Expanding infrastructure in the Arctic as visible from space

Method development:

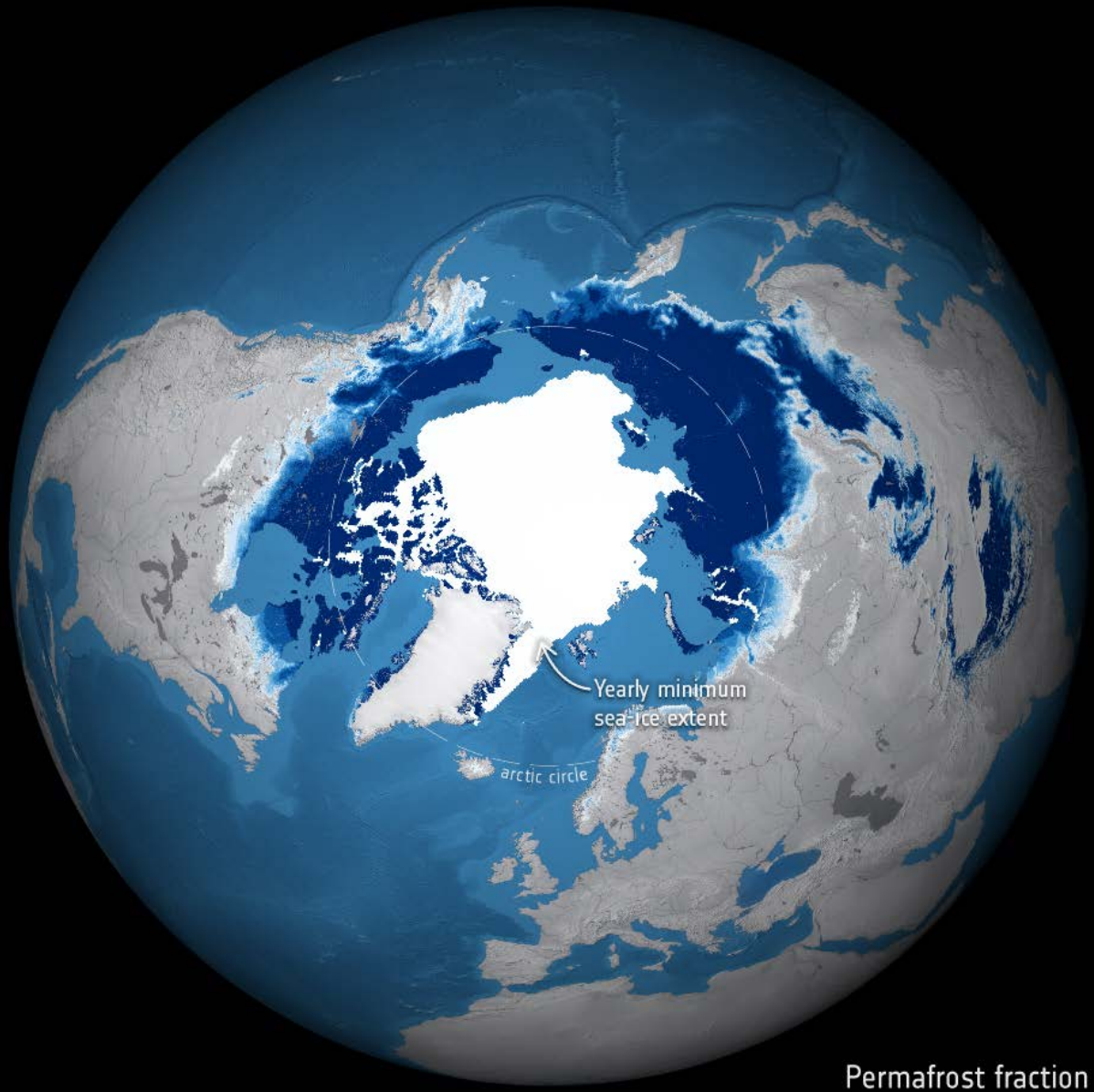
Bartsch, A., Pointner, G., Ingeman-Nielsen, T., Lu, W. (2020): Towards Circumpolar Mapping of Arctic Settlements and Infrastructure Based on Sentinel-1 and Sentinel-2. Remote Sensing, 12, 2368.

