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Impacts of Truck Traffic across Unfrozen Tundra near Toolik Lake, Alaska

Martha K. Raynolds, Tim Craig, and Zachary Meyers

Alaska

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Cover Photo

One of two trucks illegally driven across unfrozen tundra near Toolik Lake, Alaska in September 2006. BLM photograph by Boyce Bush. Other photographs in this report are by Martha Raynolds and Edith Barbour.

Authors

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ABSTRACT

In September 2006, caribou hunters illegally drove 2 vehicles across unfrozen tundra on land managed by the U.S. Bureau of Land Management in the Toolik Lake Area of Critical Environmental Concern on Alaska's North Slope. The vehicles became stuck in the tundra and were eventually excavated from frozen ground in April 2007. The extent of the impacts were evaluated in July 2007 and reevaluated in July 2008. The level of disturbance, as measured by categorical classes, thaw depth, and surface elevation, all increased significantly between years. The truck trails impacted 1457 m^2 of tundra. Habitat disturbance was quantified at 5 different levels with Level 1 being the least disturbed and Level 5 the most disturbed. In 2008 most of the trails (61%) were Level 2 disturbance, while 25% were Level 1, 8% were Level 3, 3% were Level 4, and 2% were Level 5. Since the previous year, the trails had become deeper, more water-filled, and also more visually evident. The excavation sites measured approximately 75 m^2 each, with 25 m^2 and 36 m^2 of Level 5 disturbance at the close and far excavations, respectively. In contrast to 2007, areas with Level 5 disturbance were covered with water in 2008. Soil thaw depths were significantly deeper on the disturbed areas than at the control areas for most transects, and deeper in 2008 than 2007. Similarly, surface profile elevations were lower in the disturbed areas than the control areas, and lower in 2008 than 2007. Future monitoring is recommended for 2012 and 2017, 5 and 10 years from the initial disturbance.

ACKNOWLEDGMENTS

We acknowledge the contributions of Edith Barbour and Constance Zachel, who provided invaluable field assistance. The original manuscript benefited greatly from editorial suggestions by Craig McCaa, who also shepherded this report to publication.

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1. BACKGROUND

On or around 6 September 2006, caribou hunters drove 2 vehicles across unfrozen tundra north of the Dalton Highway between milepost 291 and 292. This event, in violation of Alaska statute and federal regulations, occurred on land managed by the U.S. Bureau of Land Management (BLM) in the Toolik Lake Area of Critical Environmental Concern (ACEC). One of the vehicles, hereafter referred to as the "Far Truck," was a Ford F-150 with an estimated gross vehicle weight of 2400 kg. The Far Truck traveled about 4.6 km off the highway before it became stuck. The second vehicle, hereafter referred to as the "Close Truck," was a Dodge Ram 1500 with an estimated gross vehicle weight of 2880 kg. The Close Truck traveled about 0.85 km from the highway before it too became stuck (Figure 1).

The trucks mostly crossed tussock tundra, except under the Trans-Alaska Pipeline, where they encountered slightly wetter vegetation with fewer tussocks. The Far Truck became stuck in a moist sedge, dwarf-shrub water track, the first non-tussock tundra vegetation that it encountered. The Close Truck, whose driver(s) mostly followed the Far Truck's tracks, became stuck in tussock tundra.

Once the ground was completely frozen, attempts were made to extract the trucks in

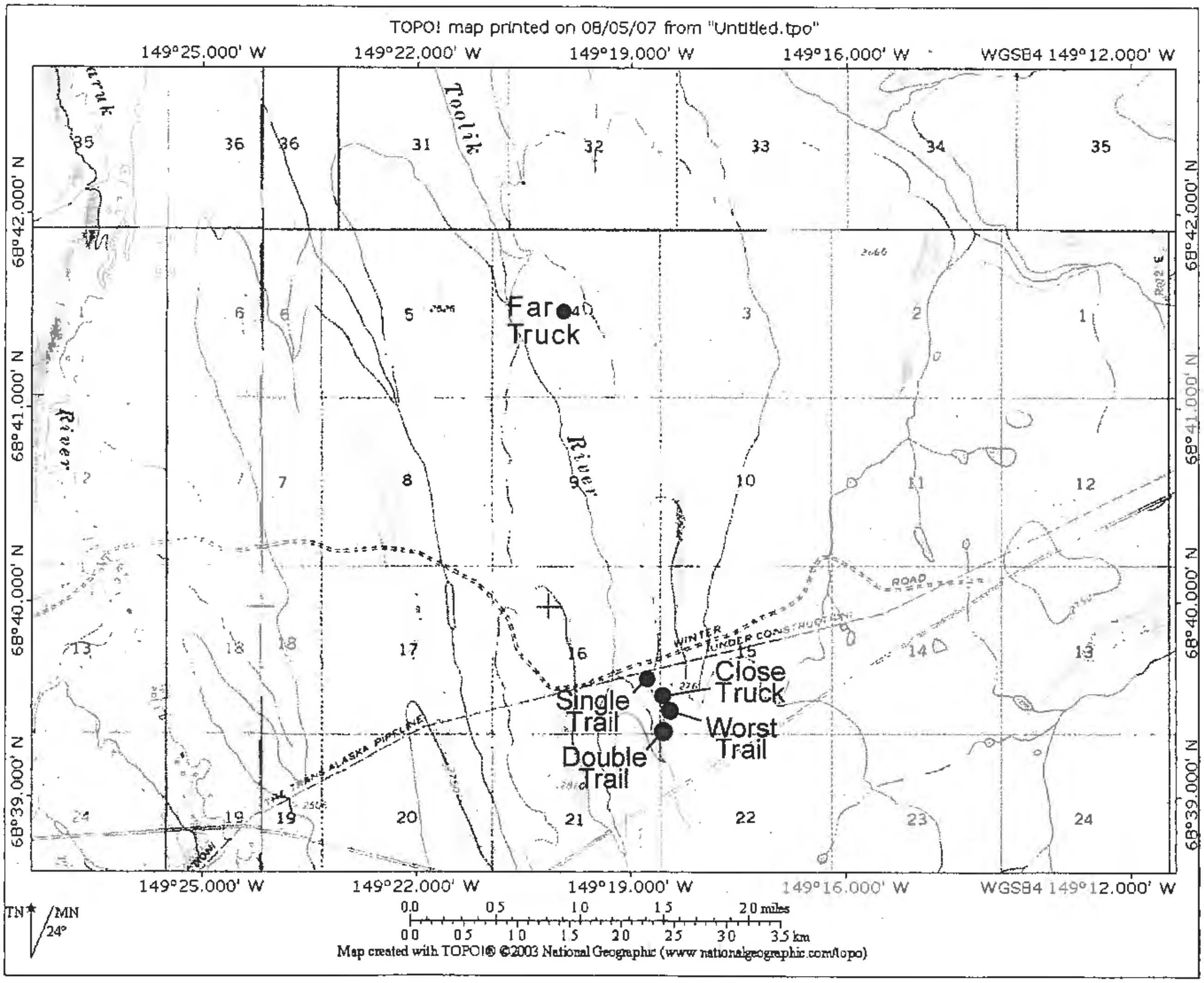


Figure 1. Location of study sites along trails created by 2 pickup trucks traveling on unfrozen tundra, Toolik Lake ACEC, Alaska in September 2006. "Far Truck" and "Close Truck" are sites where the vehicles became stuck and were subsequently extracted. "Single Trail," "Double Trail," and "Worst Trail" are locations where transects were established perpendicular to the trail.

October 2006 (twice), February 2007 (just the Close Truck), and finally in late March/early April 2007, when the trucks were successfully extracted. Final extraction involved removing frozen soil with jackhammers, placing sleds beneath each truck wheel, and skidding the trucks back to the Dalton Highway behind a Tucker Sno-Cat. Frozen, excavated soil was shoveled back into the holes left in the tundra after the trucks were extracted. Mapping that we completed the following summer (see *Methods* and *Results* sections) showed that total surface disturbance from tracks and excavations was 1558 m^2.

On 5 June 2007, a BLM employee who had monitored the excavation returned to the sites. He returned scattered excavated material to the sites, raked and leveled them (contouring the Far Truck site to slow water flow), and placed a white rock on the central unexcavated portion of each site as a reference point for photos.

The BLM contracted with the University of Alaska to assess the initial impacts from travel on non-frozen tundra and extraction of the 2 trucks and to set up procedures to monitor long-term impacts. Researchers from the University of Alaska, including one of the

Table 1. Tundra disturbance levels used to measure disturbance where habitat was disturbed by 2 pickup trucks that traveled on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska.

Measure	Level	Description
Decrease in plant cover	0	No observable change
	1	0%–25%
	2	25%–50%
	3	50%–75%
	4	75%–95%
	5	>95%
Decrease in shrub canopy	0	No observable change
	1	0%–25%
	2	25%–50%
	3	50%–75%
	4	75%–95%
	5	>95%
Organic or mineral soil exposed	0	None observed
	1	1%–5%
	2	5%–15%
	3	15%–25%
	4	25%–90%
	5	>90%
Structural damage to tussocks or hummocks	0	No observable damage to slight scuffing
	1	Tussocks or hummocks scuffed
	2	Tussocks or hummocks crushed
	3	Crushed tussocks nearly continuous or ruts starting to form
	4	Continuous rut, surface vegetation mat continuously disrupted
	5	Continuous rut cut into peat soil

authors of this report (Raynolds), visited the truck sites on 29 June, 3–4 July, and 6 July 2007, and Martha Raynolds returned 10–11 July 2008.

2. METHODS

2.1 Disturbance along truck trails

We used a categorical scale to describe disturbance along the trails created by the truck tires. To determine the proportion of the trail in each disturbance category, we used a hip chain (a device that measures distance using a string) to measure the total distances along the trails as well as the distances between changes in the disturbance categories. Disturbance categories 0–5 ranged from no disturbance (0) to complete destruction (5) of vegetation (Table 1). Levels 1–3 were based on studies of impacts of winter seismic trails on the coastal plain of the Arctic National Wildlife Refuge (after Felix and Raynolds 1989). We added 2 additional levels, 4 and 5, to characterize disturbance exceeding that caused by winter seismic vehicle traffic.

The area of the disturbance was calculated using the average tire track width measured in 2007 (30 cm) and the length of trail showing either 2 vehicle tracks (where the 2 trucks' paths coincided) or 4 vehicle tracks (where their paths diverged).

The distributions of disturbance levels in 2007 and 2008 were compared using a chi-square test to evaluate the significance of the changes.

2.2 Disturbance at excavations

At each excavation site we mapped 10-m × 10-m areas encompassing most of the disturbed ground and categorized the disturbance on the maps (Figure 2). For the most part we used the same disturbance categories as for the trails (Table 1) to calculate the area in each disturbance category for the 2 excavation sites. However, in 2007 we did not differentiate Level 1 from Level 2 in mapping the excavations.

2.3 Transects

We established 7 linear transects in 2007 and resurveyed them in 2008. These transects, 30 to 50 m long, included 2 transects at each excavation site (one across the middle of the excavation parallel to the trail, and one across the middle of the excavation perpendicular to the trail). The other 3 transects were perpendicular to the vehicle trails: one where the worst disturbance caused by both vehicles occurred, one in a location that typified the overall disturbance where both vehicles drove, and one in a location that typified the disturbance caused by a single vehicle (Table 2).

Figure 2. Martha Raynolds mapping the footprint of the excavation at the Close Truck site, 1 year after unauthorized trucks were driven over unfrozen tundra, Toolik Lake ACEC, Alaska, 6 July 2007.

We measured thaw depth, cover type, and surface elevation every meter along these transects in undisturbed (control) areas and every 0.5 m in areas adjacent to and including vehicle tracks. We measured surface elevation from a cable held about 0.5 m above the ground, stretched taut between anchors at either end of the transect. In 2008 we also measured elevation on 4 transects using a green laser pointer mounted on a tripod (Figure 3). From these data we plotted the elevation profiles of the transects, determined the average thaw depth in the control and disturbed areas, and calculated the percentage of each cover type in the control and disturbed areas. We used t-tests to test for significance of differences between control and disturbed areas of each transect, and between the disturbed area of each transect in 2007 and the same area in 2008.

Additional information on the transects and sampling methodology may be found in Appendix A.

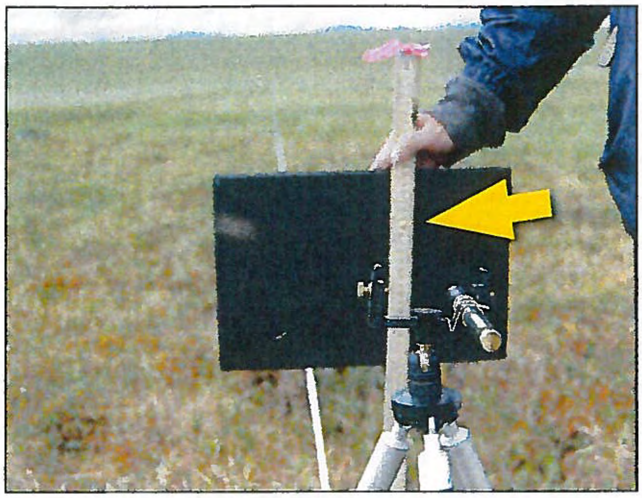


Figure 3. Laser pointer used to measure elevation along transects where 2 pickup trucks created trails by traveling on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Orange arrow points to green dot on meter stick.

2.4 Vegetation cover

We determined vegetation cover by species in July 2007 using a linear, vertical point frame (Felix and Raynolds 1989). This survey was not repeated in 2008 because the sampling is time-consuming and the results are not likely to change quickly. We recorded data in the disturbed and control portion of each of the 3 trail transects and at the perpendicular transect at each excavation site (Figure 4). The frame measured 10 points for every meter, and we recorded 10 frames for each sample. This resulted in 100 hits along 10 m of transect. We set up the frame along the tire tracks for the disturbed trail sites (perpendicular to the transects) and along the transects for the control areas and the excavation sites. We recorded the genus and species of each plant

Table 2. Description, location, and length of transects established in July 2007 to monitor tundra disturbance caused by pickup truck travel over unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska.

