Increased Arctic fire occurrence related to human activity calls for improved management

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Abstract

Arctic fires have become more frequent in recent decades. They release carbon to the atmosphere through burning organic material and degrading permafrost and thus accelerate global warming. Previous research highlighted climate variables as the driving factor of fire occurrence in the Arctic, largely ignoring the contribution of human activity. Here, we analyzed the relationship between fire occurrence and human activity, as represented by artificial light at night, from 2001 to 2013 at pan-Arctic scale. Our results show a 2.5 times higher fire occurrence in areas lit by human activity compared to control points randomly selected from areas with similar climate conditions. Moreover, fire occurrence is significantly higher when closer to light-emitting human activity, indicating a pronounced impact of human activity near lit area at pan-Arctic scale. Regional differences in fire occurrence demonstrated through case studies indicate the potential of fire management. Effective management of fires related to human activity in the Arctic is important to reduce damage to infrastructure, disturbance to permafrost ecosystems and positive feedbacks to climate warming through carbon emissions.

Main Text:

The Arctic is warming four times faster compared to the world on average[1], leading to significant changes in fire activity. Fires in the Arctic have increased both in frequency and in the length of the fire season[2]. The increasing fire activity in Arctic ecosystems has significant implications for carbon emissions[3] and ecosystem stability[4,5]. Arctic fires contribute an average of 142 Tg C annually, or 7% to global fire-related carbon emissions[6]. Fire occurrence also affects permafrost. In Alaska, thermokarst activity has increased by ~ 60% from 1950 to 2015. Although climate change is estimated to be the main driver, around 10% of the increased thermokarst activity is attributed to fire occurrence[7]. Further, increased fire occurrence creates a positive feedback, where fires promote shrubification, leading to increased fuel availability and potentially larger, more widespread fires[8].

According to current literature, climate change is the dominant factor for increasing fire occurrence in the Arctic[2,3,9–11]. Climate change leads to 1) atmospheric conditions (temperature, humidity, and wind) promoting fire weather[2], 2) higher lightning activity[2], and 3) drier vegetation and higher fuel availability[11,12]. The climate variables with strongest relationships to burned area are precipitation, land surface temperature (LST), and atmospheric dryness measured by Vapor Pressure Deficit (VPD)[3,13]. Lightning, a primary ignition source, is closely linked to these climate variables too[14].

Along with climate variables, human activity may play a role in fire occurrence[2,15]. A study of North American and Eurasian boreal forest fires showed direct correlation with fire weather and atmospheric instability but no correlation with human factors, such as roads or population density[16]. For southeastern Siberia, however, human activity plays a major role in the fire occurrence[15]. The direct link between human activity and fire occurrence in the Arctic is documented for fire ignition by humans, such as open biomass burning in forestry[17], or campfires[18]. However, industrial activity adds more complexity and may increase the risk of fires indirectly. When infrastructure is built, the original shrub-dominated landscape may be transformed to a more productive grass- and sedge-dominated one[19,20], accumulating fire fuels. Also, oil spills may increase the risk of fires[21]. While the influence of climate factors has been addressed in multiple studies[2,3,16], an assessment of fire occurrence and its relation to human activity is still lacking at pan-Arctic scale.

Artificial light at night is a reliable predictor of human activity[22,23]. In the Arctic, the area lit by human activity (lit area) increased by 4.8% annually from 1992 to 2013 and the majority of this activity originates from extractive industries[23]. Settlements and roads were used in previous studies to assess the relation of Arctic fires to human activity[13], but only ~15% of the light-emitting human activity contains settlements in the Arctic. The rest, 85%, can be attributed to industrial human activity[23], which was not fully included in previous studies. Here, we investigate 1) if fires occur more often in area lit by human activity than expected based on randomly selected control points with similar climate, and 2) if fire occurrence shows a distance relationship to light-emitting human activity in the Arctic from 2001 to 2013.

To investigate fire occurrence in the Arctic from 2001 to 2013, we utilized the MODIS Fire_cci v5.1 dataset[24] to extract burned area above 66°N and create fire scar polygons. Fire_cci v5.1 has been shown to have better performance compared to other datasets for the Arctic for the period 2001-2018[3]. We then applied a spatial clustering approach, assuming that all fire occurrences within 1 km radius belonged to the same fire event. We created fire points based on each fire polygon's centroid. For each fire polygon we calculated three key climate variables identified as main predictors of fires in previous studies[3,13,25]: average summer VPD, LST, and precipitation. In order to test if the fire occurrence locations were biased towards lit area, we established a random control point data set accounting for climate conditions as prevailing at the actual fire scars, 1000 points above 66°N with the most similar key climate variable values to each fire polygon. From this set of 1000 points, we randomly chose three points to serve as our control points for the fire polygon's centroids (Fig. 1). We used the Consistent and Corrected Nighttime Light (CCNL) annual data[26] (i.e. lit area) to calculate the distance from the fire and control points to the area lit by human activity. For 2,968 fire events, we had 8,904 control points with a range of distance to lit area from 0 km (within lit area) to 312 km. We calculated the proportion of fire points occurring within the lit area to the total number of fire points, and similarly for the control points. We then performed a two-sample test of proportions to assess if fire occurrence in the lit area was higher compared to the occurrence of the randomly selected control points with similar climate conditions. To further test if distance to light-emitting human activity had an impact on fire occurrence, we calculated distances of fire points and control points to the nearest lit area and compared their density functions.

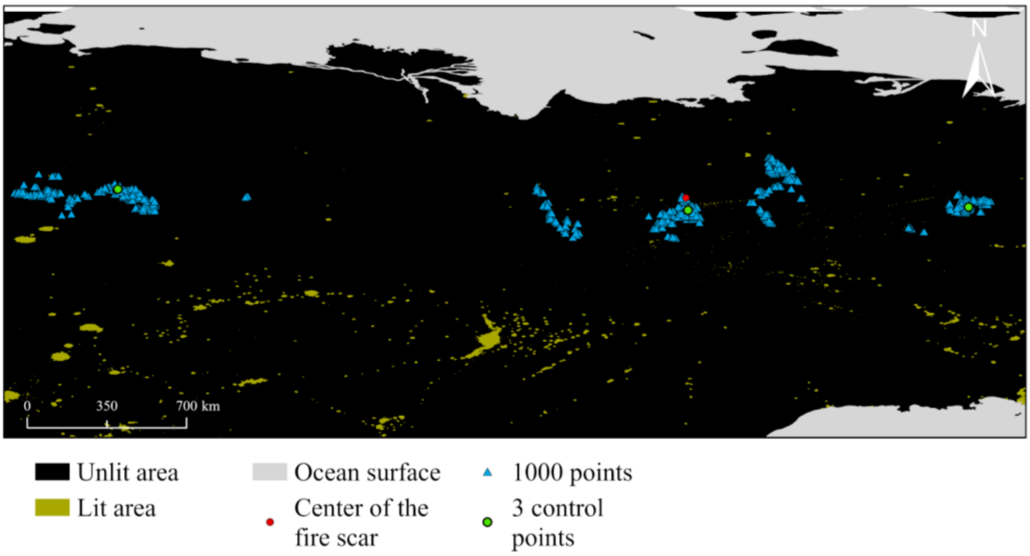

Fig. 1. Example of location of a fire scar in northeast Siberia and selection of its control points. Selection of 1000 points (blue) with similar values of key climate variables to the fire scar (red point is the center of the fire scar polygon) and randomly chosen 3 control points (green).

