## Cumulative impacts of a gravel road and climate change in an ice-wedge polygon landscape, Prudhoe Bay Oilfield, AK

#### Landscape & vegetation impacts

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Oral talk at ASSW 2021, Lisbon, Portugal, Northern Roads and Railways: Social and Environmental Effects of Transport Infrastructure (ID 19)



Environmental impact assessments for new Arctic roads do not adequately consider the long-term **cumulative impacts** from infrastructure and climate change to permafrost landscapes.

This is due in part to lack of long-term historical casestudies that followed the consequences of infrastructure once it was built.



## Direct impacts (footprint) of infrastructure:



## Elevated gravel roads



## Indirect landscape effects of roads

Thermokarst



Walker, D.A. et al., 1987. Science, 238(4828), pp.757–761.

#### Infrastructure-related time series:





Road dust

(Footprint)

Solid lines: Direct impacts

Dashed lines: Indirect impacts

Raynolds et al. (2014) Global Change Biology, 20: 1211–1224

#### Difficult to evaluate complex cumulative indirect impacts adjacent to roads









#### Or to separate the climate-related impacts from the infrastructure-related impacts

#### Temperatures and thaw depth



#### Precipitation



## Four scenarios of landscape and vegetation change\*

Ground-based studies to examine climate-related and indirect impacts of roads

\* Impacts to the ice wedges and protective intermediate layers are in separate papers (Jorgenson et al. 2015, Kanevskiy et al. 2017, 2021 in prep.)



### Scenario A. Pre-road (1949-1968)

Ecological Investigations of the Tundra Biome in the Prudhoe Bay Region, Alaska

Edited by Jerry Brown



Biological Papers of the University of Alaska Special Report Number 2 October, 1975

#### Geobotanical Atlas of the Prudhoe Bay Region, Alaska





US Army Corps of Engineers Cold Regions Research & Engineering Laboratory

Vegetation and environmental gradients of the Prudhoe Bay region, Alaska



#### Aerial photos and 1970s baseline environmental studies, U.S. IBP Tundra Biome and CRREL

## Scenarios B, C, D: Permafrost observatories

- Colleen Site (CS) and Jorgenson Site (JS)
- Climate and permafrost temperature data from Romanovsky Deadhorse station, Deadhorse Airport, Prudhoe (ARCO), and Kuparuk NWS data.



### Scenario B. Jorgenson site, climate change, no road

Relatively isolated from infrastructure impacts, large changes in thermokarst ponds since 1968







250 m transect, elevation, snow depth, thaw depth

Progression of thermokarst pond area: 1949 (0.9%), 1988 (1.5%), 2004 (6.3%), 2012 (7.5%)

Jorgenson, M.T. et al., 2015. Role of ground ice dynamics and ecological feedbacks in recent ice wedge degradation and stabilization. *Journal of Geophysical Research: Earth Surface*, 120(11), pp.2280–2297.

#### Scenarios C and D. Colleen site, climate change and road Straddles the Spine Road with different effects on each side



Time series of aerial photograph: 1949, and nearly annual 1968-2014



## Transects and plots Colleen site

- Aerial photo time series mapping
- Transect & plot surveys
  - Micro-topography
  - Permafrost cores
  - Active layer

- Environmental factors
- Vegetation
- Soil
- Snow
- Dust
- Flooding











#### Colleen transects for scenarios C and D Scenario C: Transect T1 (Thermokarst, and heavy road dust)





Scenario D: Transect T2 (thermokarst, dust, and flooding



#### Most evident impacts:

- T1 dust & thermokarst
- T2 flooding & thermokarst

#### Data: Transects T1 and T2 and 29 plots

#### Transects T1 and T2:

Ground-surface elevation, thaw depth, water depth, vegetation height, patterned-ground element, vegetation type, LAI, dust-layer thickness

#### Vegetation plots:

Soil, snow, vegetation properties in polygon centers and troughs, vs. distance from road along Transects T1 & T2







# Mapping Colleen site changes

#### Water bodies (1968–2018)

#### 1972 2013 T1 side 2013 **Entire Colleen Site** 1972 60 1972 2013 39.5% 37.8% T1 side 40 40 8.7% 30 20 19722013 1972201 1972 6.8% 3 7%3.8% Barrer hundre. Legend Road 14.99 1972 Barren T2 side Moist tundra (Types U3 + U4) 80 Wet tundra (Types M2 + M4) 70 1972 Aquatic tundra (Type E1) 60 56 89 5 Water 50 1972 T2 side 40 2013 30 Barren 20 Disturbed moist tundra (Types U3d + U4d) 10 Disturbed wet tundra (Types M2d + M4d) 2.8% 3.2% Disturbed aquatic tundra (Type E1d) Aquatic Wate 1968 1972 1976 1980 1984 1988 1992 1996 2000 2004 2008 2012 2016 2020 Water





2008 2012 2016 202

Year



Jones, B. 2020.

Raynolds et al. 2014. Poster Arcitic Change 2014

## Differences between T1 (dusted) and T2 (flooded)

#### Key environmental and vegetation variables, 2014



Conclusion: Polygon trough-center relief, thaw depths, and productivity are greater on the flooded side of the road.

# Comparison of key site factors Jorgenson (Scenario B) and Colleen transects, 2020 (Scenarios C and D)



Conclusion: Pond area, polygon morphology, thaw depths, and distribution of broad vegetation types are similar at JS and CS T1, and different at CS T2. Comparison of disturbed Colleen plots (Walker et al. 2014) with similar undisturbed plots from 1970s (Walker 1985)

#### Cluster analysis: Vegetation-unit classification



#### Synoptic table analysis of species distributions in veg units

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Ordination: Relationship of vegetation units to environmental gradients



## Scenario A: Pre-roads



- Dominantly low-centered polygons, <30 cm trough-center microrelief, dominated by wet nonacidic tundra in polygon basins and troughs.
- 1949-1968: Little change to ice-wedge thermokarst, water-bodies, or landforms... and by inference, to the vegetation.

#### Scenario B: Climate-change, no road

Deeper thaw depths, degrading ice wedges, trough subsidence



More, larger thermokarst ponds, conversion to transitional and highcentered polygons, with > 50 cm microrelief, changes to drainage patterns





More willows



#### Changes to vegetation patterns



## Scenario C: Climate change + dust

Dust layer added to soils Smothered low-growing vegetation near roads, reduced polygon microrelief

Large reductions in cover and species diversity of small forbs, mosses, lichens



Introduction of halophytic species from dust control chemicals Dust layers in snowpack near roads, altered snow albedo, early snow melt, earlier green-up, impacts to waterfowl and wildlife





## Scenario D: Climate change + dust + flooding consequences

Very large dust impacts near road



Extensive flooding, deep troughs, conversion of L.C. to H.C. polygons



Water bodies interconnected to each other and to Lake Colleen



Lush growth of wet sedge vegetation on polygon centers and aquatic sedges in troughs



Largest cumulative changes to water bodies, polygon morphology, and vegetation patterns



## Conclusions

- Scenario approach was useful to examine gradients of cumulative impacts.
- More work is needed to model the complex interactions of climate change and indirect infrastructure-related impacts.
- The results should be helpful for recommendations regarding future cumulative impact assessments of indirect impacts and climate change.

## Acknowledgments

- Jerry Brown, Kaye Everett, Pat Webber for foresight to establish 1970s IBP Tundra Biome baseline studies
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- Everyone in the IRPS project!
- The audience!



2014 Colleen field team