Transect	Type of disturbance	Location	GPS coordinates (WGS 84)	Transect length (m)	Direction	Disturbed portion
Far Truck 1	Excavation	Far truck excavation, perpendicular to direction of travel	68°41.51' N 149°19.95' W	50	East to West	20–30 m from E end, especially 22.5–29.5 m
Far Truck 2	Excavation	Far truck excavation, parallel to direction of travel	68°41.51' N 149°19.95' W	40	North to South	15–25 m from N end, especially 16.5–24.5 m
Close Truck 1	Excavation	Close truck excavation, perpendicular to direction of travel	68°39.52' N 149°18.48' W	47	East to West	20–27 m from E end
Close Truck 2	Excavation	Close truck excavation, parallel to direction of travel	68°39.52' N 149°18.48' W	30	North to South	10–19 m from N end
Worst Trail	Level 5 trail	Perpendicular to trail, 80 m south of close excavation, 700 m north of road	68°39.46' N 149°18.41' W	30	East to West	14–16.5 m from E end
Double Trail	Level 2 trail	Perpendicular to trail, 500 m north of road	68°39.33' N 149°18.58' W	40	East to West	19–22 m from N end
Single Trail	Level 1 trail	Perpendicular to trail, close to pipeline, 250 m north of close excavation	68°39.63' N 149°18.84' W	40	East to West	18–22 m from E end

hit by a descending, sharpened pin 2 mm in diameter. If the pin hit litter, bare ground (peat or soil), or water, we recorded these as well. Percent cover of disturbed and control portions of each transect was summarized by species and by total live vegetation cover vs. litter or bare ground.

2.5 Photographs

Each year we took photographs from both ends of each transect, from the edge of the disturbance looking along the transect, and from the center of the disturbance looking along the trail in both directions.

Figure 4. Vertical point frame used to measure tundra disturbance in the Toolik Lake ACEC, Alaska, 2007. The frame is 1 m long and has 10 pins spaced at 10-cm intervals along the frame.

3. RESULTS

3.1 Length, area, and disturbance level

3.1.1 Truck tracks

The portion of the trail traveled by both trucks, i.e., from the Dalton Highway to the Close Truck excavation, was 850 m. Most of the disturbance along this trail was Level 2 in both 2007 (67.3%), and 2008 (50.8%). Two tracks were visible over 68% of this distance, while 4 tracks were visible over the remaining 32% of the distance.

Only the Far Truck traveled the remaining 3733 m of the trail, from the Close Truck to the Far Truck excavation site. Because of its much longer length, the single-truck trail accounted for more of the disturbed area than the trail made by both trucks. Most of this trail had Level 1 disturbance in 2007 (51.6%) and Level 2 disturbance (62.8%) the following year. In contrast, most of the area with higher disturbance levels (Levels 4 and 5) occurred on the trail used by both trucks.

The combined length of disturbance, including the sections traversed by both trucks and sections traversed by only one truck, was 4855 m. Multiplying this length by the average tire track width of 30 cm resulted in a tire track disturbance of 1457 m^2 (Table 3).

In 2008 most (61%) of the disturbance we detected along the tracks was Level 2, an increase from 40% found in 2007 (Table 3). We also observed an increase in areas with Levels 3–5 disturbance, along with a commensurate decrease in areas with Level 1 disturbance (Figure 5). Overall, disturbance levels were significantly greater in 2008 than 2007 ($p < 0.001$).

Table 3. Length of trail, level of disturbance, and area disturbed by 2 pickup trucks that traveled on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Measured in July 2007 and July 2008.

Level of disturbance	Percent of total length in 2007	Area disturbed 2007 (m^2)	Percent of total length in 2008	Area disturbed 2008 (m^2)
0	0.1	1	0.1	1
1	51.6	751	25.3	369
2	39.8	579	60.7	885
3	6.3	92	8.2	119
4	1.7	25	3.4	49
5	0.6	8	2.3	33
Total	**100.0**	**1457**	**100.0**	**1457**

3.1.2. Excavation sites

In 2007 the Close Truck excavation disturbed approximately 47.2 m^2 and the Far Truck excavation disturbed 54.3 m^2. Of the total 101.5 m^2 disturbed, 67 m^2 exhibited the highest level of disturbance (Level 5). The excavation areas were oval-shaped and included the footprints of the trucks and the excavation activities used to extract them (Figure 6). The centers had a less-disturbed area that was protected under the middle of the trucks. At both sites, original vegetation was missing in the areas that had underlain the wheels; in these areas the frozen, disturbed soil and vegetation had been removed during excavation and later returned. At the Close Truck excavation, the soil was gray silt. At the Far Truck excavation, the soil was organic peat. The edges of the excavation areas had lower levels of disturbance caused by activities such as foot traffic and vehicle traffic on frozen tundra.

Between 2007 and 2008, the area of the highest disturbance levels (Levels 3–5) changed little (Table 4, Figure 6). However, Level 1 and 2 disturbance was more evident and covered more area in 2008. Total disturbance of the excavation sites increased during this period from approximately 102 m^2 to 152 m^2, expanding outside the 10-m × 10-m plots we established in 2007. As was the case for the truck trails, this increase in disturbed area was due to deeper thaw and some subsidence, which increased water cover (Figure 7) and decreased plant cover. In 2008 water covered 0%–25% of the Level 3 disturbance, 50%–75% of the Level 4 disturbance, and 100% of the Level 5 disturbance.

3.2 Transect thaw depth, cover, and elevation

Thaw depths in disturbed areas were significantly deeper than in control areas at all but the worst trail, where 2 trucks had traveled (Figure 8). Thaw depths were deeper in 2008 than in 2007 (35–60 cm compared to 25–45 cm). We observed little change between years in the amount of vegetative cover on portions of the transects crossing trails compared to adjacent control areas (Figure 9). The excavation sites, on the other hand, had less live vegetation and more soil and water cover than control areas. Elevations were significantly lower in the disturbed areas than in the control areas for most transects (Figure 10). Elevations of the disturbed section were lower in 2008 than in 2007 for all 4 excavation transects.

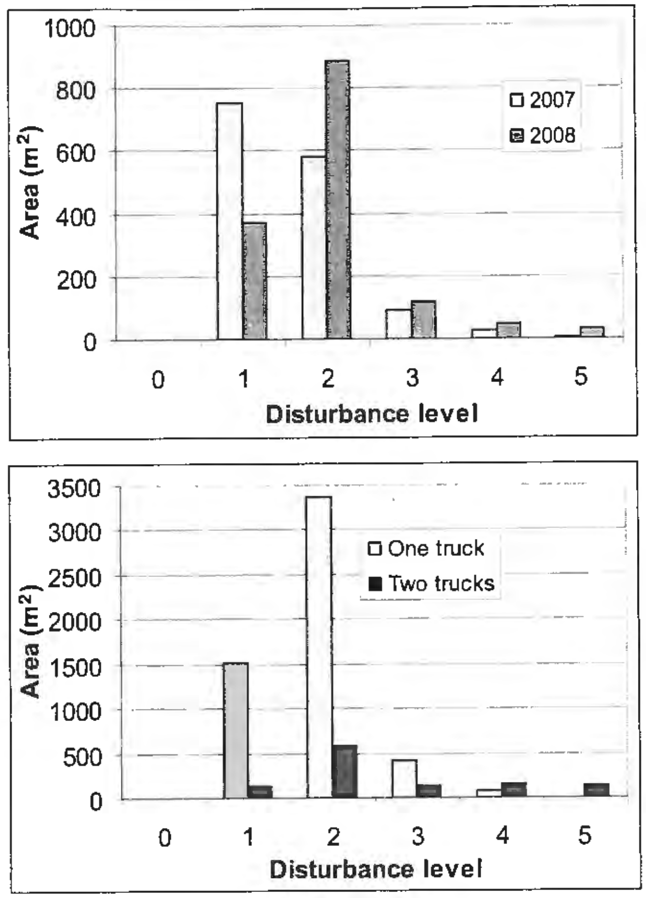


Figure 5. Area of different disturbance levels caused when 2 pickup trucks traveled on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Top – all trails evaluated in July 2007 and 2008. Bottom – trails caused by a single truck compared to trails caused by 2 trucks, evaluated in July 2008. Differences in distributions are significant (chi-square test, p<0.001).

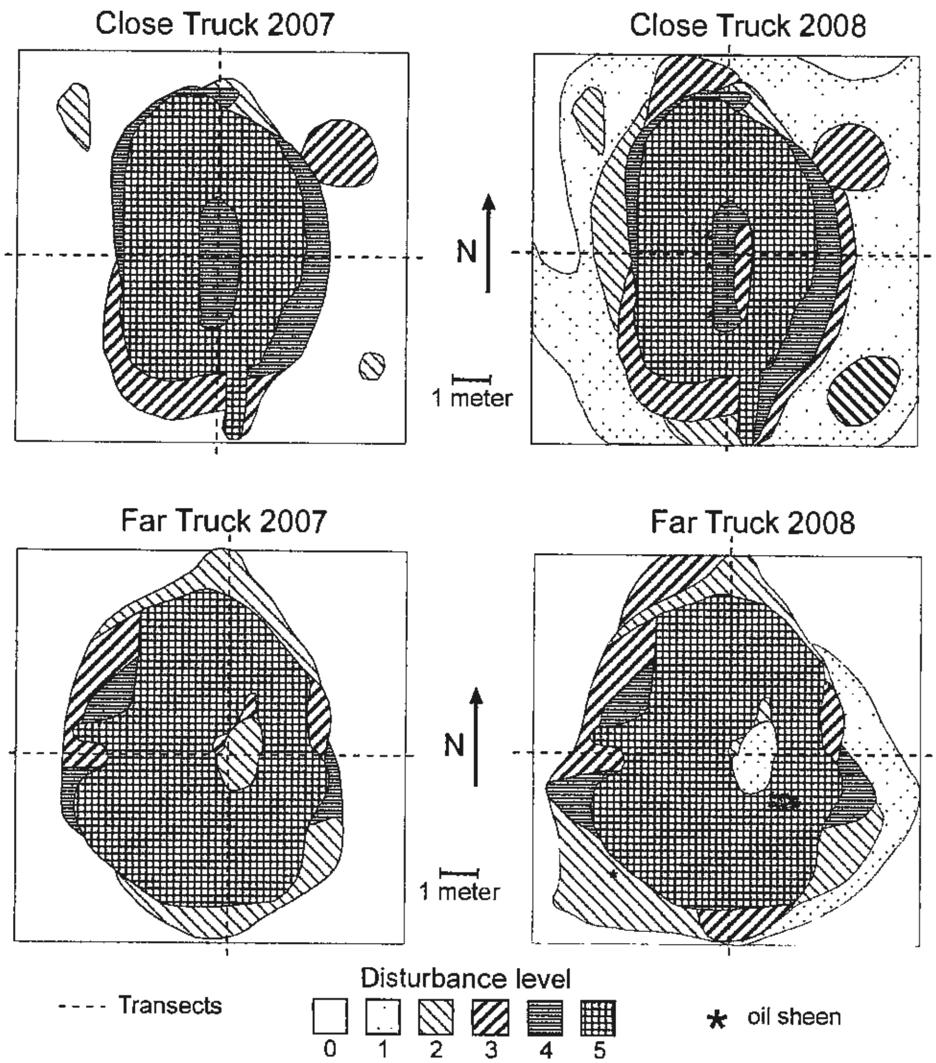


Figure 6. Maps of vegetation disturbance within 10-m × 10-m areas where trucks were excavated in April 2007 after becoming stuck in unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Central portions of the transects crossing the excavations are depicted by dashed lines. Mapping was completed in July 2007 and July 2008.

Table 4. July 2007 and July 2008 measurements of area impacted and level of disturbance caused by excavation of trucks that had become stuck after traveling on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Disturbance outside the 10-m × 10-m plots established at each site is not included in the table.

Disturbance level	Close Truck Excavation 2007 (m^2)	Close Truck Excavation 2008 (m^2)	Far Truck Excavation 2007 (m^2)	Far Truck Excavation 2008 (m^2)
0	52.8	13.6	45.7	34.3
1	2.0	34.1	9.1	7.8
2		13.4		10.8
3	7.3	5.8	4.5	7.6
4	8.9	7.6	2.7	3.7
5	29.0	25.4	38.0	35.8

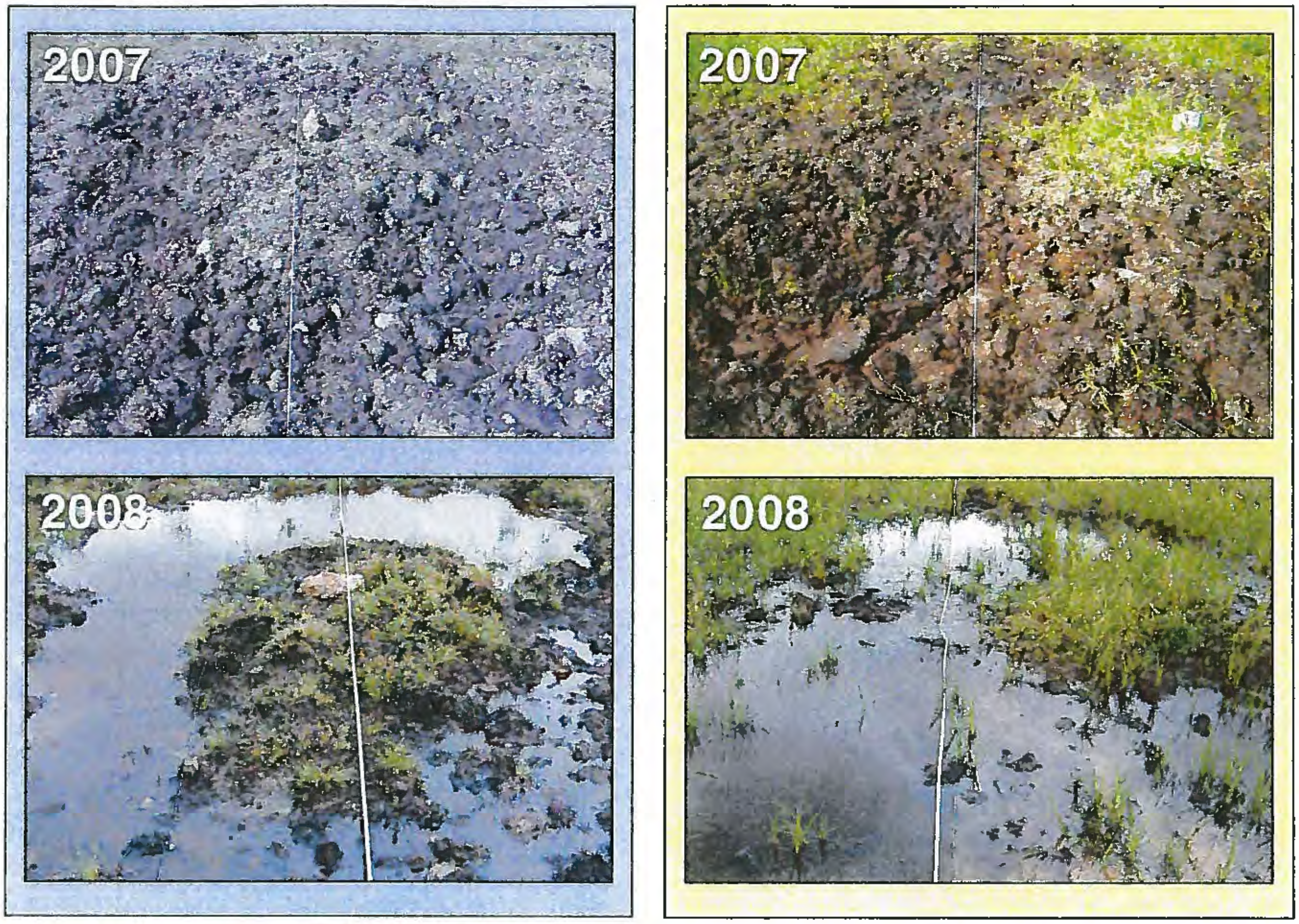


Figure 7. Photos taken in 2007 and 2008 at the Close Truck (left) and Far Truck (right) excavation sites, where habitat was disturbed by 2 pickup trucks that traveled on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. All photos were taken from the southern edge of the excavations looking north, matching the orientation of the maps in Figure 6.

