Mapping of Cumulative Impacts of Oil and Gas Development in Arctic Alaska and the Yamal Peninsula

Timo Kumpula[1], Martha K. Raynolds[2], Donald A. Walker[2]

1 University of Eastern Finland, Joensuu, Finland; 2 University of Alaska Fairbanks, USA

Figure 1

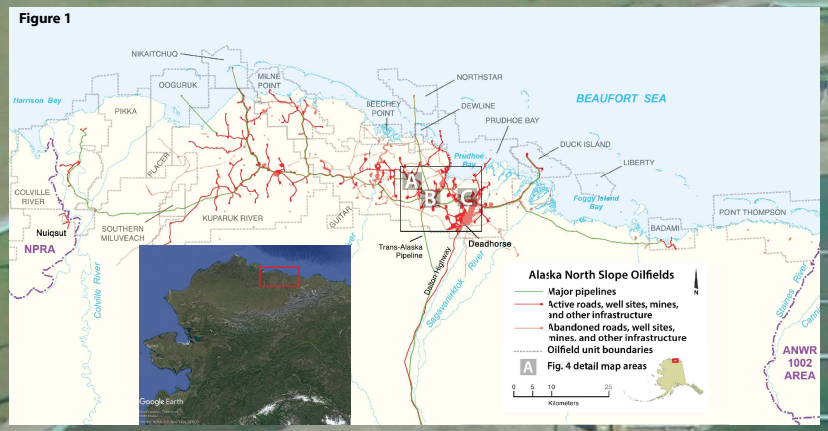


Figure 2

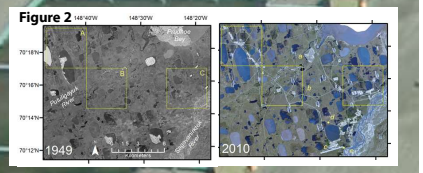


Figure 3

Integrated geoecological and historical change maps

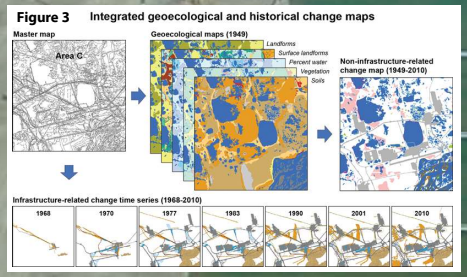


Figure 4a

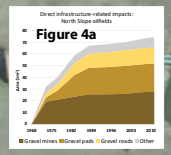


Figure 4b

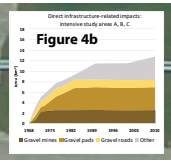


Figure 4c

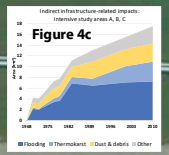


Figure 5

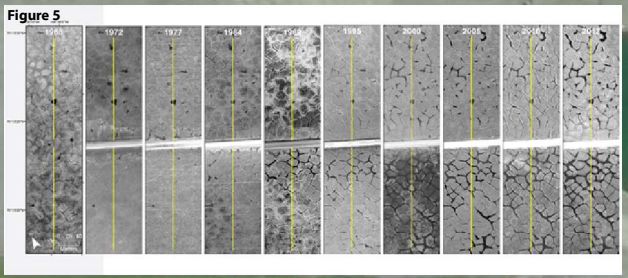


Figure 6a

Figure 6b

Figure 7

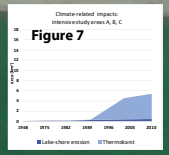
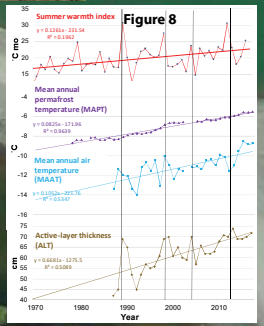


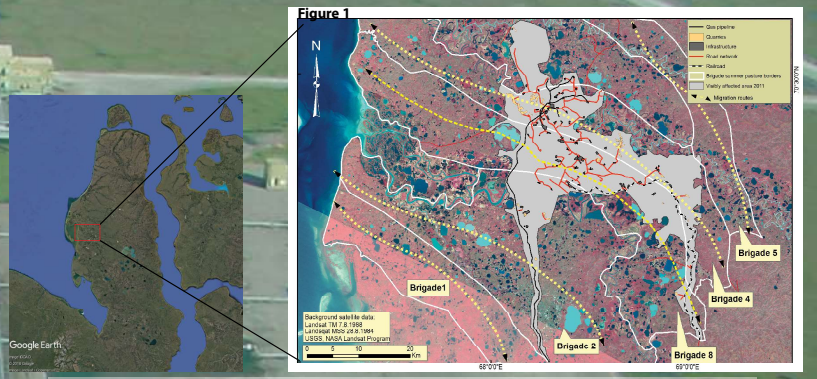
Figure 8



Conclusions

- Both fields were discovered about the same time (Prudhoe Bay Oilfield (PBO): 1968, Bovonenkovo Gas Field (BGF):1972). The PBO infrastructure network developed rapidly, and by 1977 was connected to the Trans-Alaska Pipeline. The BGF was not developed until this century, with rapid expansion since 2000, and a railroad and gasline completed by 2011.
- Different landscapes and permafrost conditions have resulted in different hazards due to warming climate. The PBO has ice-rich loess with extensive thaw lakes and ice-wedge polygons that are subject to thermokarst due to climate change and exacerbated by infrastructure effects. The BGF has tabular ground ice in the uplands, with extensive landslides and themocirques on slopes. Both areas have experienced increased effects from permafrost thaw in recent years.
- Both areas have small populations of indigenous people who have gained some economic benefits from resource development (Inupiat more than Nenets), but with major social consequences. Most threatening to both groups is restricted free access by hunters (PBO) and herders (BGF) through their traditional lands.

