chew damage from compromising the integrity of the vault, and most damage of this type does not flood the vault or cause a data outage. Bear damage incidents that have caused AK data outages can be categorized in three groups—those for which the bear damaged the enclosure door (Fig. 6b), those in which the bear removed the vault lid (Fig. 6d), and those for which the bear damaged cables external to the enclosure and vault. Damage in the first two categories (the penetration of either enclosure) is less frequent but usually more difficult and expensive to repair than damage to external cabling, which is more common but easy to repair. AEC has found that securing the vault lids with a chain and lock is effective in preventing bears from removing the lid, and now chains all vaults at stations with bear sign. AEC also secures all enclosure doors with a lock or latch, but such a mechanism will not prevent a bear from ripping a door in half. Three break-ins through enclosure doors happened during the six-year study period. The possibility of cable damage can be minimized by burying cables, running them in metallic conduit that is secured to a rigid structure in which they cannot be buried, and minimizing slack.

Alaska TA

The Alaska TA stations were predominantly installed at sites that were only accessible via helicopter. This ensured that a large percentage of Alaska TA stations were in the R4 category with no presence of human activity. Other than the stations installed on islands with no bears (P08K Saint George Island, M11K Nunivak Island, and Q23K Middleton Island), any of the Alaska TA sites could have been visited by bears.

We follow the same methods used by AEC to calculate that the Alaska TA lost 181 station-days of data to bear damage among 8308 station-days of data lost to all causes from 2015 to 2018, or 2.2%. These totals treat a loss of telemetry communication as data lost even when data are later recovered either through regained telemetry or a station visit.

Damage caused by bears at Alaska TA stations has almost exclusively been to cables at ground level (Fig. 7). Soil temperature probes that are collocated with Alaska TA seismic stations have often been found pulled up and sometimes severely damaged with the nonjacketed metal conduit unraveled. Given this additional evidence of bear activity, the extra effort to carefully protect the seismometer's sensor cable at or near ground level by burying it in high strength, polyvinyl-chloride-jacketed metal conduit has been worth it. Recurring issues with the conduit being pulled out of the conduit fittings installed on the hut and well cap have been addressed by keeping these connection points below grade when possible and adding U-bolts and hose clamps to better lock the conduit into the fitting on the station hut. Several of the unearthed sensor cables had toothmarks, yet no data were lost or impacted. The Alaska TA hut design is taller with more steeply angled sides than the AEC hut design. Bear prints and scratches found on the huts show that bears do stand up to investigate, but there is no evidence of climbing onto the hut. The few instances of damage to antennas and associated cables mounted on top of the station hut despite their exposure and weakness compared to the sensor cable shows the benefit of larger enclosures: being able to keep things higher off the ground and generally beyond the interest of bears.

Telemetry at stations helps with identifying possible bear damage issues remotely, with service crews prepared accordingly with replacement cables and sensors based on the types of failures. Telemetered data also allows for servicing prioritization and rapid response, both crucial in maintaining the Alaska TA's stipulated levels of data availability.

Other Seismic Networks

The findings from SALMON, FLATS, MMEP, AK, and Alaska TA are strengthened with the available data from other experiments (Table 1). For example, for the Wrangell Volcanic Field (WVF) experiment (see Fig. 1), there were 35 nonremote stations and zero bear disruptions. The Multidisciplinary Observations of Subduction (MOOS) experiment included six remote stations, and at least one of these (HOLG) was a bear-caused outage. For the Yahtse experiment (see Ⓔ supplemental content), for which all 11 stations were remote, there was at least one bear-caused outage over the two-year duration of the experiment. A current project in southwestern Alaska and Kodiak could provide additional data regarding bear encounters (Abers *et al.*, 2019).

All 14 AT network stations run on commercial power and are classified as nonremote (R1 or R2), except for MID (R3) (Scott Langley, e-comm., 2019). Four of the stations are on islands where bears are not naturally present (AKUT, MID, SDPT, and SMY). One bear-caused outage was reported at AT.CRAG in May 2019. No other bear encounters (including outages) were reported at the other 13 AT stations over the past decade.

The Canadian National Seismic Network (CN; Geological Survey of Canada, 1989) includes 69 stations in British Columbia and Yukon; these were classified as 19 R1, 24 R2, 11 R3, and 15 R4 (Henry Seyward, e-comm., 2019). The CN reported bear-caused outages at their stations and provided the authors with example photos of damage at YUK2 and YUK4, in Yukon, as well as at ATKO and SILO, in Ontario (Henry Seyward, e-comm., 2019).

