Artificial light at night discloses large regional differences in industrial activity across the Arctic

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Introduction

As the warming climate facilitates industrial development in the Arctic, direct anthropogenic impacts of industrial development on the Arctic ecosystem might exacerbate the effects of climate change[1]. Until now the analysis of the industrial human activity and infrastructure development in the Arctic was generally local such as at the Prudhoe Bay oil fields[2,3] or Bovanenkovo oil fields[4]. Some recent studies also showed the current state of the infrastructure development in the Pan Arctic[5,6]. However, there is no study on past activity and how the industrial development and urbanization changed throughout years, allowing us to determine the rate of development at pan-Arctic scale, and to quantify the total area that is affected by industrial human activity through time, including industrial areas that have been abandoned. We close this gap by analyzing industrial human activity and urbanization from 1992 to 2013 using Artificial Lights at Night (ALAN), because remotely sensed artificial lights deliver the signature of human activity[7,8].

Results

Research Question 1: What is the total area affected by human activity in the terrestrial pan-Arctic and how is human activity distributed regionally?

Research Question 2: How much of ALAN in the Arctic can be explained by human settlement?

- Although 95.1% of the Arctic is not affected by ALAN and the corresponding human activity, the European Arctic and oil & gas extracting regions are demonstrated to be the hotspots of the ALAN concentration.
- Human settlement explained on average 12.8% of ALAN development across the Arctic, oil & gas extracting regions of Russia (Khanty Mansi, Yamal Nenets, and Nenets) being the lowest across the whole Arctic. So, most of the spatial variation in ALAN is assumed to be related to the other human activity emitting light in the Arctic, i.e., industrial activity.

Table 1. Total area lit by human activity for different regions in the Arctic during 1992-2013 (Δ represents the change, † represents change with the starting year 1993 instead of 1992 due to missing data).

Region	Total area (km^2)	Total area lit (km^2) (fraction lit of total area)	Newly Lit Area (km^2) (fraction newly lit of total area)	Δ in ALAN from 1992 to 2013 (based on sum of regional ALAN)	ALAN explained by human settlement (Average of 1995, 2000, 2005, and 2010)	Significant increase in trend map	Significant decrease in trend map
pan-Arctic	16’216’202	962’476 (4.9%)	591’280 (3.65%)	80.89%	12.8%	1.41%	0.24%
Russia	9’353’277	593'277 (6.3%)	425’003 (4.54%)	56.90%	11.7%	1.82%	0.39%
Europe (Exc Greenland)	543’077	154'849 (28.5%)	127’490 (23.5%)	95.93%†	24.5%	9.42%	0.23%
Sweden	165’308	44'743 (27.1%)	31'972 (19.3%)	85.37%	29.4%	5.10%	0.58%
Norway*	113’395	43'251 (38.1%)	33’353 (29.4%)	162.40%†	17.1%	17.22%	0.03%
Finland	160’705	49'386 (30.7%)	36’754 (22.87%)	166.40%	27.5%	10.55%	0.16%
North America	5’012’233	53'417 (1.1%)	41’601 (0.8%)	81.85%	33.0%	0.18%	0.02%
Canada	3’504’881	15'960 (0.5%)	13’292 (0.4%)	73.83%	27.6%	0.04%	~0%

Research Question 3: How has human activity evolved spatially and temporally in the terrestrial Arctic from 1992 to 2013?