Results

Fire occurrence is significantly higher in areas lit by human activity

Our analysis revealed a significantly higher proportion of fires ($\chi^2 = 168.58$, $p < 0.001$) in the lit area (total number of fires occurring inside lit area / total number of fires) compared to a random selection of control points with similar climate as the fire polygons (total number of control points inside lit area / total number of control points). Of the 2,968 fire events across the pan-Arctic, 336 (11.3%) were located within the lit area (Fig. 2a). In contrast, only 4.6% of the randomly selected control points with similar climate variables as the fire polygons (411 out of 8,904) were located within the lit area (Fig. 2a). This indicates that fire occurrence is 2.45 times more likely in the area lit by human activity compared to randomly selected control points with similar climate.

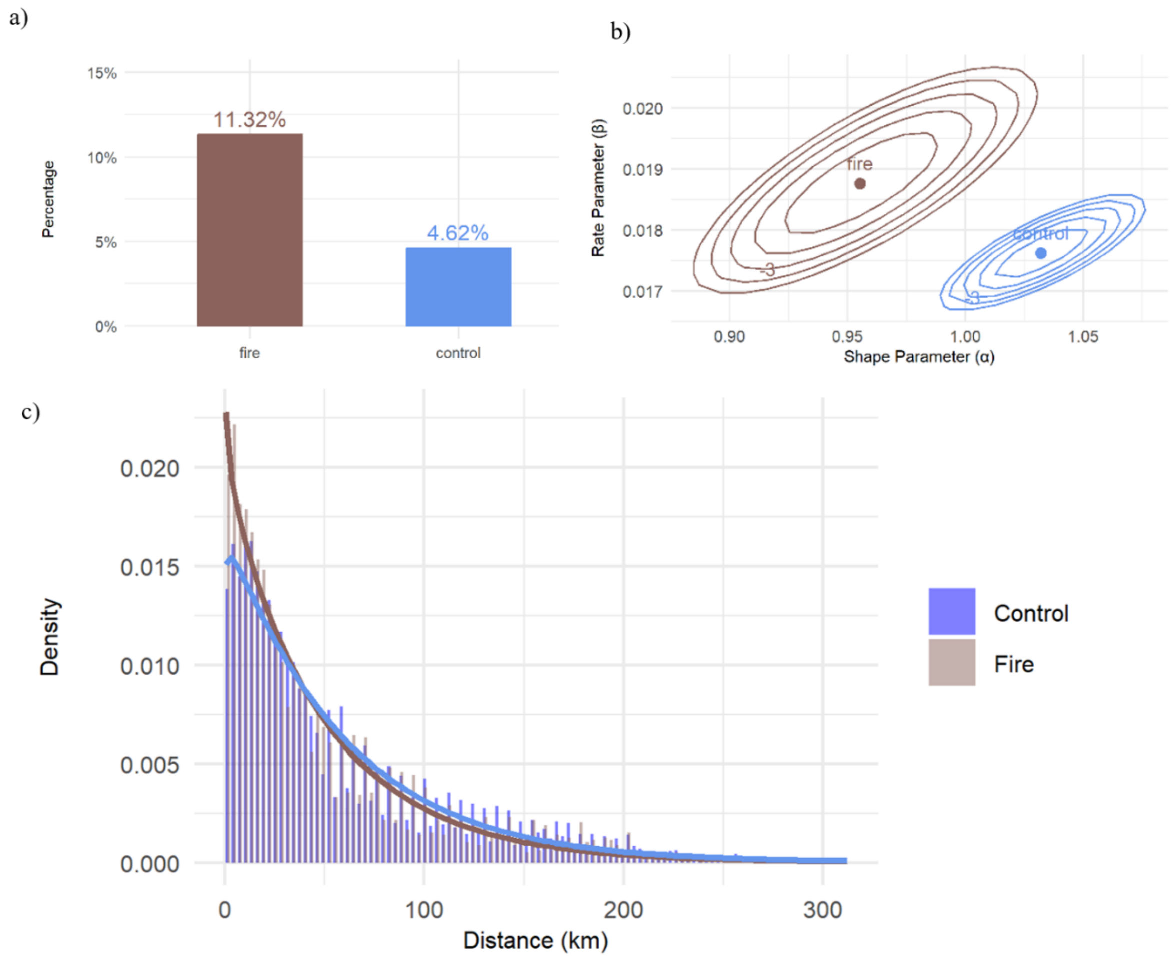

Fig. 2. Fire occurrence in the Arctic from 2001 to 2013 in relation to lit area. a) The percentage of fire events within lit area (brown bar) is significantly higher than for the control points (blue bar), b) Bivariate estimates and their uncertainties of the densities of the distance of fire events and control points to lit area, shown in the form of relative log-likelihoods as a function of the rate (β) and shape parameter (α). Dots represent the estimates and the 3rd contour line gives approximately the 95% of confidence region of the joint (shape/rate) estimate. c) Barplot of distance of fire events (brown bars) and control points (blue bars) to lit area with each bar corresponding to a 3 km bin. The solid lines show the estimated density of the distance of fire events (brown bars) and control points (blue bars) to lit area. Fire events and control points located within lit area (distance = 0 km) were excluded from this plot and analysis.

Distance to lit area plays a significant role in fire occurrence

Our analysis revealed significant differences in the distribution patterns between fire events and control points with respect to their distance to lit area, indicating that fires occur more often closer to light-emitting human activity than the control points. The gamma distribution fitted for distance between fire event and lit area yielded as estimates a shape parameter (α) of 0.95 (SE = 0.023) and a rate parameter (β) of 0.0187 (SE = 0.00059) (Fig. 2c). For the distance to control points, the gamma distribution fit yielded a shape parameter (α) of 1.03 (SE = 0.014) and a rate parameter (β) of 0.0176 (SE = 0.00030) (Fig. 2c). The confidence regions of the relative log-likelihood for both fire and control settings revealed that the estimates for shape and rate are significantly different between fire events and control points (Fig. 2b).