The power demands for operating continuous GPS stations are similar to those needed for seismic stations. The continuous GPS stations in Alaska, run by UNAVCO and AVO, also use huts at some of their remote sites. Examples of bear damage at these sites are shown in Ⓔ Figure S4.

Bears and Other Animals at Two Seismic Stations

The motion-trigger video camera at FLATS station F3TN provided some insights into understanding the station damage. Four full winters (early September to early June) of video footage were recorded at F3TN; compilations are available on YouTube (see Data and Resources). Figure 8 provides some excerpts from these videos. The first sequence—a coyote (Fig. 8a–c)—is an example of the typical animal behavior at the site: avoidance. The coyote is initially curious about the snow-covered box, but is then spooked and trots around it. The moose (Fig. 8d) glances at the station and carefully walks around it. Lynx (Fig. 8e,f) generally avoid the station box.

In contrast to other animals, bears are enticed by the station box. Three separate bear encounters are shown in Figure 9. In the first case, the black bear sow stands directly on the station box, before lightly biting the tarp on the corner of the box (Fig. 9a,b), perhaps checking for any hazard for her cubs, which come a minute later. When we visited this site, two weeks later, we found only a torn and disrupted tarp, but no unequivocal signs of bears (such as toothmarks in the box). (For better or worse, we have no video evidence of bears causing a station outage, such as those that occurred at SALMON stations, see Fig. 4.) Figure 9e,f show a black bear and a brown bear visiting F3TN, three days apart.

In fall 2018, a camera was installed at F8KN and recorded for only two months. Several black bears visited the station, disturbed the tarp, and rubbed themselves vigorously on the station box, as can be seen in the video compilation (see Data and Resources). Images from the videos can be seen in Ⓔ Figure S5. Despite frequent visits from bears, the station has not sustained any outage as it approaches the end of its fourth year.

DISCUSSION

Our documentation of bear encounters leads us to identify site remoteness as the primary factor for bear encounters. However, we did not design any experiment to test this hypothesis, and we recognize that there are many different variables that cannot be controlled based on the observations in this study. (For an example of an experiment designed to test the influence of equipment on bear encounters in an urban environment, see Johnson *et al.*, 2018.).

Bear densities—and the species of bear—are not uniform in Alaska. Furthermore, the available maps in Figure 2b–d show range, not density, which is challenging to quantify (Fig. 2a). Knowledge of the regional and local bear densities can be used to inform site selection and seismic station design such as what materials are used and whether to enhance a station with a bear deterrent.

Design Criteria for Seismic Stations in Alaska

These basic questions guide seismic station design:

1. Will telemetry be used?
2. How much power is needed and what are the available sources?
3. Is the station permanent or temporary?
4. What is the available budget?

For example, most of the seismic networks in the top part of Table 1 are in the category of temporary, untelemetered, and low-budget stations (e.g., SALMON). FLATS had telemetry. The networks in the bottom part of Table 1 in the category of permanent, telemetered, and higher budget stations. The Alaska

▲ **Figure 8.** Examples of animals not disturbing the seismic site. The sensor is buried beneath the pile of sticks near the moose's feet. The box contains batteries for powering the seismometer and radio telemetry. (a–c) Coyote approaches the site, senses something unfamiliar, and then trots away. (d) Moose. (e,f) Lynx. The color version of this figure is available only in the electronic edition.

▲ **Figure 9.** Bears recorded at FLATS station F3TN. (a) Black bear sow on 2016-05-14. (b) Biting the corner of the box. (c) Sow and two cubs. (d) Cubs tugging and ripping the tarp. (e) Black bear inspecting the station box on 2017-05-15. (Note the camera angle and color exposure are different from 2016.) (f) Grizzly bear on 2017-05-18. The color version of this figure is available only in the electronic edition.

TA stations needed to record continuously for at least two years so used a station design similar to permanent stations.

Station design criteria common to Alaska stations are:

1. scientific or operational value of the site;
2. remotely powered in conditions of low solar, low ground-level temperatures (down to −20°C), and potentially large snow accumulation, either from snowfall or drifts;
3. requiring minimal site visits (≤1 time per year); and
4. resistant to bears (this is most important for remote sites).

The final criterion is the topic of this article. Permanent stations have budgets that allow for equipment that lasts longer in harsh field conditions and is also much more resistant to bears. They also have telemetry, allowing outages to be rapidly detected.

Bear Resistant Equipment

The seismic stations in our experiment had significant differences. The SALMON stations employed ActionPacker tote boxes that were smaller, less strong, and more exposed above ground than the boxes used for FLATS. Furthermore, four FLATS stations were upgraded with subsurface bulkhead entries for cables. The extra weight of batteries in the FLATS boxes, needed for telemetry power, probably makes the boxes more difficult to dig up. For SALMON, we used a station design that had previously been very successful; probably stronger boxes—with buried cable entrances—would have helped in some cases, but we cannot be sure.