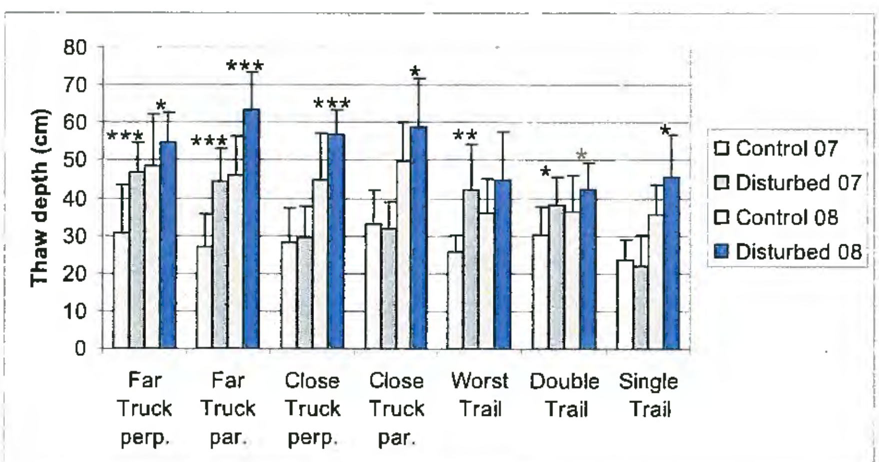


Figure 8. July 2007 and July 2008 thaw depths measured along 7 transects where habitat was disturbed by 2 pickup trucks that traveled on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. One transect was perpendicular (perp.) and one parallel (par.) to the direction of travel at the Far Truck and Close Truck excavation sites, and 3 transects were perpendicular to trails where different disturbance levels occurred (Worst Trail, Double Trail, Single Trail). T-test significance of difference between disturbed and control in each year: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

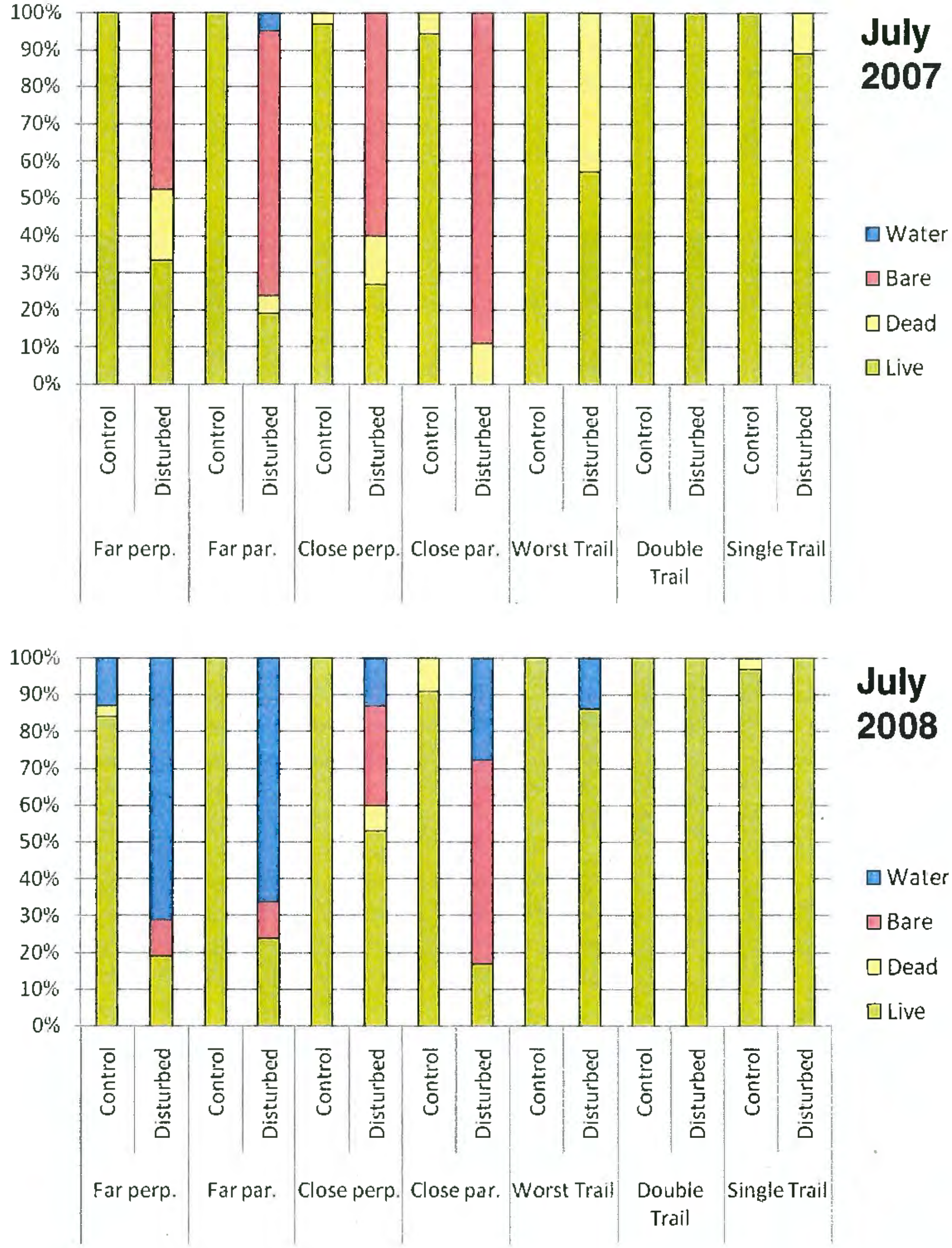
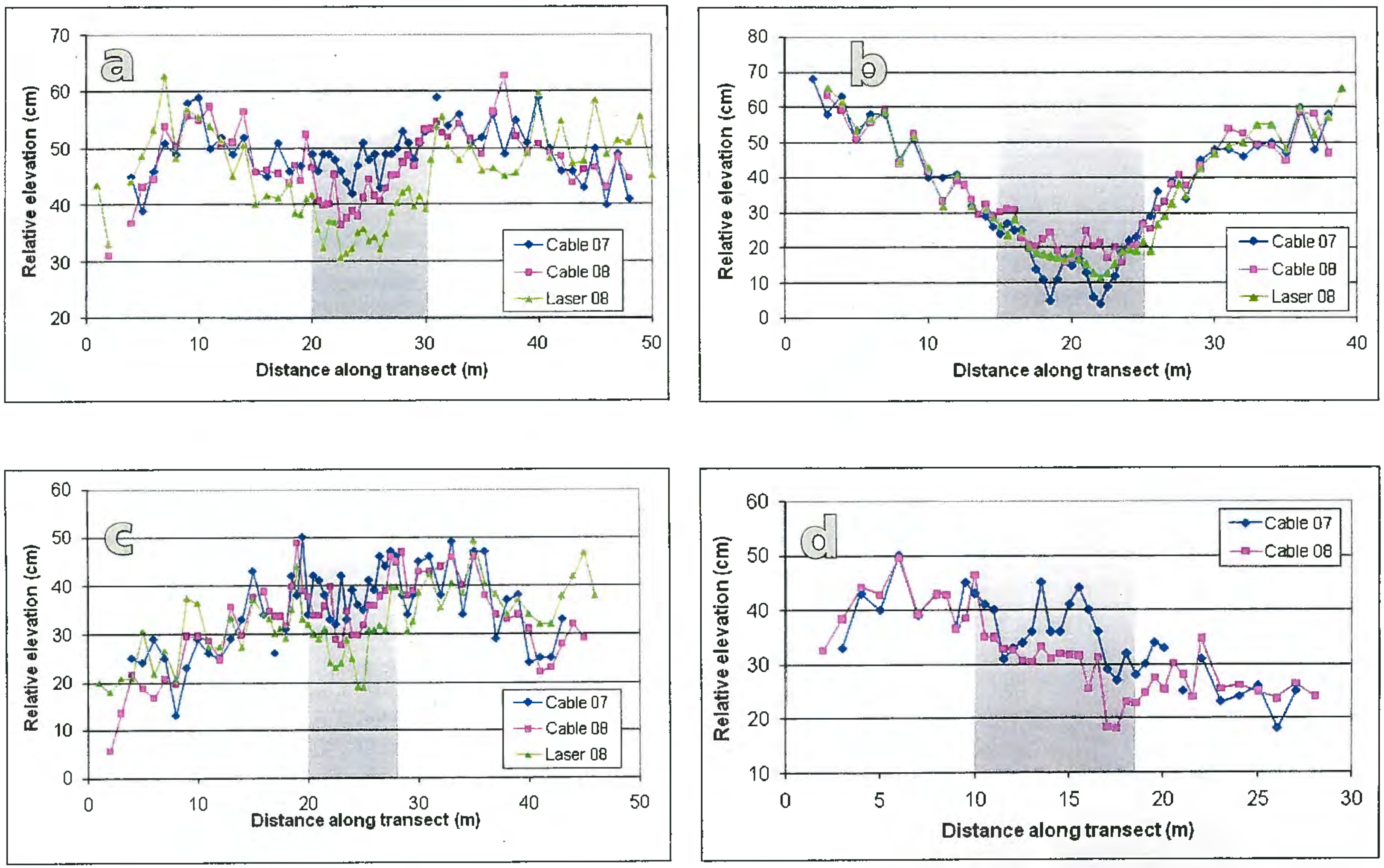


Figure 9. Percent cover of live vegetation, dead vegetation, bare soil or peat, and water measured in July 2007 and July 2008 on control and disturbed sections of 7 transects where habitat was disturbed by 2 pickup trucks that traveled on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. One transect was perpendicular (perp.) and one parallel (par.) to the direction of travel at the Far Truck and Close Truck excavation sites, and 3 transects were perpendicular to trails where different disturbance levels occurred (Worst Trail, Double Trail, Single Trail).


a
Relative elevation (cm)
Distance along transect (m)
Cable 07
Cable 08
Laser 08
b
Relative elevation (cm)
Distance along transect (m)
Cable 07
Cable 08
Laser 08
c
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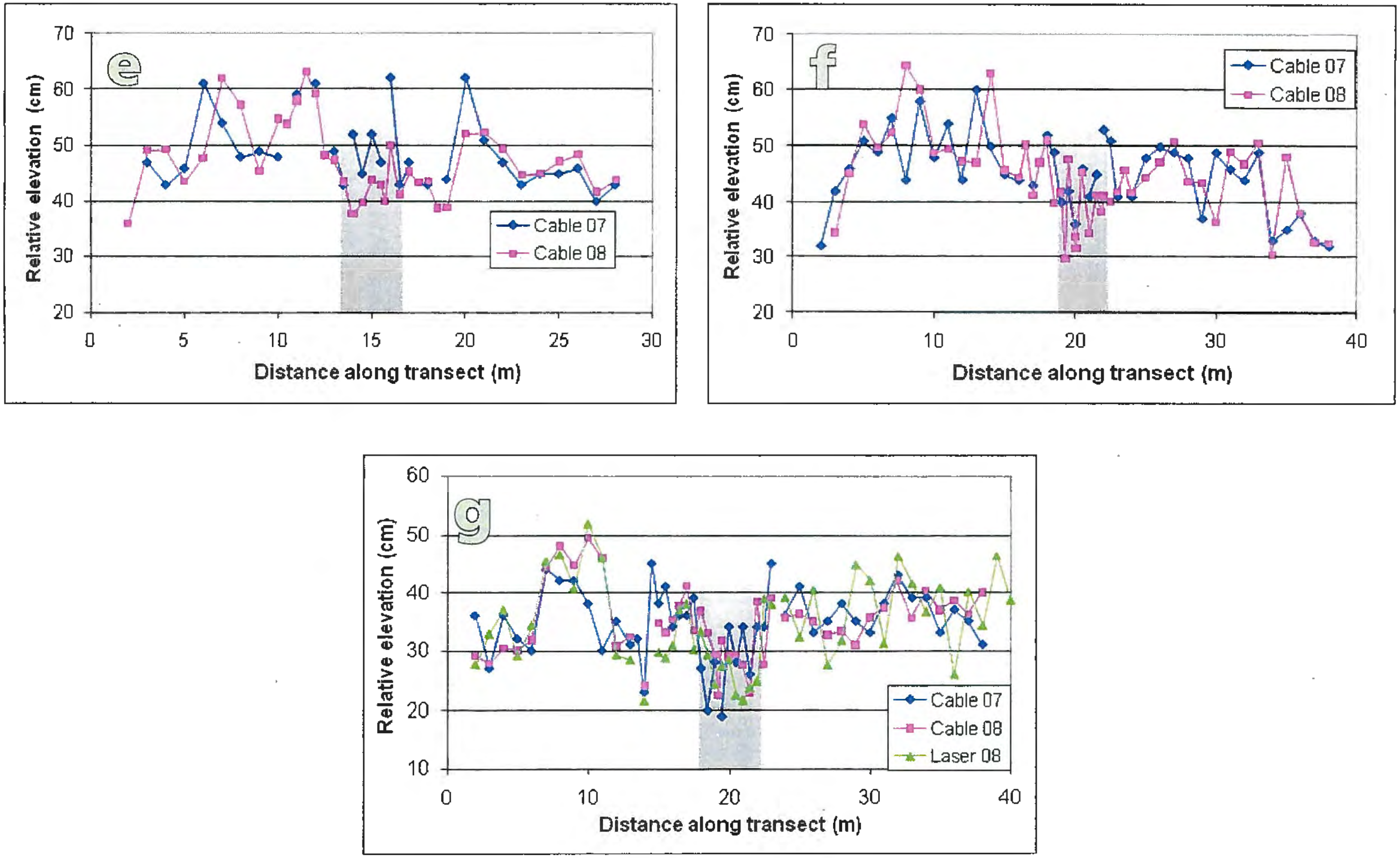

Figure 10. Elevation profiles of transects established across trails and truck excavation sites resulting from unauthorized truck travel over unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Data were collected in July 2007 and July 2008. Transects: a) perpendicular to the Far Truck excavation, b) parallel to the Far Truck excavation, c) perpendicular to the Close Truck excavation, d) parallel to the Close Truck excavation, e) perpendicular to Worst Trail (Disturbance Level 5), f) perpendicular to the Double Trail (Disturbance Level 2), g) perpendicular to the Single Trail (Disturbance Level 1). The disturbed area is in the middle of each transect, shown with gray shading. See Table 5 for t-test analysis of differences.