The fire data exhibited a smaller shape parameter compared to the control data. This means that fire occurrences are more concentrated near light-emitting human activity, with fewer events occurring farther away. While fires do occur at greater distances, these distant events are less frequent compared to the control data. The smaller shape parameter of the fire data emphasizes this pattern by creating a sharper peak closer to human activity and a longer tail extending toward greater distances (Fig. 2b and c).

The fire data distribution has a higher rate parameter compared to the control data distribution. This difference implies that fire occurrences have a higher density near light-emitting human activity than would be expected from the distribution of control points. Specifically, the density of fire occurrences decreases more rapidly with distance from human activity than the density of control points. This pattern indicates a spatial association between fire occurrences and human activity that goes beyond the natural clustering expected from the geometry of two-dimensional space.

Discussion

In this study, we have demonstrated that fire occurrence in the Arctic was spatially significantly related with light-emitting human activity when controlling for climatic conditions. More fires occurred within the lit area and in the nearby surroundings compared to what is expected based on climate only.

Drivers of fire occurrence related to industrial activity

One of the main sources of light-emitting human activity in the Arctic is the development of industrial infrastructure, especially related to extractive industries[23]. The Tokma and Khanda regions in Eastern Russia exhibited extensive industrial development due to oil and forest industries, which led to an increased number of fires via infrastructure development[27]. Our results of significantly more fires occurring within lit area compared to control points suggest that industrial infrastructure development might contribute to fire occurrence in the Arctic.

The development of oil and gas pipelines is a major component of industrial infrastructure development in the Arctic and it was observed that the amount of fires in the middle Ob River basin increased three times after the oil extraction started[28]. West Siberia is one of the oldest oil extracting regions in the Arctic, with activity dating back to the 1960s. The main portion of a very large oil and gas pipeline network that reaches more than 50,000 km was developed during the same time but more than half of the pipeline system is worn out because of old age and no investments, which lead to leaks[29,30]. From 1994 to 2010, the number of oil pipe leaks in the Russian Arctic never fell below 20,000[31]. Russia has recorded 17,000 oil spills in 2019, while the US was recording 137 spills in 2018, and Canada 60 spills in 2019[29]. Acknowledging that Russia extracts also the majority, i.e. 90%, of oil and gas in the Arctic[32], the discrepancy in oil spill frequency between countries is still higher than expected by chance. As spilled flammable hydrocarbons may ignite fires when vegetation is sufficiently present[33], fires resulting from outdated and deteriorating industrial infrastructure might be a significant factor contributing to the fire occurrence in the Arctic.

Roads are another important part of urban and industrial human activity and strongly relate to fire ignition in the Arctic[34,35]. The road network in the Arctic has expanded extensively due to resource extraction and related urbanization[35]. Although lit area is a good indicator of human activity, it does not fully capture the extensive road and pipeline network of the Arctic as most of these infrastructures are not lit[23]. Roads and pipelines in the Arctic can be considered unlit human activity connecting lit industrial and urban areas. Therefore, extensive road and pipeline networks are likely to contribute to the distance relationship of fires to light-emitting human activity identified in this study.

Another driver of fire occurrence related to industrialization is the increase in fuel availability. Following an anthropogenic disturbance in Bovanenkovo gas fields, vegetation succession became sedge-dominated[19]. Post-mined sand and sandy loam quarries in Noyabrsk[20] and coal mines around the city of Vorkuta[36] showed similar plant succession trends. The change in vegetation composition after industrial disturbance is critical for fire occurrence because graminoids that replace the original vegetation are more prone to fire and increase fire fuel availability[37], which might be another factor contributing to fire occurrence.

Case studies indicate regional differences in fire occurrence related to human activity

While industrial activity has the potential to increase fire occurrence, this effect cannot be observed uniformly across the different Arctic regions. As oil and gas extraction is one of the main drivers of the Arctic industrial growth, we focus on two case studies, 1) the Vankor oil fields in Russia (Fig. 3a), and 2) Prudhoe Bay in Alaska (Fig. 3b). Although industrial infrastructure development is similar at both sites, the Prudhoe Bay oil fields did not exhibit any fire occurrence from 2001 until 2013 according to our remote sensing data set while 40 fires occurred within the area lit by the Vankor oil fields. The vicinity of the lit area around Vankor also showed extensive fire occurrence while Prudhoe Bay showed notably less. Therefore, we cannot conclude that oil and gas extraction in the Arctic directly leads to fire occurrence (acknowledging that the two oil fields are located at different latitudes). Possible reasons for this observation should be further investigated and might include infrastructure and fire management around oil and gas extraction or environmental factors.

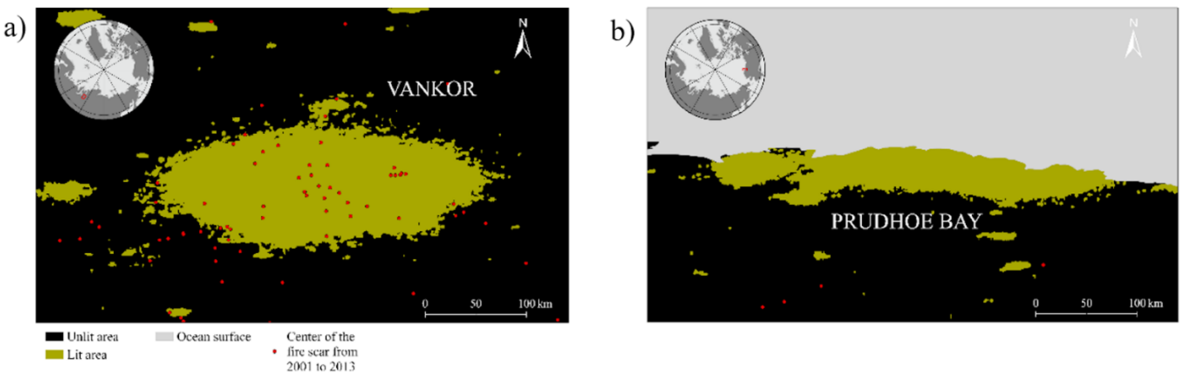

Fig. 3. Geographical distribution of fire occurrence (red points) in relation to lit area by human activity (light green) sourced mainly from oil extraction a) Vankor oil fields and b) Prudhoe Bay oil fields (made with Natural Earth, projection EPSG: 4326).

Similar observations around other major mining facilities in the Arctic support the argument that fire and infrastructure management might play an important role in preventing fire occurrence around industrial infrastructure (Fig. 4). An analysis between Russia and Norway indicated that environmental protection measures applied in the Russian mineral extraction sector are weaker compared to Norway[38]. The Kola Peninsula region, bordering the European Arctic, is an important region for mining, especially nickel, copper, and rare earth minerals[39]. The fire occurrence in the below map (Fig. 4) follows the border between Norway and Russia and all fires occur inside the Russian territory, indicating the fire management rather than environmental factors only play a major role. Another mining region in the Russian Arctic, Norilsk, exhibits more than 30 fire occurrences inside the lit area, further supporting this argument (Supplementary Information FigS1to FigS7).