Results:

Annett Bartsch, Georg Pointner, Ingmar Nitze, Aleksandra Efimova, Dan Jakober, Sarah Ley, Elin Högström, Guido Grosse, Peter Schweitzer (2021): Expanding infrastructure and growing anthropogenic impacts along Arctic coasts. Environmental Research Letters.

permafrost cci

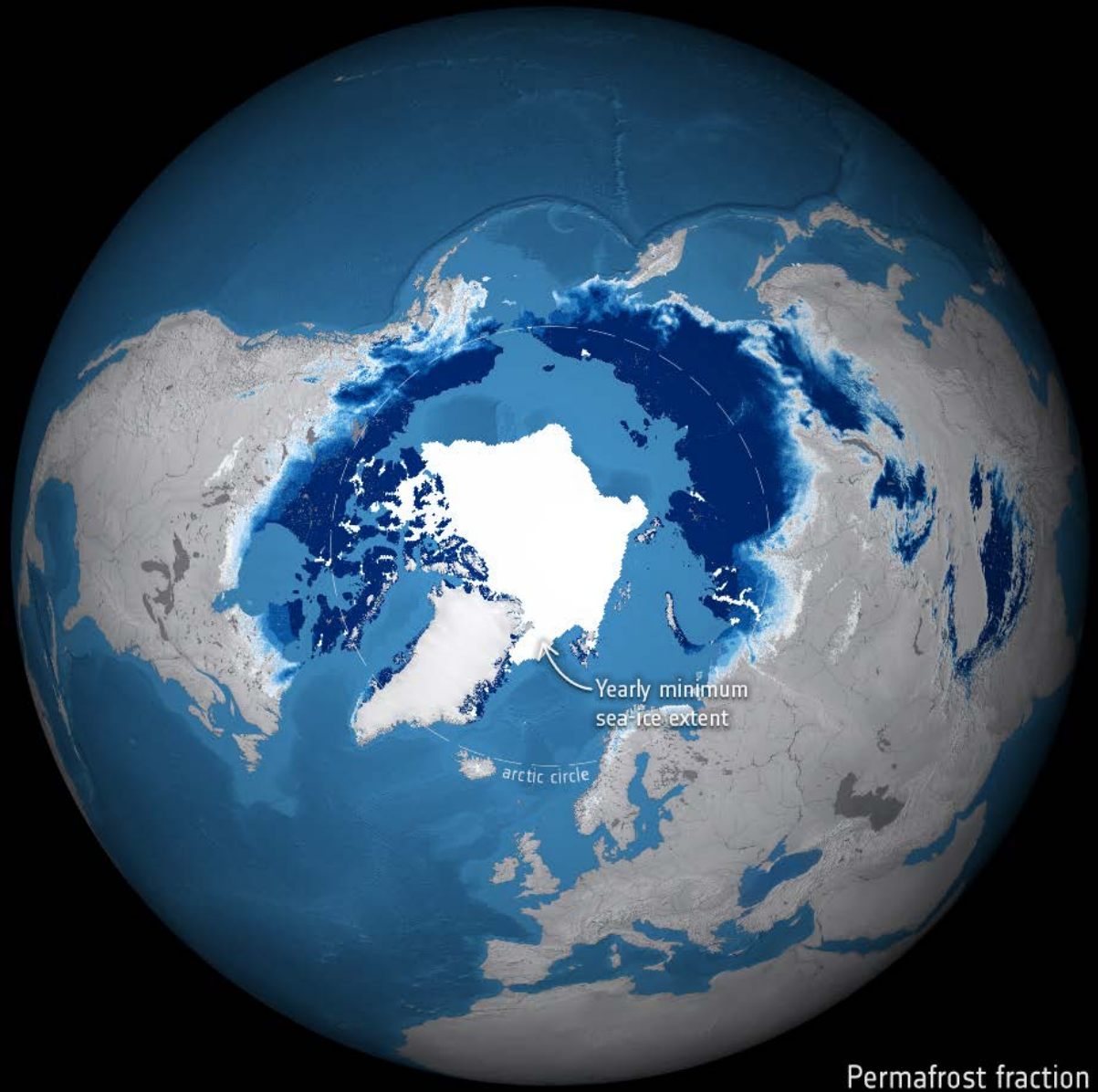
1997



Source: ESA, ESA/Permafrost Climate Change Initiative/NSIDC Sea Ice Index

permafrost
cci

2019