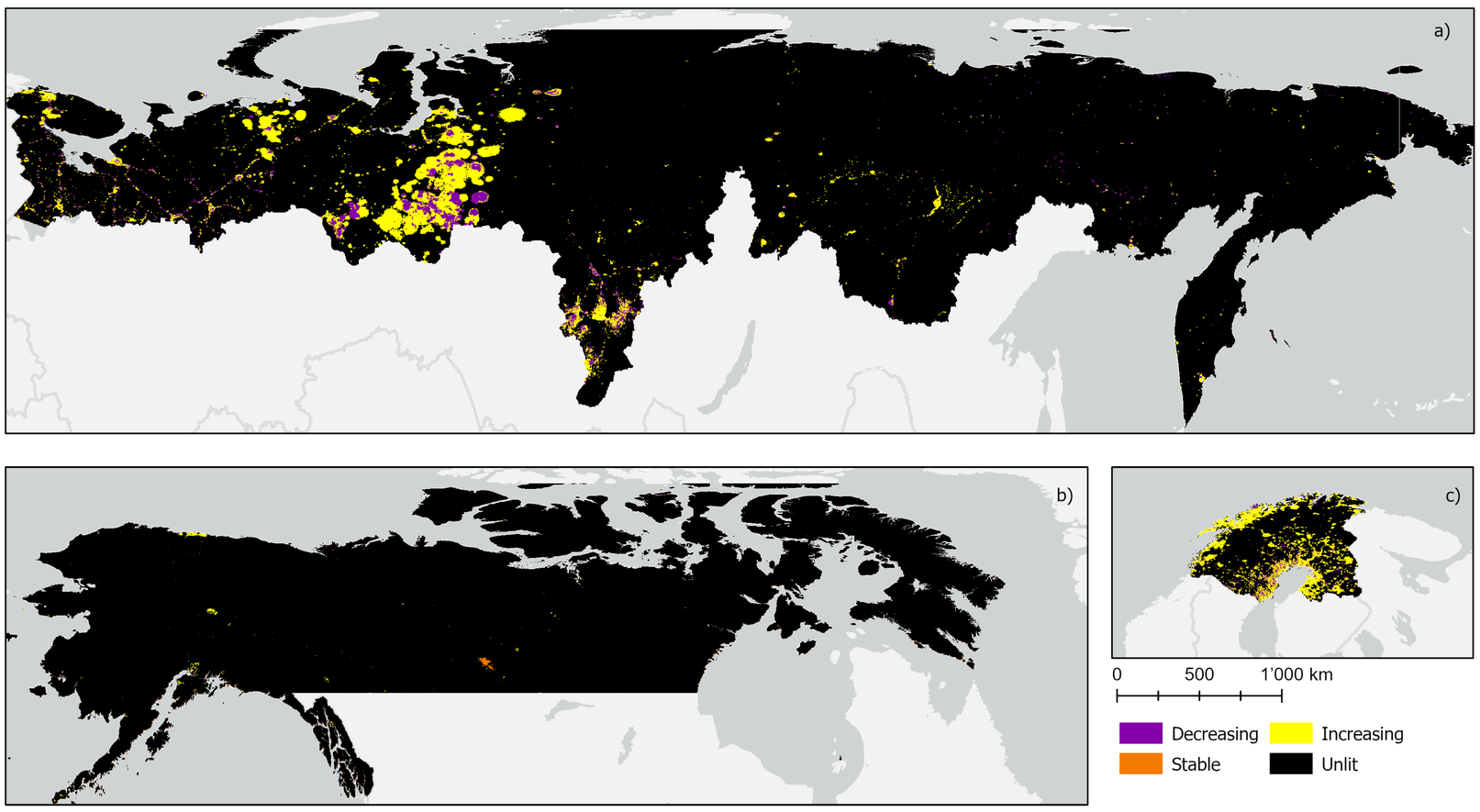

Figure 1. Pan Arctic Artificial Lights at Night (ALAN) Map with a) Russian, b) North American, and c) Scandinavian Arctic.

Russian Arctic shows the most dynamic ALAN development due to oil & gas extracting regions i.e., while old oil fields are depleted and abandoned, the new ones are developed.

Research Question 4: How do extracting industries differ in the area affected in the Arctic?