Figure 1



Bovonenkovo Gas Field Development

Figure 1 shows the location of the Bovonenkovo Natural Gas Field on the Yamal Peninsula, Russia, overlaid on the corridors of the Nenets reindeer herding brigades. Four brigades have extensive impacts in their grazing areas, especially Brigade 4 (Kumpula et al. 2012).

The growth of the Bovonenkovo development from 1985 to 2011 is shown in **Figures 2a** and **2b,** and from 1988 to 2011 in **Figure 3.**

Figure 2a

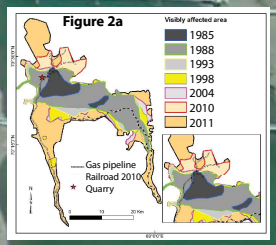
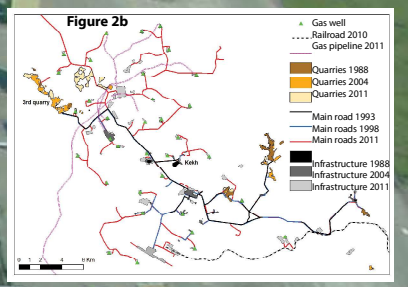


Figure 2b



North Slope of Alaska Oilfield Development

The Prudhoe Bay Oilfield was discovered in 1974. **Figure 1** shows the extent of the North Slope oilfields as of 2011. Since then, development has extended farther to the west, into the National Petroleum Reserve - Alaska (NPR-A).

Aerial photos in **Figure 2** show the extent of development in the oldest part of the Prudhoe Bay Oilfield between pre-development in 1949 and 2010. This area has not changed much since 2010 (Raynolds et al. 2014).

Maps of change in one of the boxes shown in Figure 2 (easternmost, Area C), are shown in **Figure 3**. The changes are due to both infrastructure and climate warming.

Figure 4 graphs the total area impacted a) by infrastructure on the whole North Slope; b) by infrastructure in the areas A, B, C; and c) due to indirect effects of development in areas A, B, C (Walker et al. 2019 in press).

Figure 3

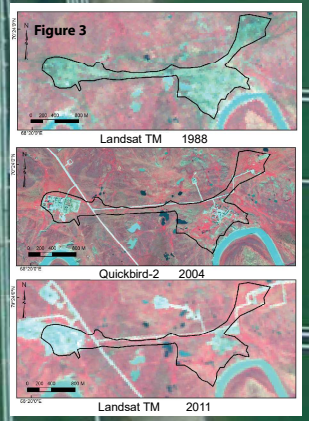


Figure 4a

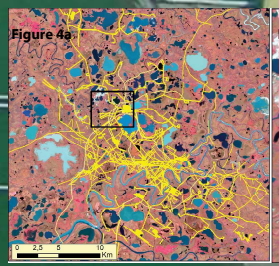


Figure 4b

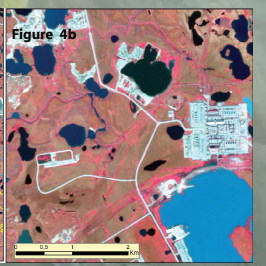
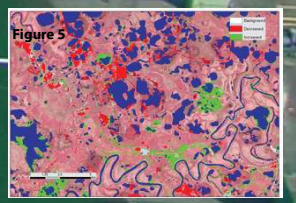


Figure 4a is a Sentinel-2 image of Bovanenkovo Gas Field dated September 1, 2016. Yellow represents different types of anthropogenic disturbance visibly affecting landcover. **Figure 4b** shows a small area in detail, with 10-m multispectral resolution, including a gas condensation plant and associated buildings.

Figure 5 shows change detection of the Bovanenkovo Gas Field 1988-2014. Landsat-derived NDVI shows reduced vegetation cover (red), mainly road and pipeline network, industrial areas and yards, and sand quarries. Increased vegetation cover (green) reveals revegetation of areas affected by off-road vehicle activity in late 1980's and a road network built in the mid 1990's. Lakeshores with dropping water levels also show increased vegetation.

Figure 5



Climate Impacts

Figure 5 shows the development of thermokarst at the Lake Colleen study site, Prudhoe Bay Oilfield (Walker et al. 2014). This is an air-photo time-series of change, from 1968 to 2013, where the band in the center of the 1972-2013 photos is the Spine Road. Vertical yellow lines are 200-m transects on both sides of the road. Aerial photographs courtesy of BP Alaska.

Photos in **Figure 6** are from 2015, showing **6a)** the relatively well-drained NE side of the road and **6b)** the relatively wet SW side of the road, where ice-wedges have melted and created troughs that are filled with water. Both sides of the road were low-centered polygons with rims in 1968 and have transitioned to high-centered polygons due to thawing of the ice wedges.

The graph in **Figure 7** shows the dramatic increase in climate related impacts since 1990 (thermokarst, lakeshore erosion) in study areas A, B, C.

The graph in **Figure 8** shows the correspondence between warming air temperatures and thawing soils at a site near Prudhoe Bay (Walker et al. 2019 in press). The red is summer warmth index, the sum of monthly means above 0 degrees C, the purple is the mean annual temperature of the frozen soils at 10 m, the blue is mean annual air temperature, and the gold is the maximum summer thickness of the thawed soil layer above the permafrost. Note the correspondence between warm summers (red) and deeper thaw (gold), which melts the tops of the ice wedges.

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