Table 5. T-test of differences between elevation profiles across trails and truck excavation sites resulting from unauthorized truck travel over unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Data were collected in July 2007 and July 2008. n.s. = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, NA = data not available.

Transect	Disturbed vs. control 2007	Disturbed vs. control 2008 (measured by cable)	Disturbed vs. control 2008 (measured by laser)	Disturbed 2007 vs. disturbed 2008 (measured by cable)	Disturbed 2007 vs. disturbed 2008 (measured by laser)
Far Truck excavation perpendicular	n.s.	***	***	***	***
Far Truck excavation parallel	***	***	***	*	n.s.
Close Truck excavation perpendicular	n.s.	n.s.	**	**	***
Close Truck excavation parallel	n.s.	n.s.	NA	**	NA
Worst trail	n.s.	***	NA	*	NA
Double trail	n.s.	**	NA	n.s.	NA
Single trail	***	*	***	n.s.	n.s.

3.3 Point-frame vegetation cover

Cover of live vegetation measured in 2007 by point-frame sampling was less in all disturbed areas than control areas (Table 6) and was >90% less in the excavation areas. Cover of live vegetation in the trails was 87% less in the Worst Trail and 28% and 34% less in the Double and Single trails, respectively. Reduction of nonvascular cover (mosses and lichens) was generally more than reduction in vascular cover. However, this was difficult to measure in this first summer after disturbance, as many of the mosses and lichens were broken and detached. Although these plants appeared to be alive in 2007, some may die in subsequent years. Species-level data are presented in Appendix B.

3.4 Maps and photographs of disturbance

Photographs of the transects are included in the compact disc attached to this report and are listed in Appendix C. Example photos of the 3 trail sites are shown in Figure 11. We established a set of standard photo points to ensure that photographs are taken from the same sites and with the same field of view each year.

4. DISCUSSION

We calculated the area impacted by the trucks by adding the area of the excavation sites to the product of the length of the discernible disturbance along trails and the width of the tire tracks. In subsequent years, as subsidence occurs, the impacted area will likely increase (Felix et al. 1992). The types of impacts will also change with time. Initial impacts included destruction of vegetation along with some change in surface elevation due to the excavations and the tire tracks. Based on studies of similar disturbance in the Arctic National Wildlife Refuge, subsidence is likely to occur in and adjacent to areas with disturbance greater than Level 2, causing increases in soil moisture and changes in plant species composition (Felix et al. 1992, Emers et al. 1995). Revegetation of bare areas will occur, but in many cases, revegetated areas will exhibit a different species composition than the original vegetation. The Arctic National Wildlife Refuge studies also indicated that decreased cover values, changes in thaw depth, surface elevation, and species composition are likely to persist for longer than 10 years (Emers et al. 1995). Even the Tucker

Sno-Cat tracks that were visible in 2007 are likely to persist for at least 5 years.

In 2008 many of the depressions created by the truck disturbance were water-filled, at least partly because 2008 was a cool, wet summer in comparison to the warm, dry summer of 2007. However, the presence of standing water in the tracks also creates a positive feedback: the sun warms the water, which in turn thaws the permafrost, causing a reduction in soil ice that leads to further subsidence and even more surface water ponding. As a result, the disturbance level of the trails increased between 2007 and 2008, and the trails, because of their significantly deeper thaw depths, were significantly lower than the surrounding tundra. The size of the area affected at the excavations also increased, suggesting that subsidence may spread from the original impacted areas to adjacent areas in the future (Felix et al. 1992).

Our work shows that the disturbed areas are continuing to change rapidly. The first 2 years of data give a solid description of the initial level of disturbance. Long-term monitoring should include 5-year and 10-year resampling of the sites (2012 and 2017).

5. SUMMARY

Two vehicles driven across non-frozen tundra in September 2006 affected over 1607 m^2 of tundra. We quantified the habitat disturbance at 5 different levels, with Level 1 being the

Table 6. Percent cover of vegetation categories and percent decrease between vegetative cover in control sites and sites disturbed by truck trails and excavations resulting from unauthorized truck travel across unfrozen tundra in Toolik Lake ACEC, Alaska, September 2006. Measured by point-frame sampling in July 2007.

Disturbance type	Cover	% Cover Control	% Cover Disturbed	% Cover Decrease in Disturbed
Far Truck excavation perpendicular	Live vegetation	118	10	92
	Vascular	62	7	89
	Moss	56	3	95
	Lichen	0	0	none
Close Truck excavation perpendicular	Live vegetation	102	3	97
	Vascular	51	3	94
	Moss	37	0	100
	Lichen	14	0	100
Worst Trail	Live vegetation	116	15	87
	Vascular	37	11	70
	Moss	74	4	95
	Lichen	5	0	100
Double Trail	Live vegetation	128	92	28
	Vascular	60	42	30
	Moss	62	47	24
	Lichen	6	3	50
Single Trail	Live vegetation	141	93	34
	Vascular	67	46	31
	Moss	71	39	45
	Lichen	3	8	*More lichen in disturbed than control*

least disturbed and Level 5 the most. In 2008 the amount of disturbance along trails and at excavation sites by category was: 411 m^2 of Level 1 disturbance, 909 m^2 of Level 2 disturbance, 132 m^2 of Level 3 disturbance, 60 m^2 of Level 4 disturbance, and 94 m^2 of Level 5 disturbance. Over half of the Level 5 disturbance occurred where the trucks were excavated. In addition, thaw depths were generally deeper in disturbed areas than control areas, and trails were generally lower than the surrounding tundra. Plant species cover was reduced by disturbance, though differences were only significant for the excavations. Nonvascular plants (mosses and lichens) were generally more affected than vascular plants. We noted significant differences in measured parameters between the first and second year after disturbance. In 2008 the greater thaw depths in both the control and disturbed areas and the lower elevations in disturbed areas (especially the excavations) resulted in pooling of surface water at excavation sites. The types of impacts and area impacted are likely to change over the next 10 years, and continued monitoring is recommended.

Figure 11. Photos of trails caused by pickup truck travel on unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Top – Worst Trail, looking south. Middle – Double Trail, looking south. Bottom – Single Trail, looking south.

6. REFERENCES

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APPENDIX A. RECOMMENDATIONS FOR FUTURE SAMPLING

These transects should be resampled and photographed in 2012 and 2017 (5 and 10 years post-disturbance). This would take approximately 3 person-days of field time each year. In addition, the trails should be reevaluated to determine whether the proportion in each disturbance level changes (1 person-day). The vegetation point-frame sampling would take an additional 2 person-days of field time, for a total of 6 person-days each year. In 2017 a long-term resampling schedule should be determined.

For questions, contact Martha Raynolds (MarthaRaynolds@alaska.edu), 907-474-6720.

A.1 Repeating trail disturbance measures

Measuring the proportions of the trails with 2 or 4 tracks need not be repeated. This distinction will only become less visible and more difficult to determine with time. The proportions measured in 2007 can be used for all subsequent calculations. Similarly, the length of the track measured in 2007 can be used for all subsequent calculations. The disturbance rating along the trail should be repeated to document recovery by determining the percentage of the trail in each disturbance category. A hip chain is useful, but well-calibrated paces can also be used, as the goal is to obtain a percentage of the total trail length. Bring a copy of the disturbance rating sheet on water-resistant paper and refer to it often to maintain consistency of ratings.

A.2 Updating the maps

Make copies of the 2008 maps or use a clear overlay to map changes. Using pin flags and a tape to mark the outline of the 10-m × 10-m square and center lines is very helpful. Mapping at the excavation sites will likely need to be expanded in future years to include all of the areas disturbed by subsidence. Use the same 5 disturbance level categories as for the trails.

A.3 Repeating the transect measurements

We permanently marked the ends of the transects with pieces of rebar 0.75 m long and 9.5 mm in diameter, hammered into the tundra until only about 0.3 m was sticking out of the ground. We then placed white PVC pipe (about 1.5 m long, with an outside diameter of 19 mm) over the rebar and attached aluminum tags with identification information at ground level. The locations where transects crossed the trails were recorded from a Garmin eTrex® GPS in degrees decimal minutes using WGS 84 (Table 2 in the report).

Print the forms that are specific to each site (name and sampling locations are already filled in). Bring new aluminum tags to replace missing or illegible ones. Upon arrival at the site, make sure the ends of the transects are still well marked. The rebar may have jacked out and need to be pounded in again.

The laser technique we used for measuring transect elevations in 2008 was much quicker to set up and measure than the cable technique. The laser dot, visible even on sunny days, expanded in diameter to only about 1 cm at 25 m and did not enlarge much beyond that distance. However, the laser's greatest benefit was that it eliminated the error introduced by the cable's sag across long transects. Cable sag makes the center of the transect seem higher than it really is relative to elevations taken at the ends of the cable, particularly for transects longer than 40 m. As a result, the graphs for the 50-m transects parallel to the truck excavations exhibit higher values for the cable transects than for the laser transects in the transects' centers, where the excavations are located (Figure 10 a, c). Comparisons between years for cable data are still valid because cable sag is probably consistent between years. Nonetheless, future comparisons could be improved by using just the laser technique.

One unresolved problem with the laser is that it cannot be used in rainy weather because it might short-circuit. This could be remedied by placing a shelter over the instrument.

Another modification that would improve the year-to-year consistency of the elevation data would be to place small pin-flags at each measuring point. Even a few centimeters of horizontal variation in the measured location of these points can make a large (≥10 cm) difference in recorded elevations (the difference between being on top of or between tussocks). Exact relocation of measuring points would also allow paired t-test analysis, which would strengthen statistical tests of between-year changes. Again, we recommend using a green laser for measuring elevation and thaw depth, rather than the much more elaborate cable system, which is subject to inaccuracies due to cable sag.

A.4 Repeat point framing

Bring the data sheet that shows the sections of the transect that were sampled with the point frame in 2007 and repeat the point-frame sampling in the same locations. Use a small level to ensure that the frame is more or less level vertically and horizontally. It can also be useful to bring the species list from previous years, as the same species will likely be hit in subsequent years. Collect samples of any unknown species you hit and bring them back to Toolik Field Station for identification. The Toolik herbarium has good collections of non-vascular and vascular plants.

A.5 Repeat photographs

Bring the data sheet that shows the photo point numbers and locations. Three types of photographs have been taken during this project. Landscape photographs are taken by including a small amount of sky in the top of the photograph. Photos of the disturbance are taken from either edge of the disturbance, framed so as to include just the disturbed area. Vertical photos are taken looking straight down. It is very easy to confuse which photo is which, so take them in a consistent order (preferably the order on the data sheet), and write down the photo numbers as you take them. Take additional photos of the general site and of people sampling.

A.6 Materials list

- Frame pack to carry point frame, meter sticks, etc.
- 4 aluminum tags to replace any missing/illegible ones
- 400 small pin flags (to permanently mark measuring points along transects)
- 1 meter stick
- 1 green laser pointer
- 1 tripod with rotating, adjustable top
- Small umbrella or other shelter for laser
- 1 50-m tape
- Thaw probe (1-m long)
- Digital camera
- GPS
- Pencils
- Markers (including one that will write on overlays for making changes to excavation maps)
- Clipboard
- 1 copy of disturbance rating descriptions on water-resistant paper
- 2 trail disturbance data sheets on water-resistant paper
- 2 copies of maps of excavations on water-resistant paper
- 7 transect elevation, thaw and cover data sheets on water-resistant paper
- 10 point-frame data sheets
- 1 photo point data sheet (3 pages long) on water-resistant paper
- Point frame (vertical frame: 1-m long with 10 pins and 2 legs – borrowed from Arctic National Wildlife Refuge, contact Janet Jorgenson or Dave Payer)
- Small level (for point frame)
- Duct tape (at least 20 cm for restraining point frame pins)
- Rubber bands (to stop point frame from sliding down point frame legs)

APPENDIX B. COVER SAMPLING RESULTS BY SPECIES

Table B-1. Species and percent cover sampled in July 2007 on disturbed and control portions of transects across trails created by unauthorized truck travel across unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Data from vertical point-frame sampling. See Table B-2 for species codes.

Transect	Vascular Species	% cover	Moss Species	% cover	Lichen Species	% cover	Non-vegetated	% cover
Close Truck								
Control	BETNAN	5	AULTUR	9	CETCUC	3	Litter	43
	CARBIG	2	DICRA	12	CETISL	2		
	CASTET	4	HYLSPL	4	CLAGRA	3		
	ERIVAG	16	SPHAG	12	CLARAN	4		
	LEDDEC	13			DACARC	2		
	RUBCHA	3						
	VACVIT	8						
Disturbed	BETNAN	1					Litter	3
	ERIVAG	2					Water	1
							Bare soil/ peat	96
Far Truck								
Control	BETNAN	5	SPHAG	53			Litter	70
	CARROT	19	leafy liver-wort	3				
	ERIANG	1						
	SALFUS	37						
Disturbed	CARROT	2	SANUNC	2			Litter	5
	ERIANG	1	SPHAG	1			Bare soil/ peat	92
	RUBCHA	2						
	SALFUS	2						
Worst Trail								
Control	ANDPOL	1	AULTUR	7	CLAGRA	1	Litter	30
	BETNAN	4	DICRA	8	CLARAN	4		
	ERIANG	1	HYLSPL	3				
	ERIVAG	6	POLJUN	13				
	LEDDEC	5	SPHAG	43				
	PEDLAB	1						
	RUBCHA	6						
	SALARC	1						
	VACVIT	12						

(cont.)