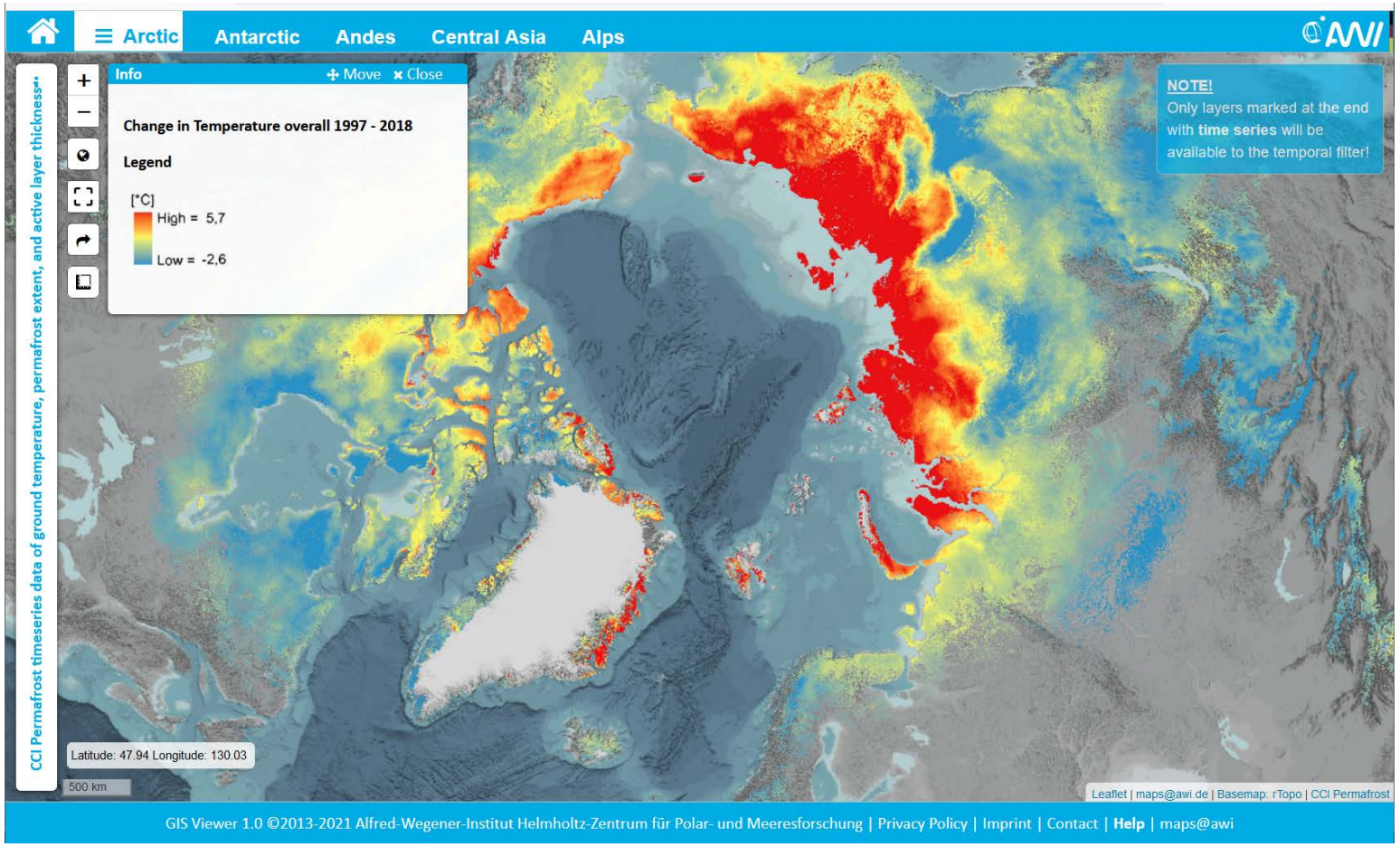


Permafrost fraction (%)
2019
10 50 100

Source: ESA, ESA/Permafrost Climate Change Initiative/NSIDC Sea Ice Index

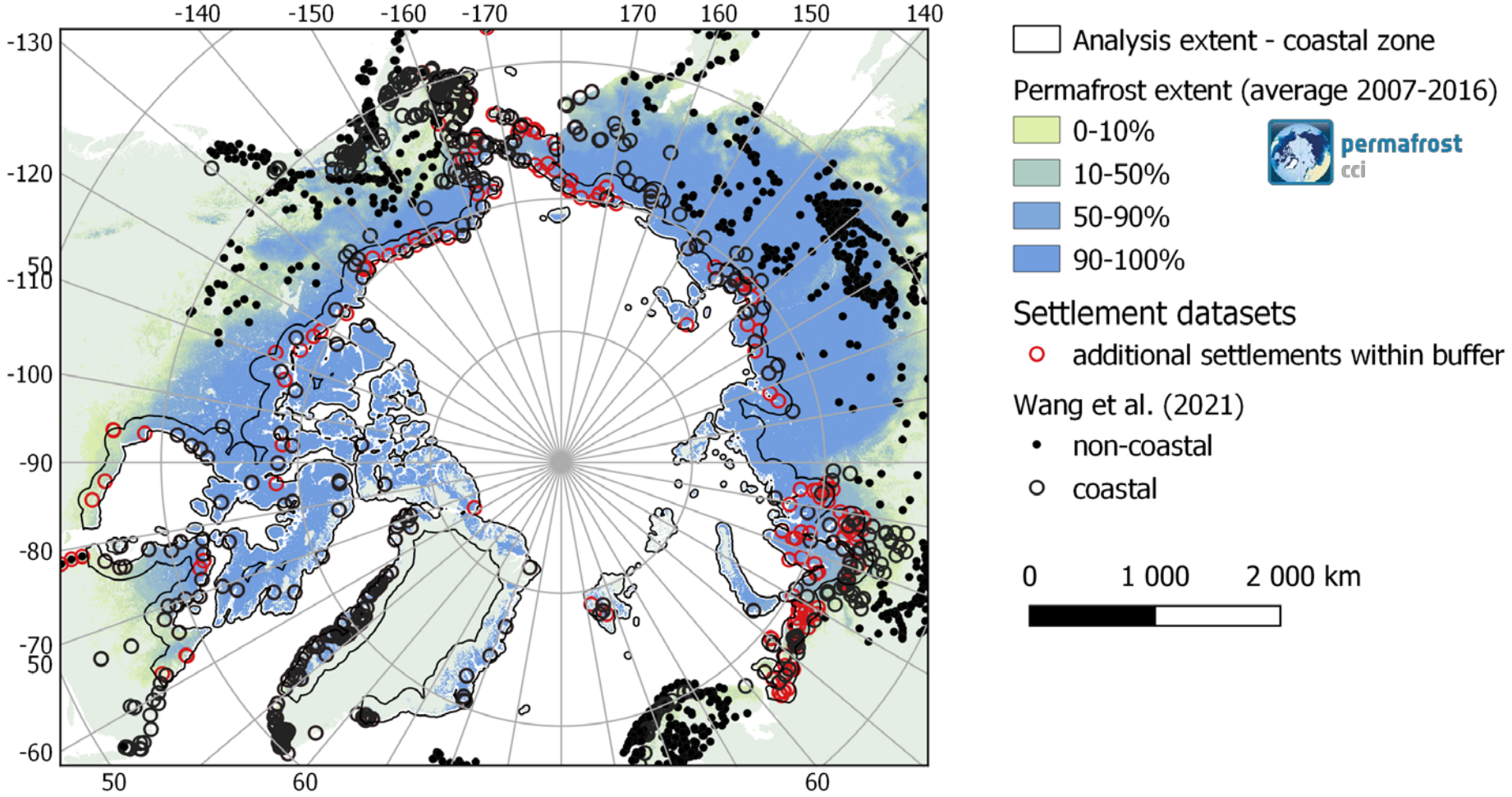
Permafrost_cci data in AWI WebGIS (public)