Although there are many variables to consider among different seismic networks, we advocate the common sense finding that stronger equipment leads to fewer bear-caused outages. The weakest, lightest station boxes were used in SALMON and were heavily disrupted (Table 3). Stronger, heavier boxes were used in FLATS and were minimally disrupted (Ⓔ Table S1). The strongest, and often heavier, equipment used by the permanent networks results in a low number of outages (Table 1) relative to the total number of outages and the total number of operating stations. Other findings include: buried cables are more protected than cables exposed at the ground surface, and burying the cables within polyvinyl-chloride-jacketed metal conduit further improves security.

Electric Fences as Bear Deterrents

Electric fences have been used, or considered, for deterring bears from apiaries (bees), crops, camps, and industrial sites; a subset of literature includes Storer *et al.* (1938), Wooldridge (1983), McKillop and Sibly (1988), Huygens and Hayashi (1999), Creel (2007), Otto and Roloff (2015), Johnson (2018), and Smith *et al.* (2018). The basic concept is that a curious bear approaches a fenced-in region, touches the fence, receives a shock, and leaves the area. Ⓔ Figure S6 shows two examples, for a black bear in California and a polar bear on Cooper Island, Alaska.

Within the United States, electric fences have been in use by personnel within several government agencies:

- Alaska Department of Fish and Game (Alaska Department of Fish and Game, 2018);
- U.S. Geological Survey (Alaska Science Center): Smith (2005) and Figure 10c,d;
- U.S. National Park Service: Sousanes, Hill, Bower, *et al.* (2017), Sousanes, Hill, Johnson, and Miller (2017) (Fig. 10a,b);.
- U.S. Bureau of Land Management (Craig, 2004);
- U.S. National Forest Service (Karsky *et al.*, 2007); and
- U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 2015).

Figure 10 shows examples of electric fences protecting scientific monitoring equipment from bears.

Electric fences in Alaska would need to meet the design criteria for seismic stations, described earlier. They would need to be tested alongside running seismometers, to ensure that the seismic recording system is not compromised by the operation—including electric discharge when triggered—of the electric fence. An electric fence could also impact other choices for a seismic station. For example, solar panels mounted on poles might be easily destroyed by bears; therefore, one might opt to use batteries instead. However, a functioning fence could protect the solar panels along with the rest of the seismic equipment. As far as we know, electric fences have not been tested or considered for year-round seismic stations (see also Ⓔ Fig. S7).

SUMMARY

We document bear encounters in Alaska and northwestern Canada at 11 seismic networks, eight of which include lower-budget, temporary-style station installations and three of which include higher-budget, permanent-style station installations. We conclude with a set of summary points and recommendations for future seismic experiments in remote regions where bears are present.

Our summary points are:

1. Stations in remote regions of Alaska and northwestern Canada are more likely encountered and disrupted by bears than stations in less remote regions (Table 1). Among all 265 remote stations analyzed over the multiyear time period, there were 44 documented bear-caused station outages. Among all 290 nonremote stations, there were only two outages, both at stations classified as R2 for remoteness (ZE.HOPE and AT.CRAG). This finding was most pronounced with the SALMON experiment (Table 3). Among the 22 station-years of the most remote (R4) stations, there were 19 bear encounters (B2–B6), including 12 disrupted stations (B4–B6), nine of which were outages (B5/B6). None of the least remote SALMON stations (R1) showed evidence of any bear encounter. Notably, 100% of SALMON data losses was because of bears.
   The reasons for remote stations being disrupted might be that the remote regions have more bears and fewer novelties (such as a seismic station) for them to investigate. Bears are smart and curious, so they like to investigate anything they find that is novel within their range.
2. The impact of bears is amplified when the cost to record data is taken into account. Because bear-caused outages occur at remote sites (R3/R4), the costliest data are lost

▲ **Figure 10.** Examples of electric fences installed to protect scientific measuring equipment in Alaska. (a) Bear damage to a National Park Service weather station at Salmon River in 2012. (b) Same site as in (a), but after electric fence were installed in 2013. No equipment has been damaged at this site since 2013. Photos provided by National Park Service (NPS). NPS weather stations are discussed in Sousanes, Hill, Bower, *et al.* (2017), Sousanes, Hill, Johnson, and Miller (2017). (c,d) U.S. Geological Survey (USGS) weather stations in northern Alaska. Photos provided by USGS, Alaska Science Center. (e) Sea ice monitoring station, offshore northern Alaska (Druckenmiller *et al.*, 2009). Photo provided by Andy Mahoney. (f) Zoom-in on (e). The color version of this figure is available only in the electronic edition.