Table B-1 (cont.). Species and percent cover sampled in July 2007.

Transect	Vascular Species	% Cover	Moss Species	% Cover	Lichen Species	% Cover	Non-vegetated	% Cover
Worst Trail								
Disturbed	BETNAN	1	SPHAG	4			Litter	25
	CARBIG	1					Peat	71
	ERIVAG	6						
	RUBCHA	1						
	VACVIT	2						
Double Trail								
Control	BETNAN	11	AULTUR	6	CETCUC	1	Litter	43
	CARBIG	1	DICRA	6	CLARAN	1		
	CASTET	1	HYLSPL	12	DACARC	4		
	ERIVAG	8	SPHAG	37				
	LEDDEC	13				6		
	POLBIS	1	leafy liver-wort	1				
	RUBCHA	1						
	SALPUL	1						
	VACVIT	23						
Disturbed	ANDPOL	1	AULTUR	6	CETCUC	2	Litter	51
	BETNAN	11	DICRA	11	PELMAL	1	Pear	1
	CARBIG	1	HYLSPL	10				
	CASTET	1	POLJUN	2				
	ERIVAG	13	SPHAG	18				
	LEDDEC	4						
	RUBCHA	2						
	VACVIT	9						
Single Trail								
Control	ANDPOL	1	AULTUR	6	CETISL	1	Litter	39
	BETNAN	13	DICRA	5	CLARAN	2		
	CARBIG	3	HYLSPL	5				
	CASTET	1	POLJUN	2				
	ERIVAG	10	SPHAG	53				
	LEDDEC	16						
	PEDLAB	2						
	RUBCHA	8						
	SALPUL	2						
	VACVIT	11						

(cont.)

Table B-1 (cont.). Species and percent cover sampled in July 2007.

Transect	Vascular Species	% Cover	Moss Species	% Cover	Lichen Species	% Cover	Non-vegetated	% Cover
Single Trail								
Disturbed	BETNAN	8	AULTUR	3	CETCUC	1	Litter	42
	CARBIG	1	DICRA	4	CLAGRA	1	Peat	2
	CASTET	6	HYLSPL	10	CLARAN	3		
	ERIVAG	4	SPHAG	22	DACARC	2		
	LEDDEC	8			PELMAL	1		
	RUBCHA	4						
	SALPUL	3						
	VACVIT	12						

Table B-2. Plant species recorded by point-frame sampling on transects across trails created by unauthorized truck travel across unfrozen tundra, Toolik Lake ACEC.

Code	Genus & Species
Vascular	
ANDPOL	*Andromeda polifolia*
BETNAN	*Betula nana*
CARBIG	*Carex bigelowii*
CARROT	*Carex rotundata*
CASTET	*Cassiope tetragona*
ERIANG	*Eriophorum angustifolium*
ERIVAG	*Eriophorum vaginatum*
LEDDEC	*Ledum palustre* ssp. *decumbens*
PEDLAB	*Pedicularis labradorica*
POLBIS	*Polygonum bistorta*
RUBCHA	*Rubus chamaemorus*
SALARC	*Salix arctica*
SALFUS	*Salix fuscescens*
SALPUL	*Salix pulchra*
VACVIT	*Vaccinium vitis-idaea*
Mosses	
AULTUR	*Aulacomnium turgidum*
DICRA	*Dicranum* sp.
HYLSPL	*Hylocomium splendens*
POLJUN	*Polytrichum juniperinum**
SANUNC	*Sanionia uncinata*
SPHAG	*Sphagnum* sp.
Lichens	
CETCUC	*Flavocetraria cucullata*
CETISL	*Cetraria islandica*
CLAGRA	*Cladonia gracilis*
CLARAN	*Cladina rangiferina**
DACARC	*Dactylina arctica*
PELMAL	*Peltigera malacea**

* tentative species identification

APPENDIX C. PHOTOGRAPHS

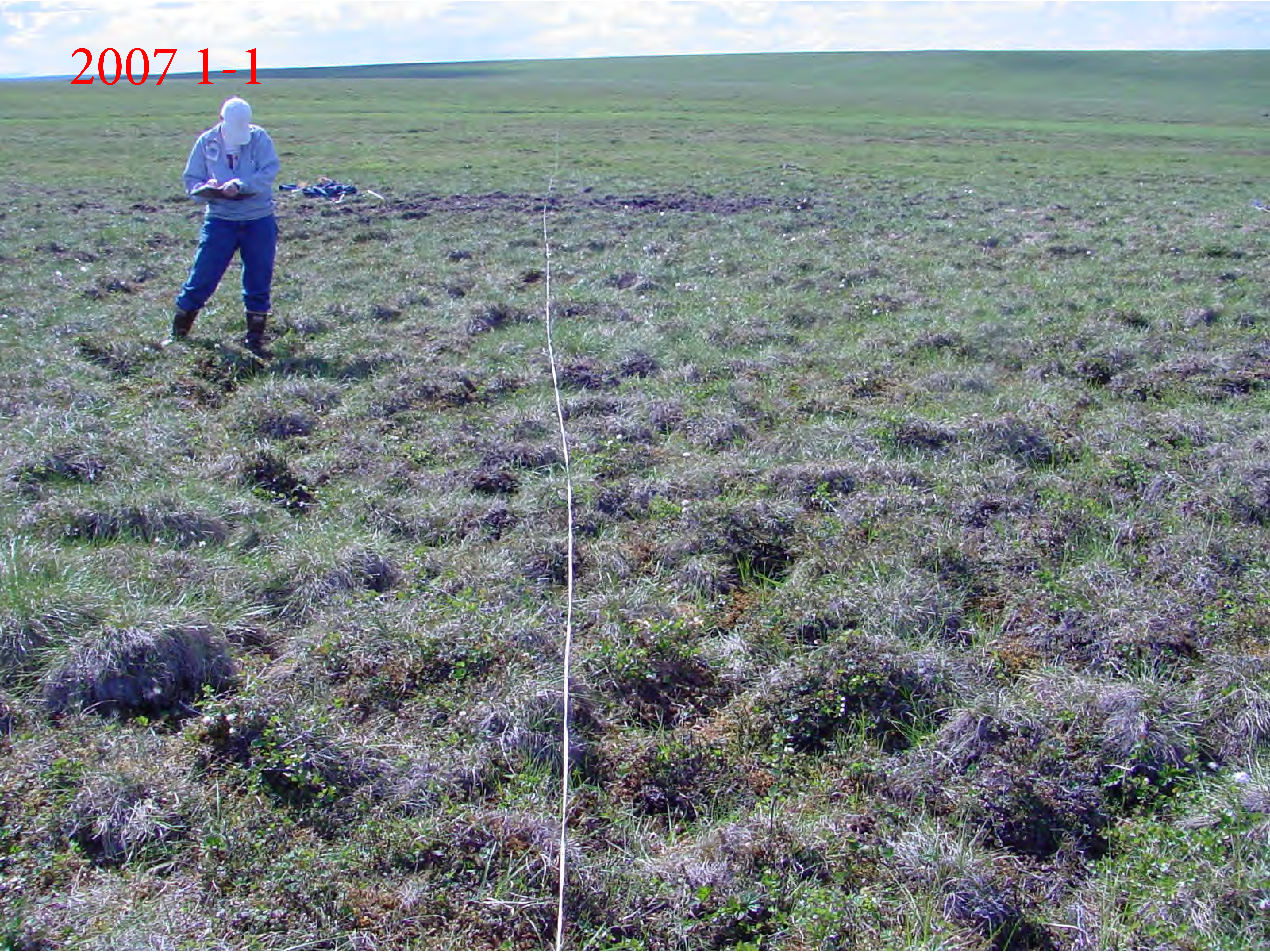
Table C-1. Photograph points at transects in disturbed areas resulting from unauthorized truck travel over unfrozen tundra in September 2006, Toolik Lake ACEC, Alaska. Photographs taken at these points in 2007 and 2008 are included in digital form (jpeg format) on the compact disc at the end of this report.

Transect # and Orientation	Location	Perspective	Photo #
Transect 1 – Perpendicular to Close Truck excavation	East end, looking W	Landscape view	1-1
	20 m from E end, looking W	Landscape view	1-2
	20 m from E end, looking W	Just disturbance	1-3
	23.5 m from E end, looking down	Vertical	1-4
	27 m from E end, looking E	Just disturbance	1-5
	27 m from E end, looking E	Landscape view	1-6
	West end, looking East	Landscape view	1-7
Transect 2 – Parallel to Close Truck excavation	North end, looking S	Landscape view	2-1
	11 m from N end, looking S	Landscape view	2-2
	11 m from N end, looking S	Just disturbance	2-3
	15 m from N end, looking down	Vertical	2-4
	19 m from N end, looking N	Just disturbance	2-5
	19 m from N end, looking N	Landscape view	2-6
	South end, looking N	Landscape view	2-7
Transect 3 – Perpendicular to Worst Trail (Disturbance Level 5)	East end, looking West	Landscape view	3-1
	14 m from E end, looking W	Landscape view	3-2
	14 m from E end, looking W	Just disturbance	3-3
	14 m from E end, looking down	Vertical	3-4
	15 m from E end, looking N	Landscape view	3-5
	15 m from E end, looking S	Landscape view	3-6
	15.8 m from E end, looking down	Vertical	3-7
	16 m from E end, looking E	Just disturbance	3-8
	16 m from E end, looking E	Landscape view	3-9
	West end, looking East	Landscape view	3-10
Transect 4 – Perpendicular to Far Truck excavation	East end, looking West	Landscape view	4-1
	22 m from E end, looking W	Landscape view	4-2
	22 m from E end, looking W	Just disturbance	4-3
	22 m from E end, looking down	Vertical	4-4
	30 m from E end, looking E	Just disturbance	4-5
	30 m from E end, looking E	Landscape view	4-6
	West end, looking East	Landscape view	4-7

(cont.)

Table C-1 (cont.). Photograph points at transects in disturbed areas.

Transect # and Orientation	Location	Perspective	Photo #
Transect 5 – Parallel to Far Truck excavation	North end, looking S	Landscape view	5-1
	16 m from N end, looking S	Landscape view	5-2
	16 m from N end, looking S	Just disturbance	5-3
	20.5 m from N end, looking down	Vertical	5-4
	25 m from N end, looking N	Just disturbance	5-5
	25 m from N end, looking N	Landscape view	5-6
	South end, looking N	Landscape view	5-7
Transect 6 – Perpendicular to Double Trail (Disturbance Level 2)	East end, looking West	Landscape view	6-1
	18 m from E end, looking W	Landscape view	6-2
	18 m from E end, looking W	Just disturbance	6-3
	18 m from E end, looking down	Vertical	6-4
	20 m from E end, looking N	Landscape view	6-5
	20 m from E end, looking S	Landscape view	6-6
	22 m from E end, looking down	Vertical	6-7
	22 m from E end, looking E	Just disturbance	6-8
	22 m from E end, looking E	Landscape view	6-9
	West end, looking East	Landscape view	6-10
Transect 7 – Perpendicular to Single Trail (Disturbance Level 1)	East end, looking West	Landscape view	4-1
	East end, looking West	Landscape view	7-1
	18 m from E end, looking W	Landscape view	7-2
	18 m from E end, looking W	Just disturbance	7-3
	18 m from E end, looking W	Vertical	7-4
	20 m from E end, looking N	Landscape view	7-5
	20 m from E end, looking S	Landscape view	7-6
	22 m from E end, looking E	Vertical	7-7
	22 m from E end, looking E	Just disturbance	7-8
	22 m from E end, looking E	Landscape view	7-9
	West end, looking East	Landscape view	7-10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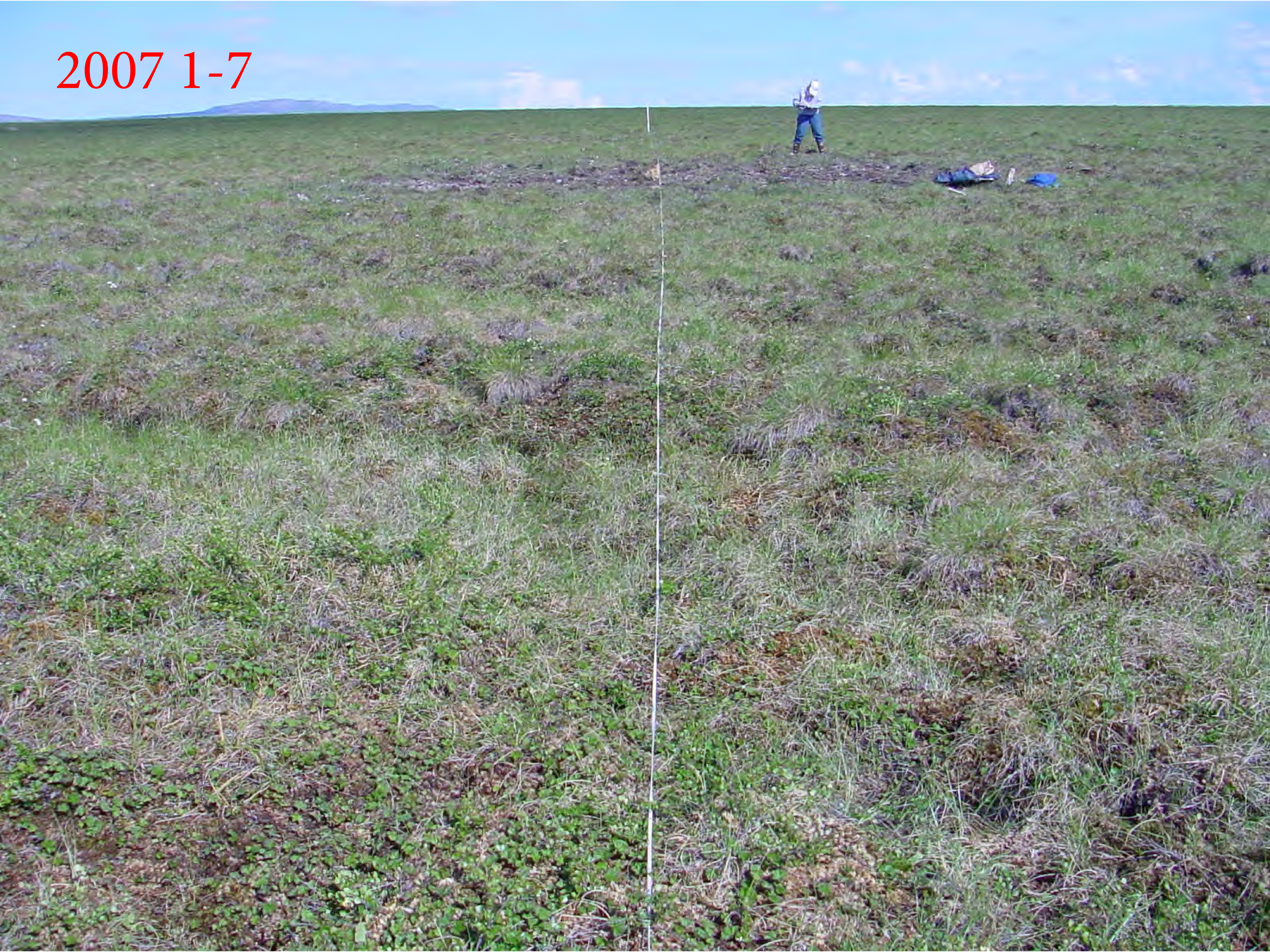