- Ground temperature (2m depth) change 1997-2018



Fokus on:

- Land area within 100 km buffer from coast
- Permafrost area only



Bartsch, Pointner, Nitze, Efimova, Jakober, Ley, Högström, Grosse, Schweitzer (2021), ERL

Objectives

1) Identify infrastructure potentially impacted by recent climate change
2) to document the added value of satellite-derived infrastructure maps along the Arctic coasts compared to existing sources
3) to identify and quantify change of recent human impact across the Arctic

https://permafrostcoasts.org/digital-media/ L. Farquharson, UAF

Infrastructure - Currently available records

- Remote sensing
  - Global datasets of **build-up** areas
    - Not all Arctic settlements included, limitation to buildings
  - Global datasets of **nighttime light** information
  - Precise local accounts for some sites
    - Derived manually using aerial photographs and/or very high resolution satellite data

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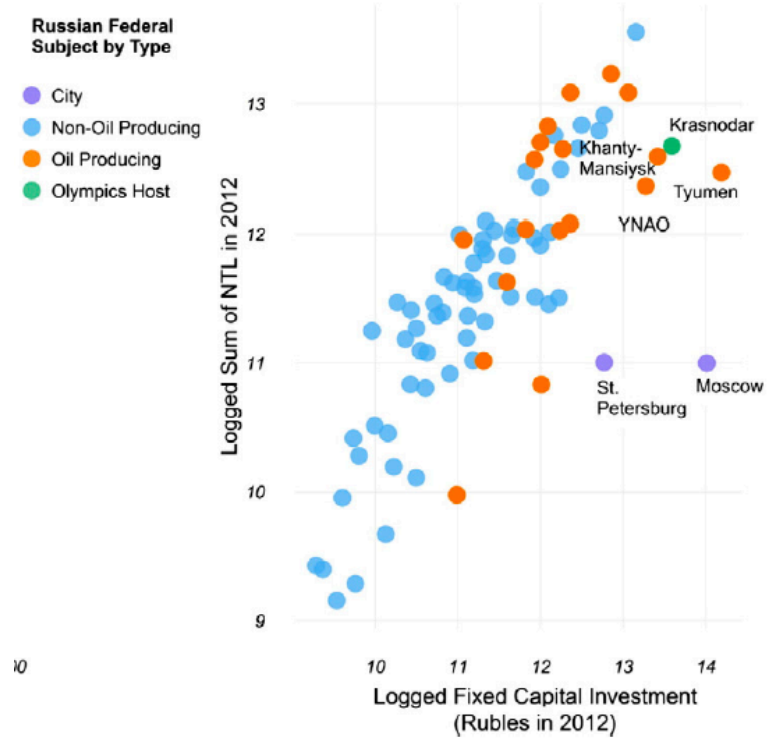
Bennet & Smith 2017