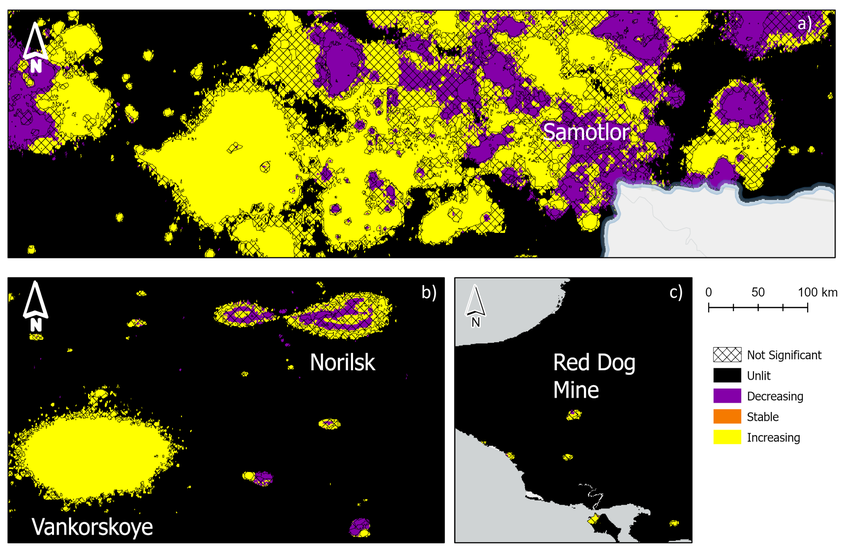

Figure 2. a) Part of the oil & gas extraction region of Yamal-Nenets and Khanty-Mansi including Samotlor oil fields in the southeast of the map b) Vankorskoye oil fields and Norilsk Mine, c) Red Dog Mine.

The total area affected by ALAN and corresponding human activity in Norilsk is ~4,700 km^2, in Vankorskoye is ~12,500 km^2, and in Red Dog mine is ~ 150 km^2.

The total area affected by ALAN in the main oil and gas extracting regions in the Russian Arctic (Khanty Mansi, Yamal Nenets, and Nenets) is 332'292 km^2, almost the size of Germany, so 41.7% of the total area that are affected by ALAN in the pan-Arctic are in these three sub regions.

The Samotlor oil field in Khanty Mansi (indicated in figure 2a) is the largest in Russia and one of the largest in the world. The development of the field started in 1967 and the extraction started in 1969. Following the global oil crisis, peak extraction was achieved in 1980 with 3.2 million barrels per day, which dropped to less than 1 million barrels per day in the 1990s. More than 20,000 wells have been drilled in this field together with 5,911 km of oil pipelines and 1,923 km of hard surface roads.

Methods

Study is conducted in the Pan Arctic based on the regions outlined in the Arctic Human Development Report (2015). Consistent and corrected nighttime light dataset from Zhao et al., (2022)[10] is utilized to run the analysis from 1992 to 2013. We analyzed the ALAN trend by applying simple linear regression for every pixel from 1992 to 2013 for each region in pan-Arctic to measure the slope of the trendline and tested the significance of the slope based on P-Values.

The Global Human Settlement Layer (GHSL) is prepared by utilizing census data, and available for every five years between the years 1975 and 2030. To determine the relationship between GHSL and ALAN, we utilized linear spatial regression for different Arctic regions. The R-Squared values indicated the total variation in ALAN explained by the GHSL. We calculated the average of four years(1995, 2000, 2005, and 2010) to reach the mean value of R-squared values and reported that in our analysis.

Discussion

Our results for industrial human activity impacted areas are more amplified compared to previous studies, which can be due to higher coverage of total area towards southern latitudes or lower resolution of ALAN dataset, but if light pollution is also considered as human impact, then the other studies might be underestimating the anthropogenic impact in the pan-Arctic.

The day-light cycle of the Arctic is very different from lower latitudes; therefore, it is important to assess how the specific adaptations of endemic Arctic species are affected by the light pollution. We demonstrated that almost 800,000 km^2 of the Arctic is affected by the artificial light pollution induced by industrial human activities, which will in return have an impact on the species that are adapted to very specific light conditions of the Arctic.

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