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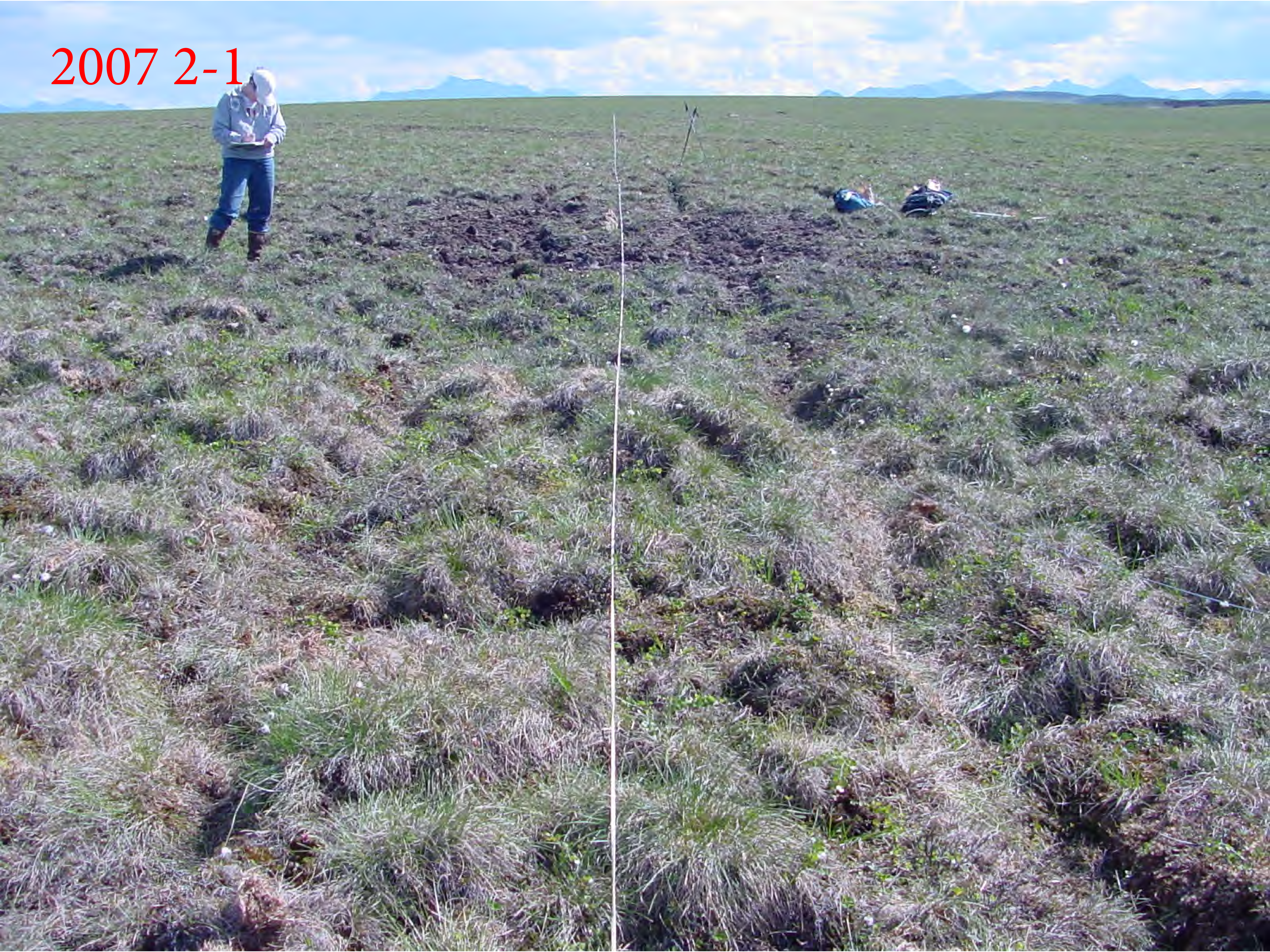
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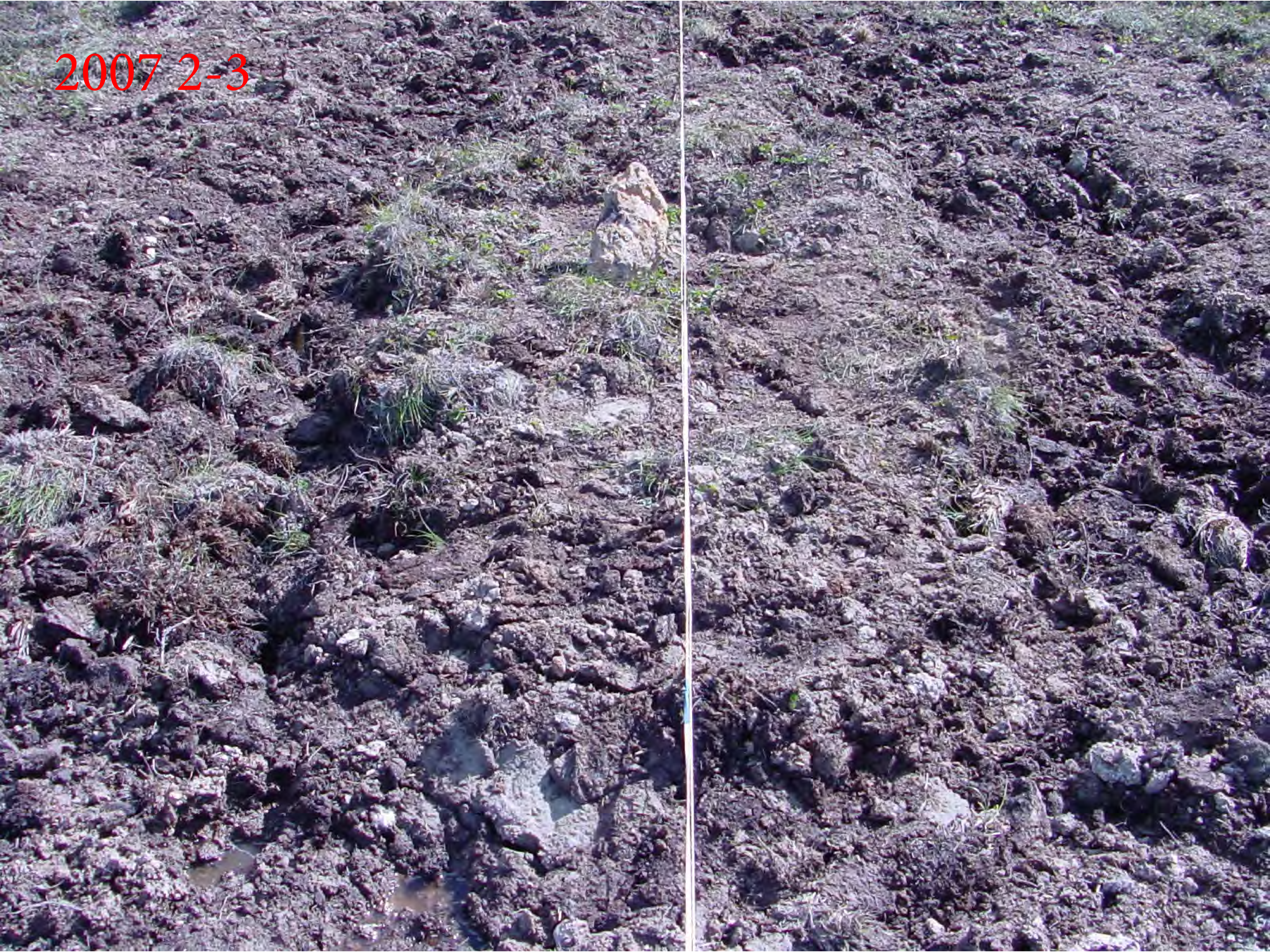
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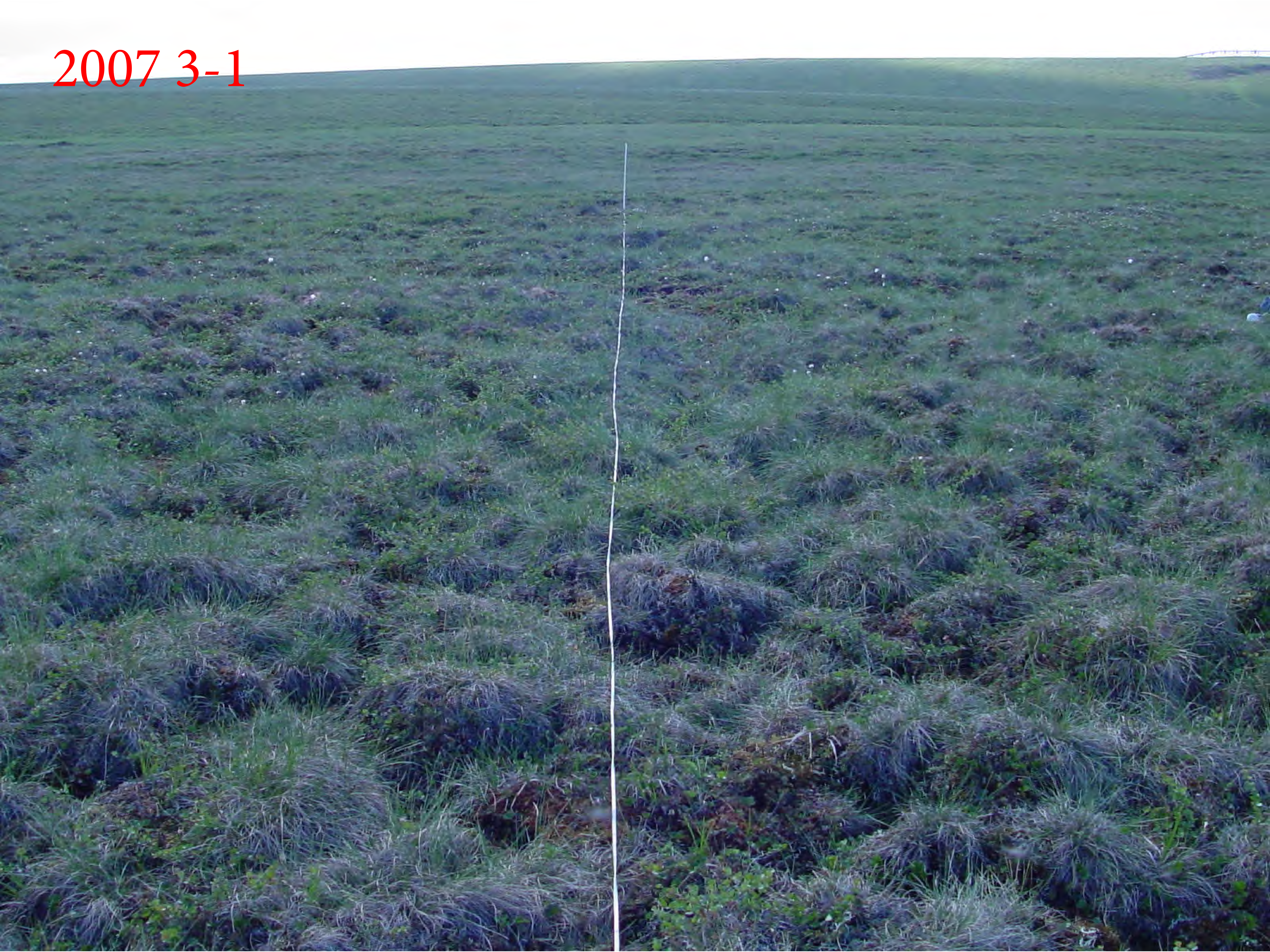
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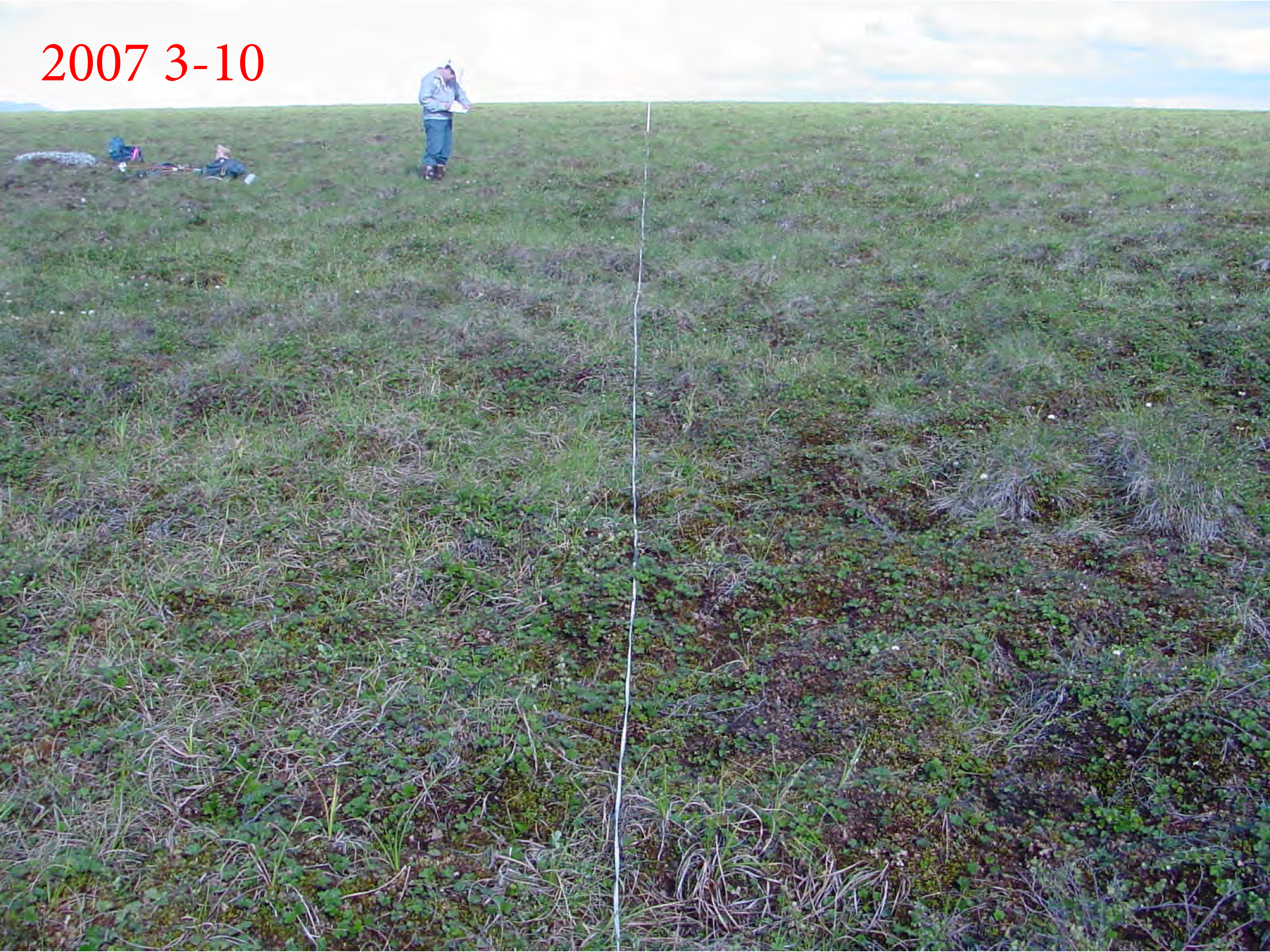
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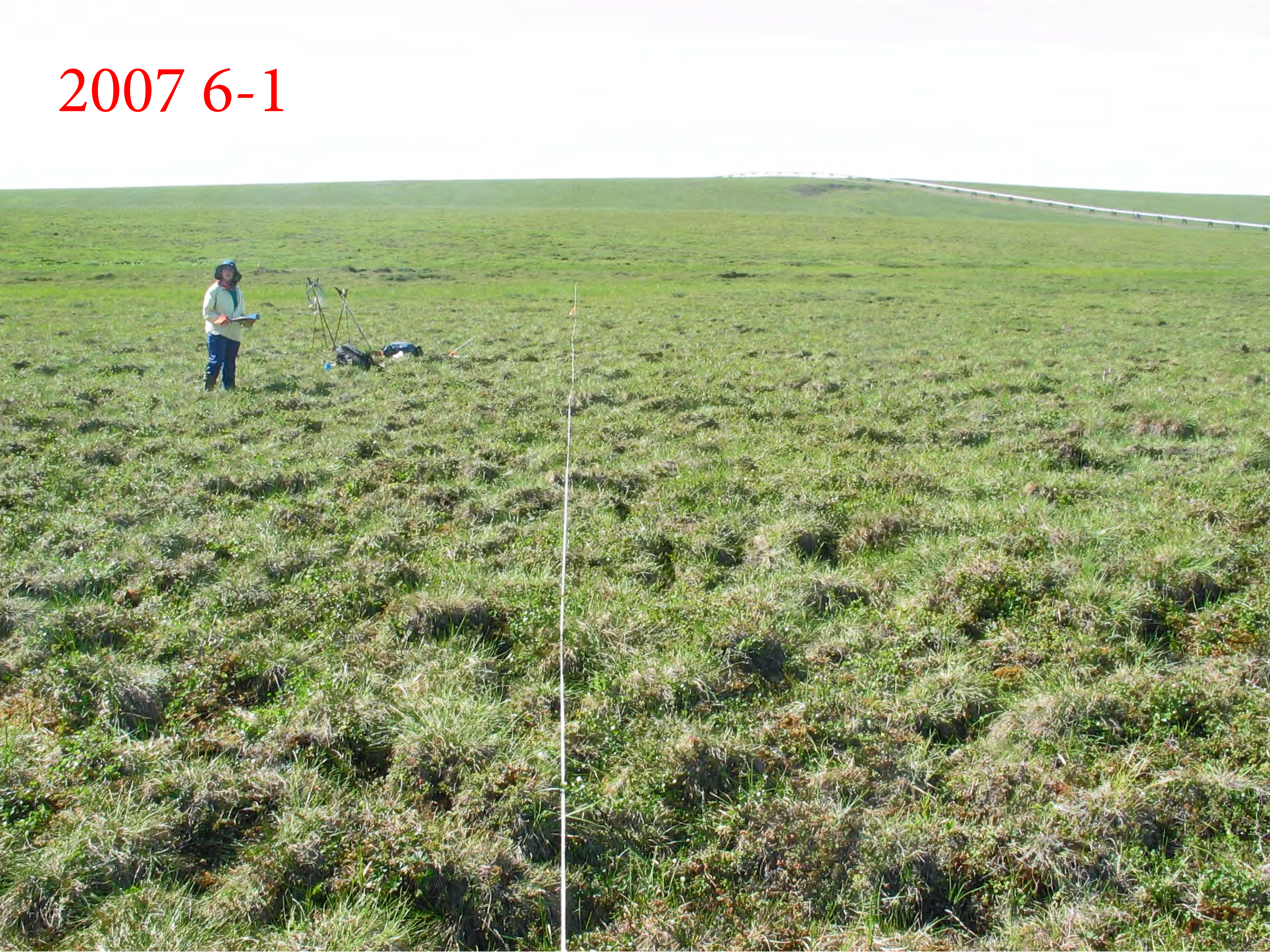