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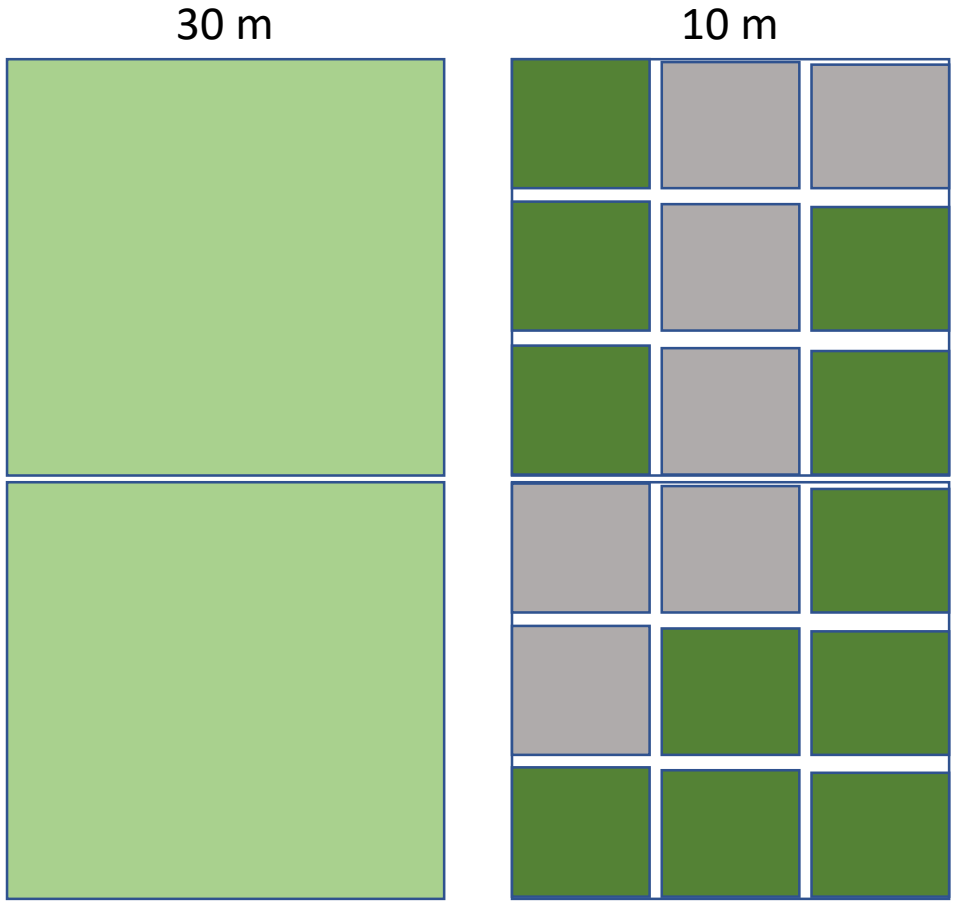
  - Precise local accounts for some sites
    - Derived manually using aerial photographs and/or very high resolution satellite data
- Open Streep Map
  - Inconsistent information on settlements and infrastructure, many gaps across the Arctic, partially limited geometric accuracy, unknown timestamp
  - But currently most complete account, used in several studies

What else can be provided with satellite data considering new missions?

What data sources could be used?

- Landsat (30m) popular for Arctic landcover mapping but settlements and infastructure rarely mapped
  - Spatial resolution largely insufficient (e.g. Kumpula et al. 2012)
- Sentinel-1 and Sentinel-2 provide now data at 10 m resolution