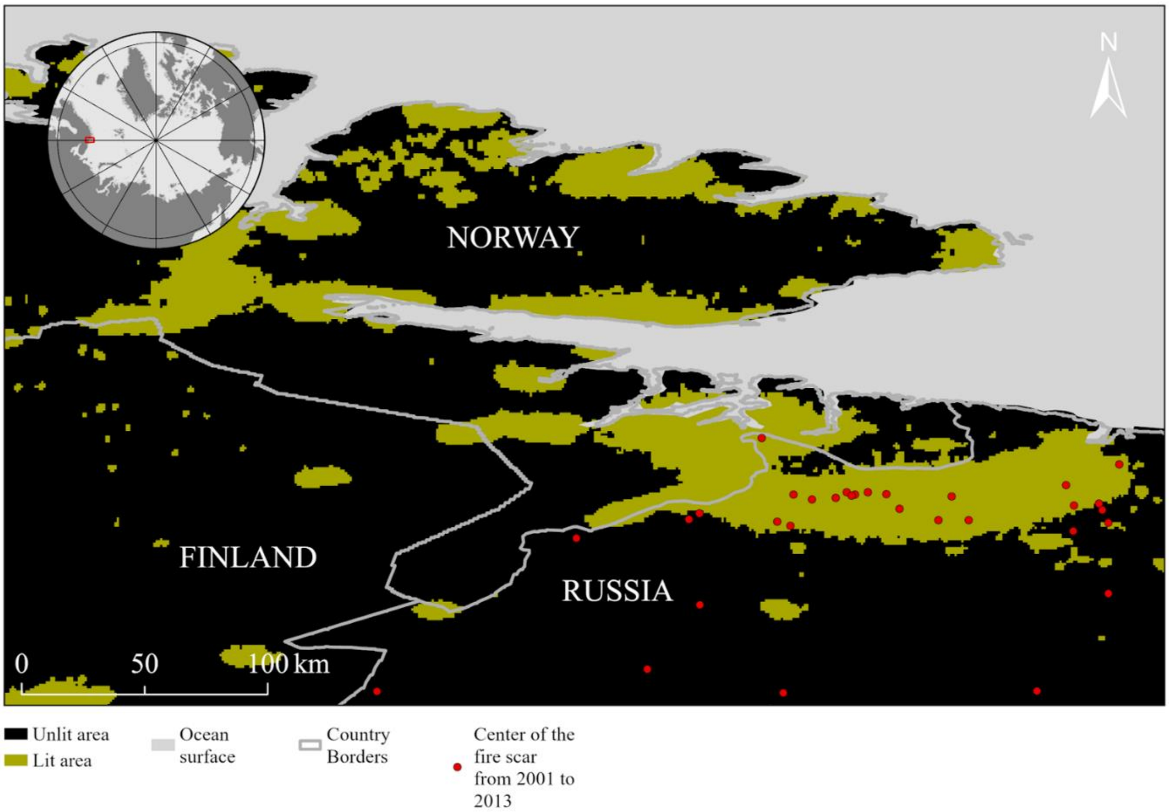

Fig. 4. Geographical distribution of fire occurrence (red points) in relation to lit area by human activity (light green) in the European Arctic, sourced mainly from mining. Despite wide-spread distribution of lit area, fires are concentrated regionally. While only the centroids of the fire polygons are displayed, the fire polygons do not extend across the border to Norway or Finland (made with Natural Earth in WGS 84, projection EPSG: 4326).

It was estimated that by 2050, 70% of the Arctic infrastructure will be under threat by ground instability due to permafrost thaw[40], with a wide range of implications from carbon release[41] to pollution[42]. Our results indicate that fires occur more often in areas with human activity, which may further accelerate permafrost thaw[43,44]. Fire management to prevent increased fire occurrence and related thermokarst effects in areas of human activity should therefore be of high interest to protect Arctic infrastructure.

Fire management has the potential to reduce the effects of human activity on fire occurrence in the Arctic

Our analysis showed increased fire occurrence in lit area and nearby surroundings compared to randomly chosen control points with similar climate conditions. Potential causes of increased fire occurrence near lit area might be related to increased ignitions by humans, increased flammability through oil leaks, and increased fuel availability at the disturbed sites due to graminoids becoming more dominant. Our regional case studies indicated that fire and infrastructure management might alleviate increased fire occurrence associated with human activity observed at pan-Arctic scale. Increased fire occurrence around human activity might partially be prevented by regulations and maintenance of infrastructure. Increased fire occurrence associated with human activity and its effects on infrastructure, permafrost, ecosystems, livelihoods, and positive feedback to climate warming have to be considered for a sustainable development in the Arctic.

Methods

Study area: We analyzed the terrestrial pan-Arctic above 66° N latitude up to 75°N latitude (Artificial light at night data do not extend beyond 75°N latitude). The study area includes boreal forest and tundra biomes.

Artificial Light At Night (ALAN) data: We used "A Consistent and Corrected Nighttime Light dataset" (CCNL 1992-2013) based on Defence Meteorological Satellite Program data, which corrects three problems associated with the dataset: interannual consistency between the different satellites used, saturation due to low radiometric resolution (DN values with a range of 0-63), and blooming due to data resampling and atmospheric conditions[26]. We chose the CCNL dataset, because the better calibrated VIIRS nighttime lights dataset which extends until present is not corrected for ephemeral lights (Aurora borealis, northern lights), leading to an overestimation of artificial light in the Arctic[45]. Other available datasets which aim at correcting for the aurora influence are not robust enough[23].

Between 1992 and 2013, several isolated pixels (around 3% of the lit pixels) were illuminated only once in regions where human activity was highly improbable; therefore, the outliers were removed based on the method used in Akandil et al., (2024)[23].

For each year from 1992-2013 we calculated the cumulative ALAN map across years by aggregating the lit pixels up to the given year (e.g. to create the cumulative map of 2005 we aggregated every year's lit pixels from 1992 until 2005). So, each year's cumulative ALAN map is used as the basis for the calculation of the distance to the nearest light-emitting human activity of each fire that year. We chose to use cumulative data, because a small disturbance may have effects on the landscape and the ecology of the region for many decades in the Arctic[46].

In the Arctic context, light-emitting human activity excludes activities such as reindeer herding or forestry as these activities do not emit lights.