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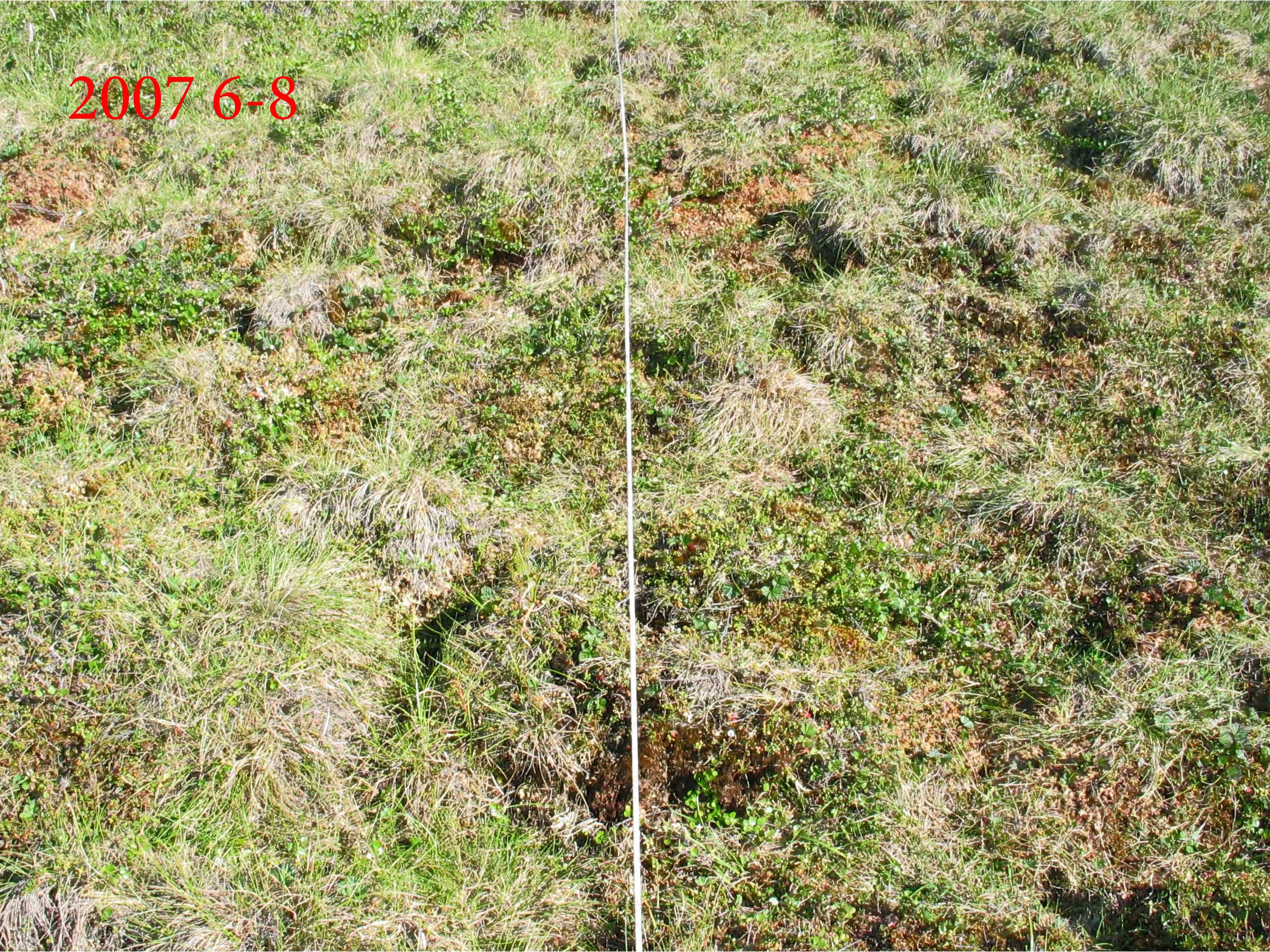
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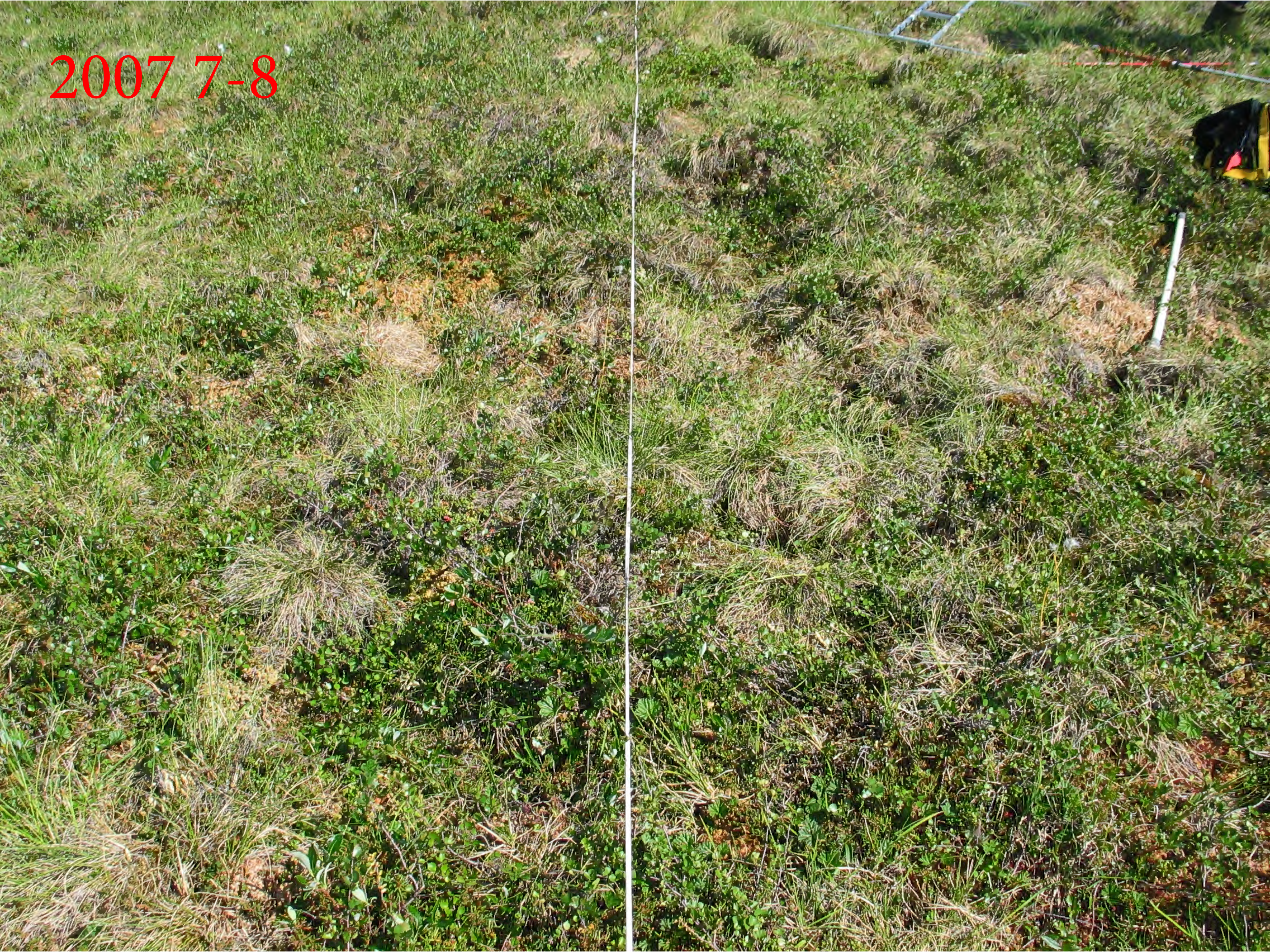
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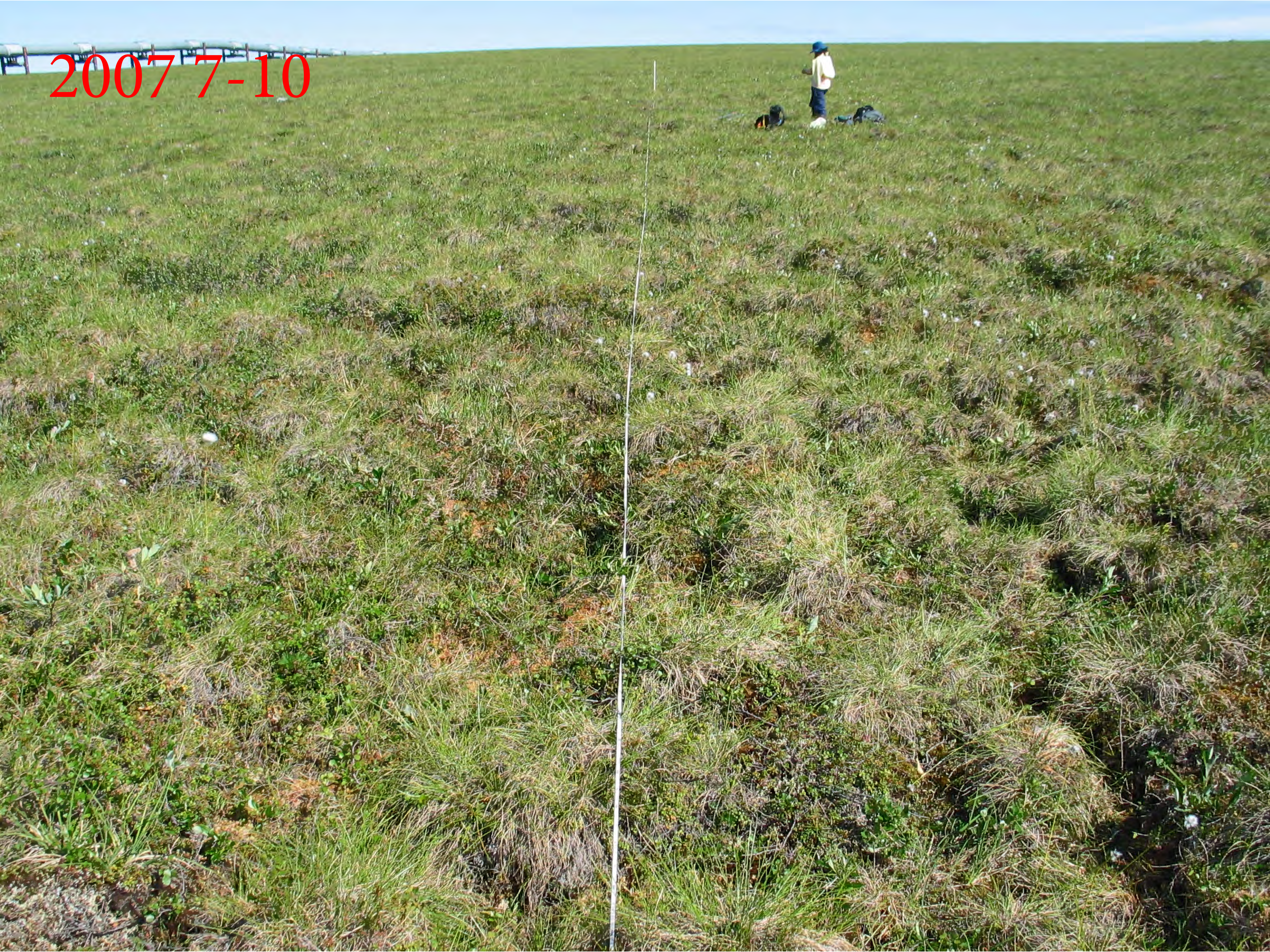