- Example Longyearbyen

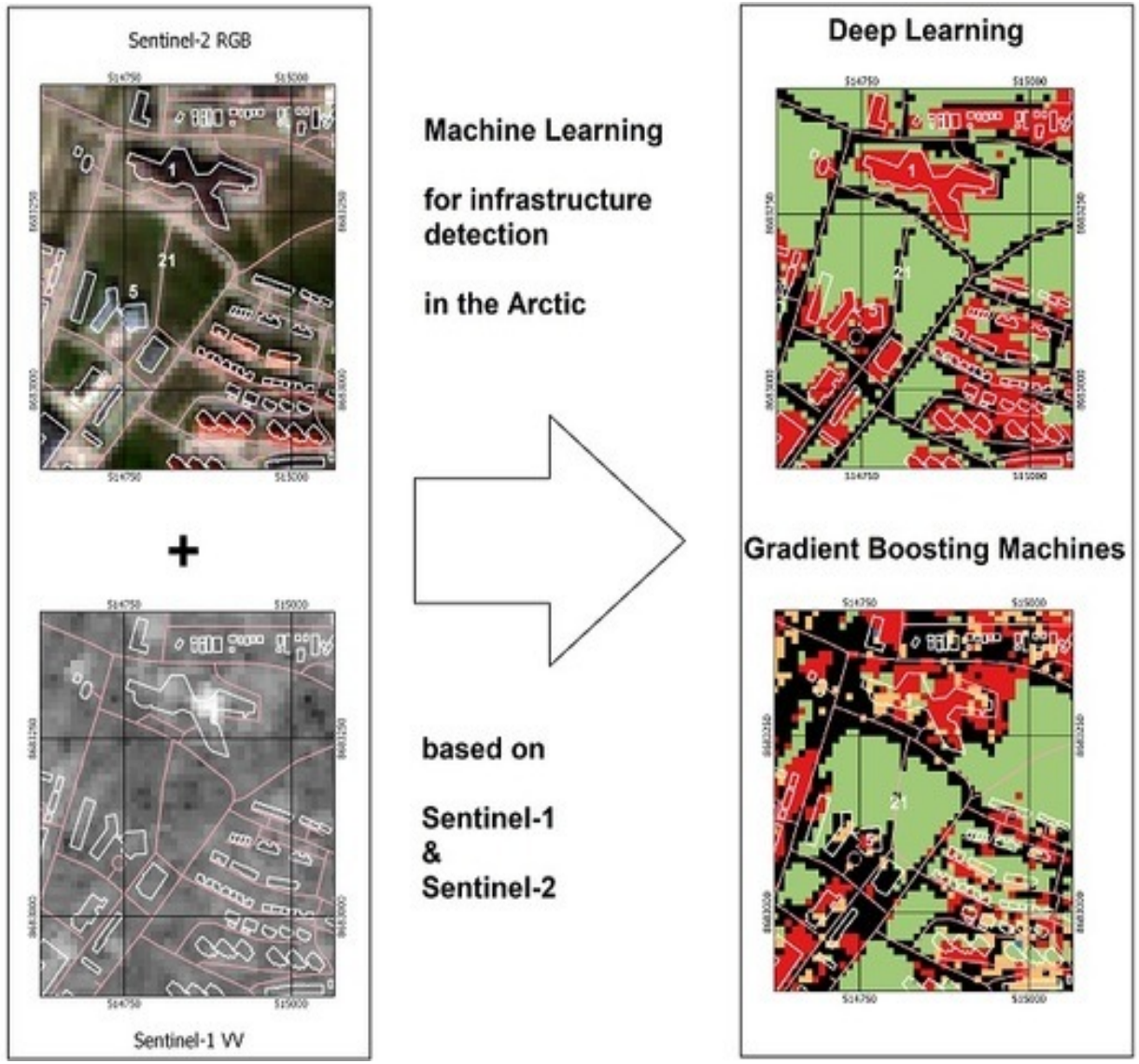
  1 – UNIS building

  21 - footpath

- Target classes
  - Buildings

    Roads
  - Other human impacted area

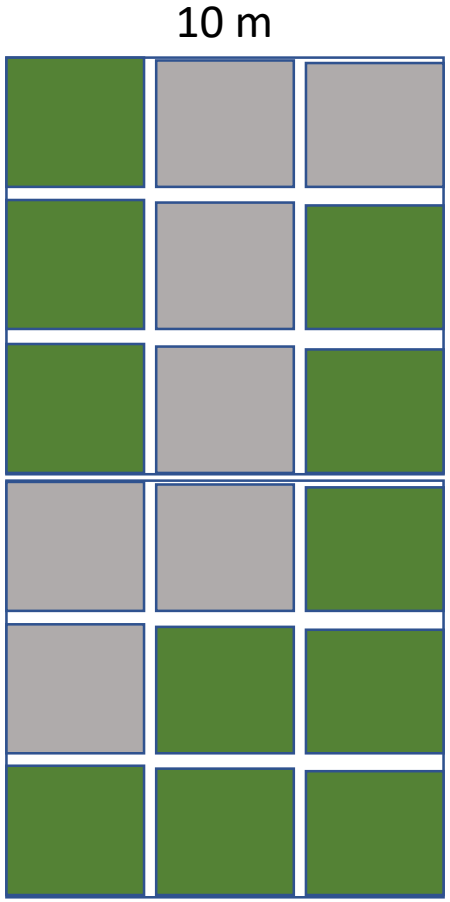
- GBM also includes
  - Vegetated areas
  - water