Climate data: To control climatic conditions, we defined sampling areas for control points with climate conditions comparable to those of the fire scars that actually burned. We used the key climate variables for fires identified in earlier studies, i.e., precipitation, land surface temperature, and atmospheric dryness of a given year, i.e., for a fire event in 2005, we extracted the 3 climate variables for the fire polygon of 2005 to understand the climate conditions when the fire happened.

Average temperature and the summer precipitation explained 90% of the variation in the total burned areas between 1950 and 2009[25], so we decided to use average summer precipitation to quantify the precipitation variable. We downloaded the monthly precipitation data (PPT) from the TerraClimate dataset[47] with a spatial resolution of 1/24 degree (~ 4000 m). We calculated the average summer precipitation based on June, July, and August monthly averages.

Vapor Pressure Deficit (VPD) is the measure of atmospheric dryness which is the difference between the amount of water in the atmosphere and the amount of water the atmosphere can hold at saturation. It has been demonstrated that VPD influences the burned area significantly in the Arctic[3,13], therefore we downloaded VPD data from the TerraClimate dataset[47] with a spatial resolution of 1/24 degree (~ 4000 m). We calculated the average VPD for June, July, and August monthly VPD averages.

Land surface temperature (LST) is another variable that has been shown to influence the burned area[3,13], therefore we downloaded the MODIS 11C3[48] monthly LST data with a resolution of 5600 m for June, July, and August and calculated the mean LST.

We resampled the LST data to the same resolution as PPT and VPD by using the bilinear method in the Terra[49] R-package.

Fire data: We created burned area polygons by converting the MODIS Fire_cci v5.1[24] burned area pixel product at 0.00224573° (ca. 250 m x 100 m at 66° N) resolution to burned area polygons using Google Earth Engine[50]. We then grouped and assigned the resulting polygons that lie within 1 km distance of another to the same fire event in ArcGIS Pro (version 2.8). This step was necessary to avoid individual pixels next to a burned area were classified as a separate fire event. Lastly, we calculated the centroids of each burned area polygon to retrieve the fire point. A more detailed description of the individual processing steps for Google Earth Engine and ArcGIS Pro can be found in the GitHub repository for this article.

Control point generation: For each fire scar we retrieved the mean LST, VPD, and PPT values with the extract() function in Terra R-package. Based on the standard deviation and the mean values of the fire scar climate variables, we sorted the pixels across the Arctic with climate values closest to those of the fire scar and chose the top 1000 pixels as the pool for sampling. We randomly chose 3 points from this pool as control points.

Distance calculation: We calculated the distance of fire and control points to the nearest lit area with the distance() function in the Terra R-package. We calculated the distance using a stepwise approach for any distance > 50 km to avoid exceeding computational limits. This means any distance which exceeded 50 km was rounded up to the nearest 2 km distance such as 52 or 54 or 56. If the distance was less than 50 km, the precise calculation was performed. We assigned the distance to the nearest lit area, to all 2968 fire points and their three corresponding control points.

Statistical analysis: To test if the proportion of fire occurrences was significantly higher in areas of light-emitting human activity, we calculated the proportion of fire points and control points within lit area to the total number of fire points and control points respectively. We performed a two-sample test for equality of proportions with continuity correction[51] to understand if the proportion of fire points was significantly different from the proportion of control points with similar climate values.

To understand if there was a distance relationship of fires with lit area, we compared the distribution of the fire occurrence data outside of the lit area with the control points data outside the lit area. We fit Gamma density over the distribution along the distance from the lit area for the fire and control datasets. We also fit Weibull densities as well as two-component mixtures of Gamma and Weibull, respectively. As there were no significant differences between Gamma and Weibull and because we were unable to achieve a satisfactory fit for the mixtures, we chose Gamma for our results because of better numerical stability. We plotted the curves and also the relative log-likelihood for shape and rate parameters with 95% confidence regions in one single panel to understand if the rate and shape parameters differed significantly between fire occurrence and control data (Fig. 2b).

All statistical analyses were conducted in R (version 4.3.1; R: The R Project for Statistical Computing (r-project.org)).

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Competing interests: The authors declare no competing interests.

Data and Materials Availability: The consistent and corrected nighttime light (CCNL) dataset is based on DMSP and available as GeoTIFF format at https://zenodo.org/record/6644980 . Terra climate data of precipitation and VPD is available at Catalog http://thredds.northwestknowledge.net:8080/thredds/catalog/TERRACLIMATE_ALL/data/catalog.html. Land Surface Temperature data of MODIS 11C3 can be downloaded from https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/61/MOD11C3/ . Fire data of MODIS Fire_cci v5.1can be downloaded from https://data.ceda.ac.uk/neodc/esacci/fire/data/burned_area/MODIS/pixel/v5.1/

Code Availability: The R scripts that are used to process the CCNL, Climate Variables, and Fire data to generate the 'Cumulative ALAN for every year', 'Centroids of the fire scars', 'Extracting climate variables of the original fire scar', 'Calculating the distance to nearest lit area for fire events', and 'Calculating the distance to nearest lit area for control points' are available on https://github.com/cengizakandil/Fire_ALAN

Supporting information for

Increased Arctic fire occurrence related to human activity calls for improved management

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This PDF file includes:

Supporting Figures S1 to S7

Supplementary Material

Case studies of fire occurrences in different major Arctic mining sites above 66 N° latitude.