due to bears. In turn, there were zero data losses due to bears at the cheaper-to-access, least remote (R1) sites.
3. Other animals besides bears—such as moose, lynx, coyote, and smaller animals—do not seem to pose a threat to seismic equipment. Mountain goats and rodents, such as marmots, may have damaged seismic stations in the Yahtse experiment. Lighter seismic installations, such as nodal sensors spiked into the ground, could be prone to disruption by a range of animals smaller than bears.
4. At permanent-style networks AK and TA, bears caused outages at 21 stations—all remote. Bear-caused data losses account for <5% of total data losses, which includes data later recovered by regained telemetry or a station visit. This relatively low fraction is attributed to the use of stronger equipment, notably fiberglass huts that are secured to the ground.
5. The number of bear encounters with remote seismic stations is an underestimate, because many bears will inspect stations but leave no trace. Without motion-trigger cameras at each site, we cannot account for all possible encounters—only the ones that leave evidence behind (tracks, scat, toothmarks, etc.).

With regard to future seismic installations in remote regions within bear territoy, our recommendations for seismic stations (permanent or temporary) are as follows:

1. Budget to deter bears.
2. Use as strong equipment as your budget and logistics can allow. Bear-caused outages are lowest for stations at permanent networks, higher for FLATS stations, and highest for SALMON and MMEP stations. Station housings that are more difficult to dig up, bite, and damage will have a better chance of surviving.
   It is possible that the hut used at permanent stations could be improved further to deter bears. For temporary experiments, optimal station boxes could be designed and tested (e.g., Johnson *et al.*, 2018).
3. Do not stage any unsecured gear at any site. In 2015, boxes with 12 batteries were staged at three FLATS sites, and two of the boxes were severely disrupted.
4. Take photographs when arriving and leaving each site. Document all evidence of bears, whether station damage (B3–B6) or not (B2). Evidence of bears, but without station damage, includes seeing a bear nearby (e.g., SALMON stations WFLW and HLC5 in 2017; Table 3) or seeing bear tracks or bear scat nearby.
5. Consider using motion-capture cameras. These cameras are inexpensive ($100–$500) relative to the cost to access remote sites. The FLATS camera at F3TN in central Alaska ran on eight AAA batteries through the entire winter and provided a complete record of all activities at this one station.
6. Appropriate training and precautions must be undertaken to keep people safe during installation, servicing, and removal of seismic stations in bear territory. Employing bear guards, regularly training crew to handle firearms for predator defense, and choosing less remote site locations away from known bear territory are appropriate measures. In addition, education on bear behavior, coordinating travel so that no crews are left on site without a means of transport, streamlining installation so that crews are on site as little as possible, providing adequate means of communication (e.g., satellite phone, hand-held radios), and maintaining a culture of awareness will help to mitigate risk. No seismic data are worth human life or injury.

Specifically for future seismic experiments in remote regions within bear territory (e.g., FLATS, SALMON, and MMEP), our additional recommendations are as follows:

1. The station box should be staked down and probably partially buried, as in Figure 3a. None of the station boxes in the eight seismic experiments (Table 1) were staked, but in hindsight this should have been part of the design. Any cables entering the box should be buried and, ideally, within metal conduit. Partial burial of the station box can increase the risk of flooding from snow melt or other sources. Probably the current practice of partial burial is a good one, because it offers enough air needed for the air-alkaline batteries, the box is enough above ground to avoid flooding, and the box is enough buried to make it difficult for the bears to pull it out. The GPS antenna, for example, can be inside the plastic boxes; they work fine even within densely forested regions.
2. A minimal level of telemetry—such as state-of-health once an hour—is helpful to have, in advance of annual visits to stations. Knowing whether a station is on allows one to prepare for how much spare gear to bring.
3. Consult other scientists who face similar challenges of sustaining monitoring equipment in Alaska. Consider testing and using electric fences.