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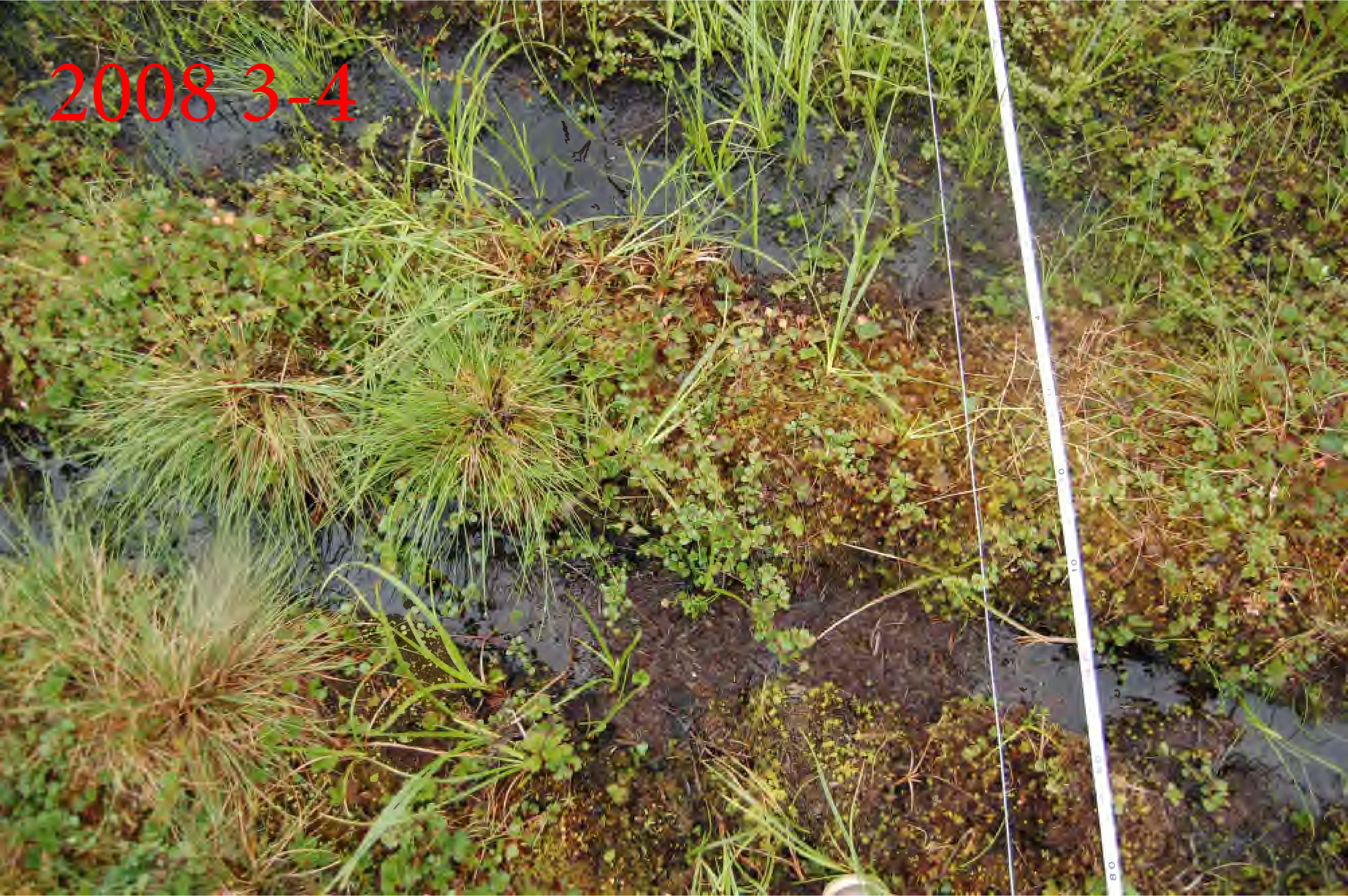
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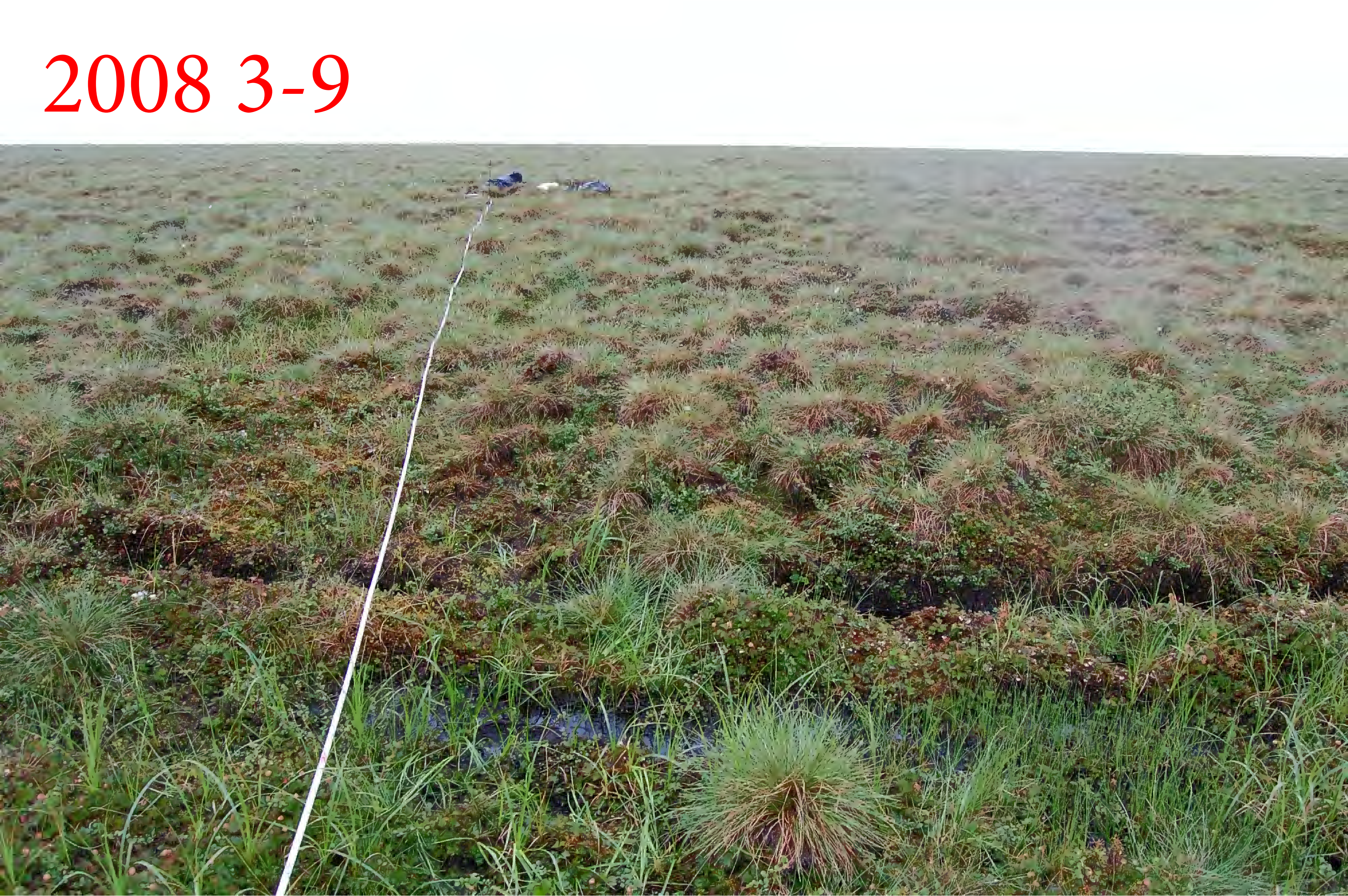
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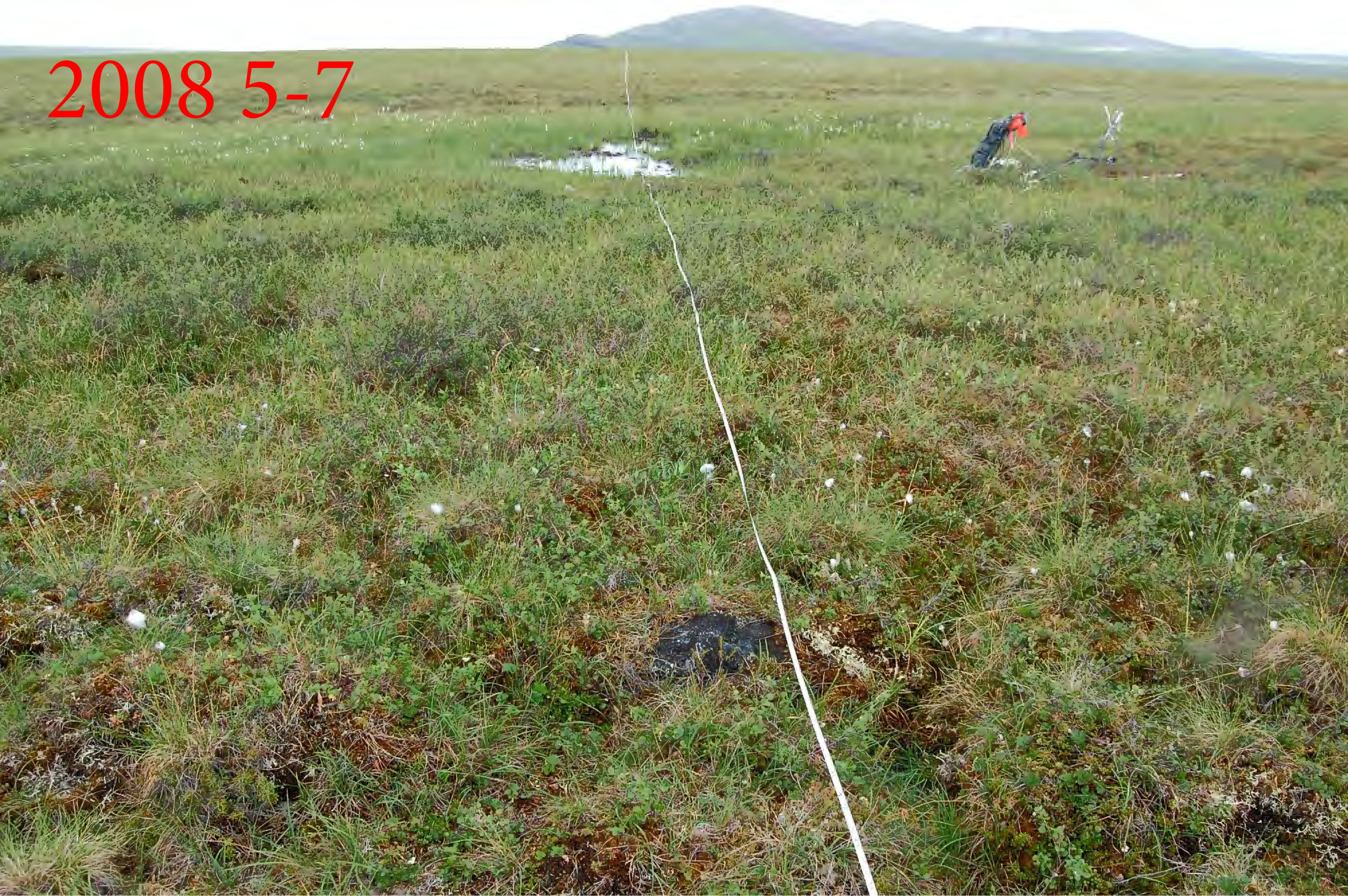
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