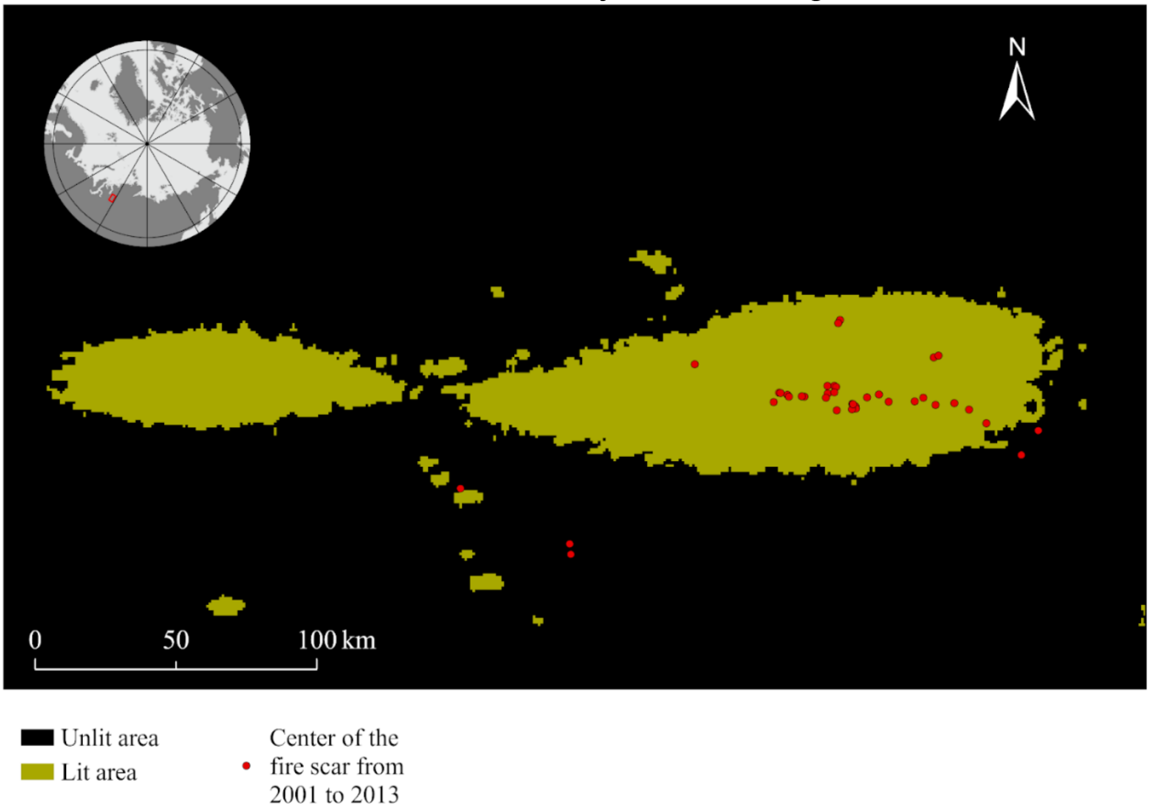

Fig. S1. Fire occurrence in Norilsk in Russia (made with Natural Earth, projection EPSG: 4326).

Norilsk is located in Krasnoyarsk, Russia and the largest palladium and class I nickel extractor globally. Platinum, copper, cobalt, and rhodium are also extracted[1]. Norilsk is known for "the world's most polluted Arctic region", with extreme increase in atmospheric sulphur, copper, and nickel concentrations leading to tree death rates of up to 100% equaling to the destruction of 24,000 km^2 of boreal forest[1]. There were more than 30 fire occurrences from 2001 to 2013, the majority within the lit area.

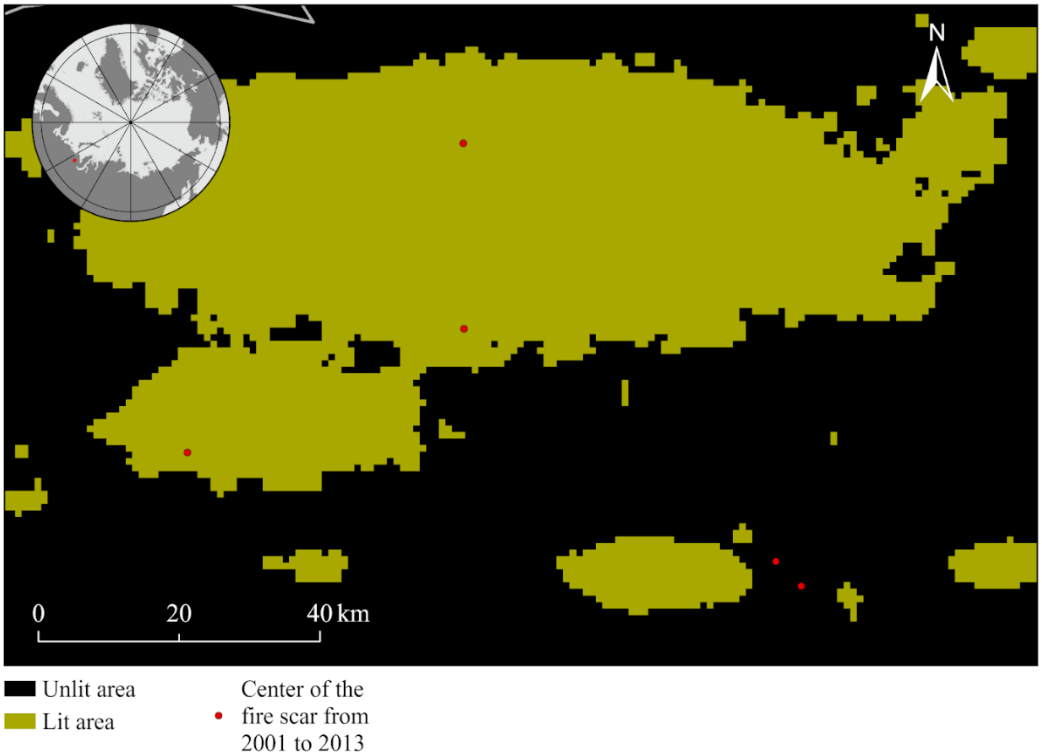

Fig. S2. Fire occurrence in Vorkuta in Russia from 2001 to 2013 (made with Natural Earth, projection EPSG: 4326).

Vorkuta was founded as a gulag prison camp by Stalin and primarily used to extract coal from the rich Pecora Basin[2]. With the collapse of the Soviet Union, Vorkuta's population dropped from more than 200,000 inhabitants in 1986 to 77,000 in 2018[2]. Currently the city still has some coal mining. There were 3 fires occurring from 2001 to 2013 within the lit area, and 2 in the nearby surrounding.