DATA AND RESOURCES

Seismic data holdings from all stations in this study are archived at the IRIS Data Management Center. The data pertinent to this study are field notes and photographs, all of which are not publicly accessible. The authors have reviewed field notes and have tabulated information on bear encounters and data outages. The compilations from Southern Alaska Lithosphere and Mantle Observation Network (SALMON), Fault Locations and Alaska Tectonics from Seismicity (FLATS), Mackenzie Mountains EarthScope Project (MMEP), Yahtse, Alaska Seismic Network (AK), and Alaska Transportable Array (TA) can be found in the digital collection of Tape *et al.* (2019). Compilations of animal footage at F3TN are available on YouTube at https://youtu.be/6-6tBKLCCk4, https://youtu.be/1XsAZ3VAgZw, https://youtu.be/HjxjzRuxQHA, and https://youtu.be/gmAo50UFt5w (last accessed July 2019). A video compilation of black bear visits to F8KN can be found at https://youtu.be/crgu1rVp0Do (last accessed July 2019). The website for Alaska Department of Fish and Game is http://www.adfg.alaska.gov (last accessed November 2018).

ACKNOWLEDGMENTS

The authors acknowledge the seismic networks listed in Table 1: Broadband Experiment Across the Alaska Range (BEAAR, Christensen *et al.*, 1999; Ferris *et al.*, 2003), Alaska Receiving

Cross-Transects for the Inner Core (ARCTIC, Song and Christensen, 2004), Multidisciplinary Observations Of Subduction (MOOS, Abers and Christensen, 2006; Li *et al.*, 2013), Yahtse (Larsen and West, 2009; Bartholomaus *et al.*, 2015), Fault Locations and Alaska Tectonics from Seismicity (FLATS, Tape and West, 2014; Tape *et al.*, 2018), Southern Alaska Lithosphere and Mantle Observation Network (SALMON; Tape, Christensen, and Moore, 2015; Tape *et al.*, 2017), Mackenzie Mountains EarthScope Project (MMEP; Schutt and Aster, 2015), Wrangell Volcanic Field (WVF, Christensen and Abers, 2016), Transportable Array (TA; Incorporated Research Institutions for Seismology [IRIS], 2003), AK (Alaska Earthquake Center, University of Alaska Fairbanks, 1987), and AT (National Oceanic and Atmospheric Administration [NOAA], 1967). All of the temporary experiments were supported by the National Science Foundation and the Program for the Array Seismic Studies of the Continental Lithosphere (PASSCAL) Instrument Center. The authors thank Scott Langley for providing the numbers for AT used in Table 1. Scott is a Senior Electronics Specialist at the National Tsunami Warning Center, where he has worked for the past 10 yr installing and maintaining seismic and tsunami equipment throughout Alaska. The authors thank John Paskievitch for describing the history of the design of the Alaska Volcano Observatory (AVO) huts. For the past 31 yr, John has led and managed the operational side of the AVO seismic monitoring network. He is also the Associate Director of Instrumentation, U.S. Geological Survey (USGS) Volcano Science Center. The authors thank Henry Seywerd for providing R1–R4 classifications for the CN network stations and for providing photos of bear damage to CN stations. Since 2012, Henry has been Head of Operations at the Canadian Hazard Information Service with primary responsibility for field operations of the Canadian National Seismograph Network. Hundreds of field participants were involved in the servicing of seismic stations discussed in this article. Here, the authors acknowledge some of the key participants from SALMON (Doug Christensen, Carl Tape, Melissa Driskell, Nealey Sims), FLATS (Carl Tape, Kyle Smith), MMEP (Derek Schutt, Rick Aster, David Heath, Michael Baker), Yahtse (Chris Larsen, Tim Bartholomaus), and Alaska TA (Ryan Bierma, Doug Bloomquist, Robert Busby, Max Enders, Jeremy Miner, Jason Theis). For content or feedback about bears, C. Tape thanks Sterling Miller, Kerry Nicholson, Craig George, and Tom Smith. For content of feedback about electric fences, C. Tape thanks Pam Sousanes, Heather Johnson, Hajo Eicken, Rick Golightly, Eileen (Creel) Verbeck, George Divoky, Dick Shideler. The photographs in Figure 10d–f were provided by E. Creel and R. Golightly, with permission granted by Hoopa Valley Tribe and Humboldt State University, Arcata, California. Ellie Boyce of University NAVSTAR Consortium (UNAVCO) provided valuable information regarding the maintenance of continuous Global Positioning System (GPS) stations in Alaska (Ⓔ Fig. S4). Nate Murphy identified the telemetry change caused by a bear at F6TP (Ⓔ Fig. S2b). The authors thank Rick Aster (Colorado State University) and Heather Johnson (USGS) for feedback on the article. C. Tape acknowledges Tape and Gustine (2014) for inspiring the use of motion-sensitive cameras to observe wildlife in remote Alaska. The seismic experiments in this study were supported by National Science Foundation Award Numbers EAR-1251971 (SALMON), EAR-1352688 (FLATS), EAR-1460533 (MMEP), EAR-0810313 (Yahtse), and EAR-1261681 (Alaska TA).

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Published Online 21 August 2019