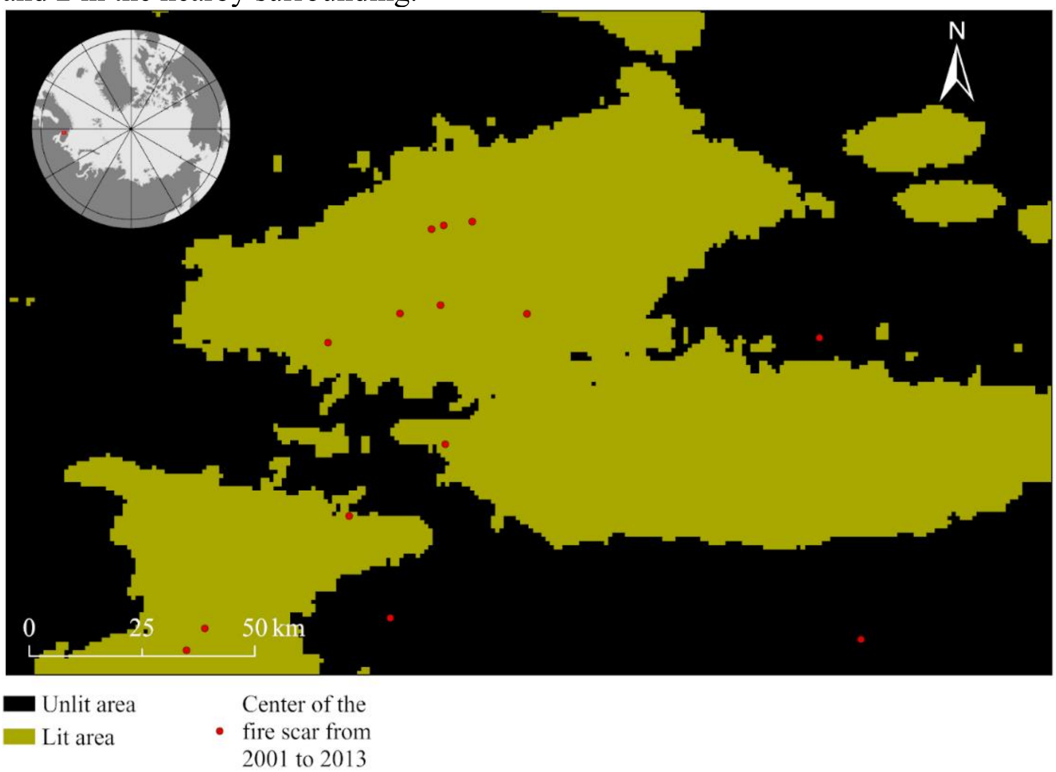

Fig. S3. Fire occurrence around the Olenegorsk mine in Russia from 2001 to 2013 (made with Natural Earth, projection EPSG: 4326).

The Olenegorsk iron mine is the northernmost iron extraction in Murmansk, Russia and there have been more than 10 fire occurrences from 2001 until 2013 within the lit area.

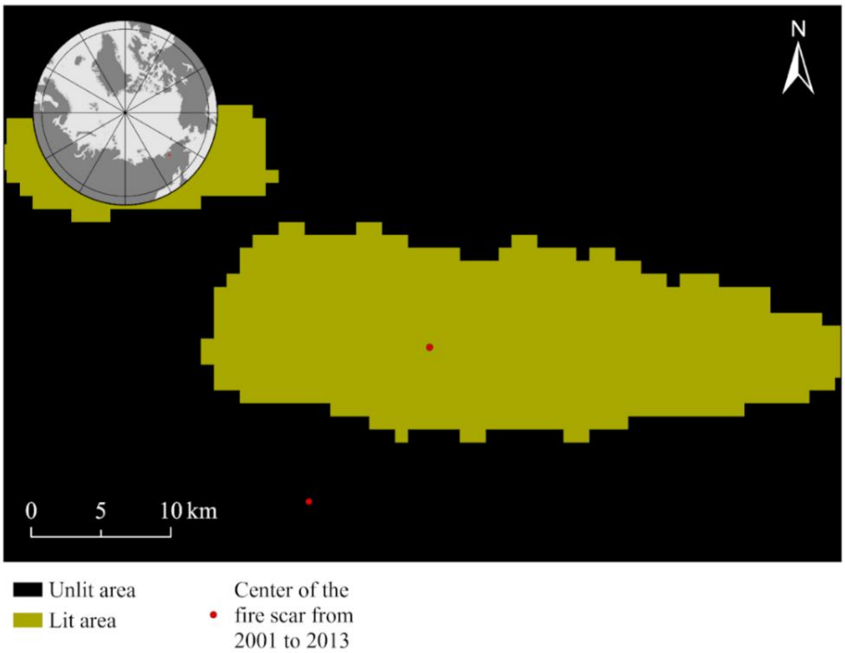

Fig. S4. Fire occurrence in the Bilibino mine in Russia from 2001 to 2013 (made with Natural Earth, projection EPSG: 4326).

The Bilibino mine in Chukotka, Russia has one of the largest undeveloped copper deposits in the world. We only observe 1 fire occurrence within the lit area.

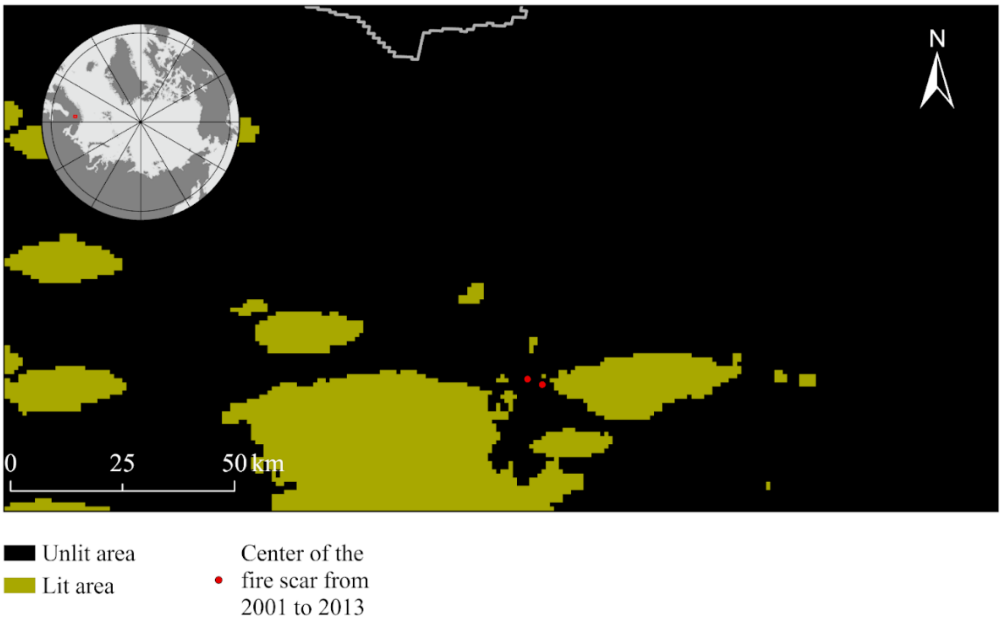

Fig. S 5. Fire occurrence in Kittilä mine in Finland from 2001 to 2013 (made with Natural Earth, projection EPSG: 4326).

Kittilä mine in Finland is the largest gold deposit in Europe[3]. Open pit mining began in 2002 with two open pits. There were 2 fire occurrences outside of the lit area from 2001 to 2013.

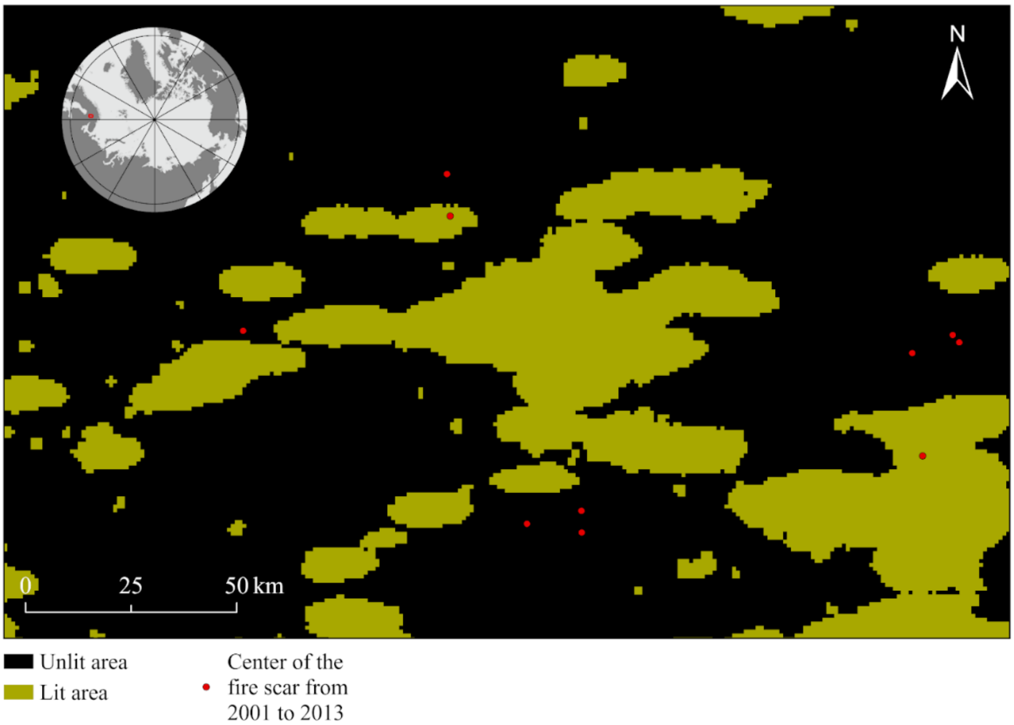

Fig. S 6. Fire occurrence in the Kevitsa mine in Finland from 2001 to 2013 (made with Natural Earth, projection EPSG: 4326).

Kevitsa is a copper and nickel mine located in Finland, 140 kilometers north of the Arctic circle. Drilling at the site started in the 1980s for diamond drilling. But only after nickel and copper mineralization was found, the construction at the site started in 2010[4].

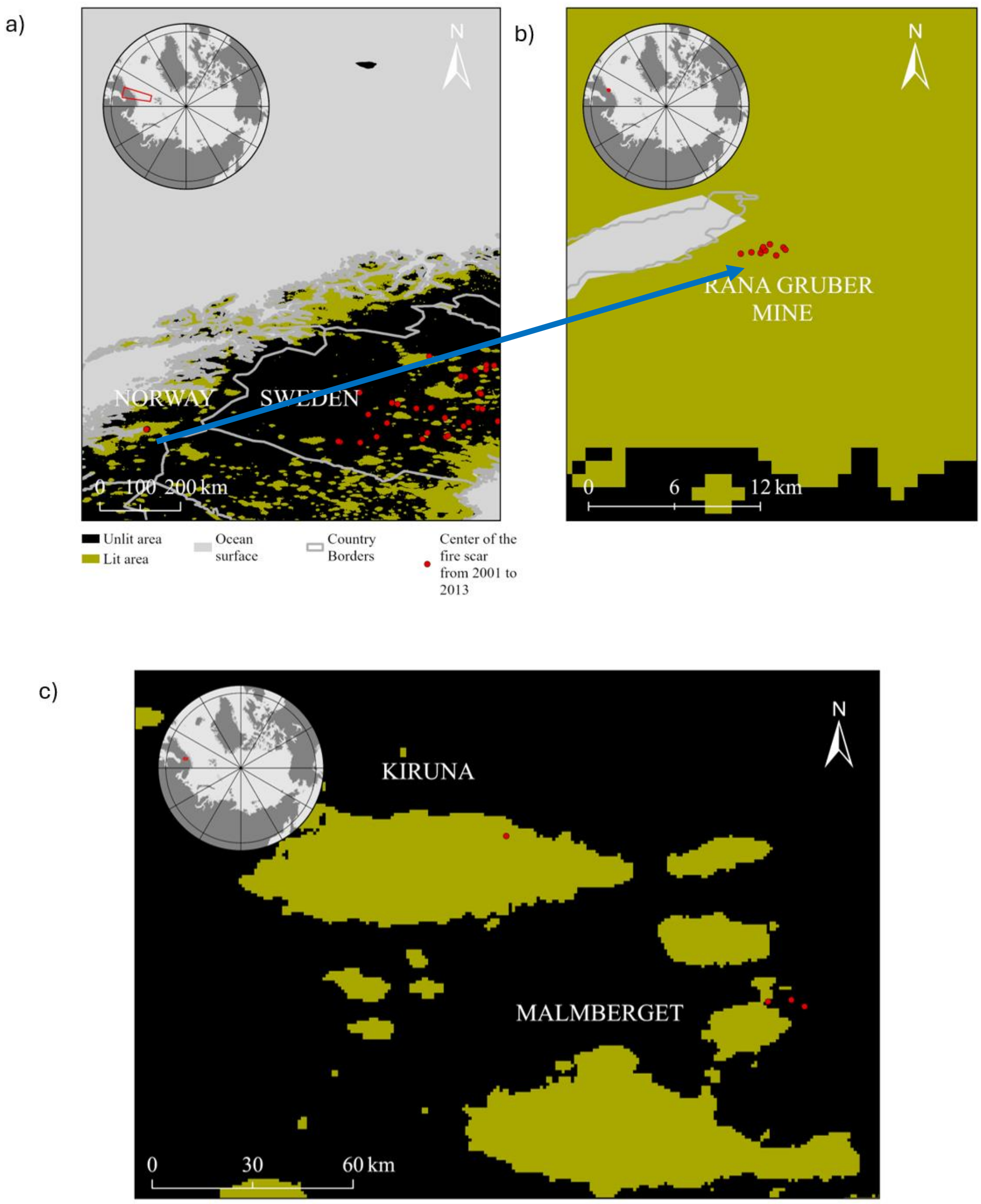

Fig. S 7. Fire occurrence in a) Norway and Sweden, b) Rana Gruber Mine in Norway, and c) Kiruna and Malmberget mine in Sweden from 2001 to 2013 (made with Natural Earth, projection EPSG: 4326).

Rana Gruber is the world's first carbon free iron ore mine[3]. The Norwegian Arctic has had 10 fires from 2001 until 2013 and all located around the Rana Gruber mine. Fires happened every year, except 2001 and 2003.

Kiruna is Sweden's northernmost city with the world's largest underground iron ore mine in the world[3]. In 2004, it was decided that due to underground mining, the town center should be moved 3 kilometers. In 2020, an earthquake with magnitude of 4,9 was triggered due to mining. There was only 1 fire occurrence in this Swedish mine site from 2001 to 2013.

Malmberget is one of the oldest and still in operation mines in the world, mining activity extending back to 1741.

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