(2016-2018)

Bartsch, Pointer, Ingeman-Nielsen & Lu (2020), RS

Requires vegetation for areas without human impact



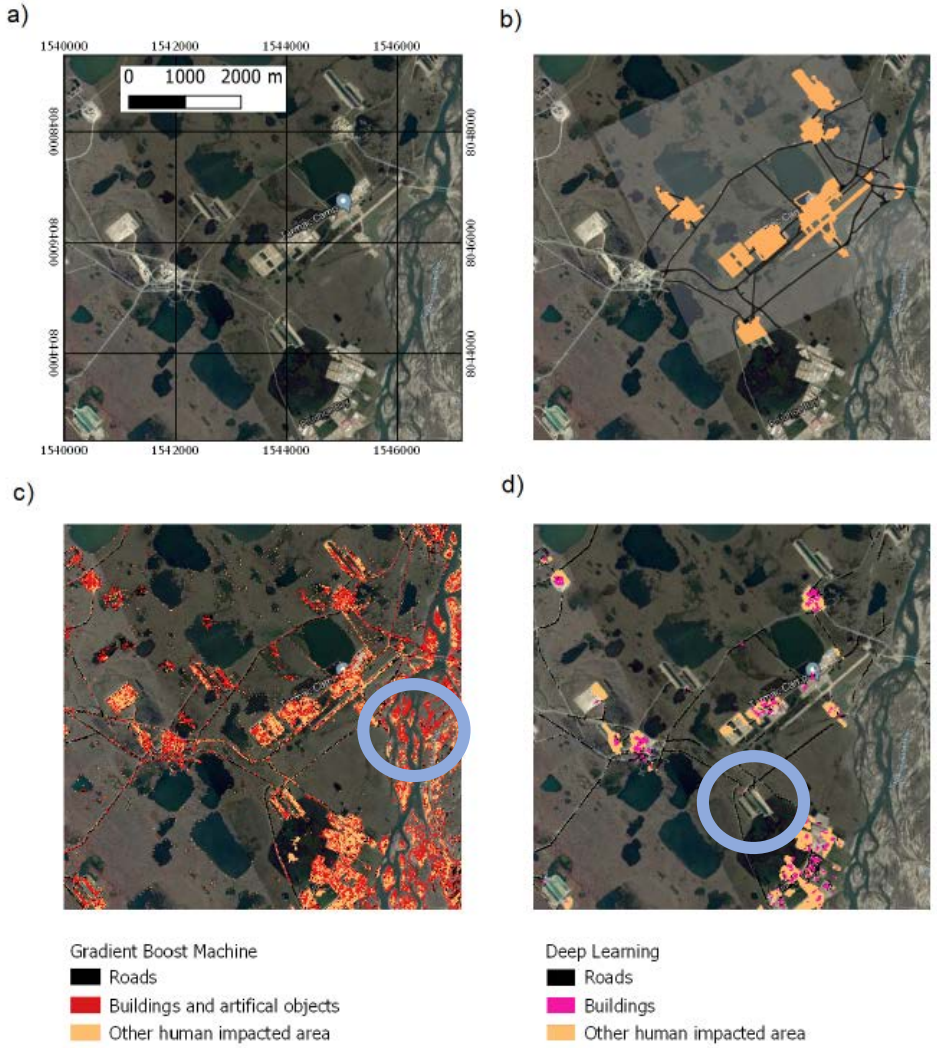
Classification errors in high Arctic locations

Southampton Island, Canada – new road to Boas River oil shale site

Example Prudhoe Bay, Alaska

Google Hybrid background map

Gradient Boost Machine classification result



high-resolution validation dataset (area C of the work in Raynolds et al. 2014)

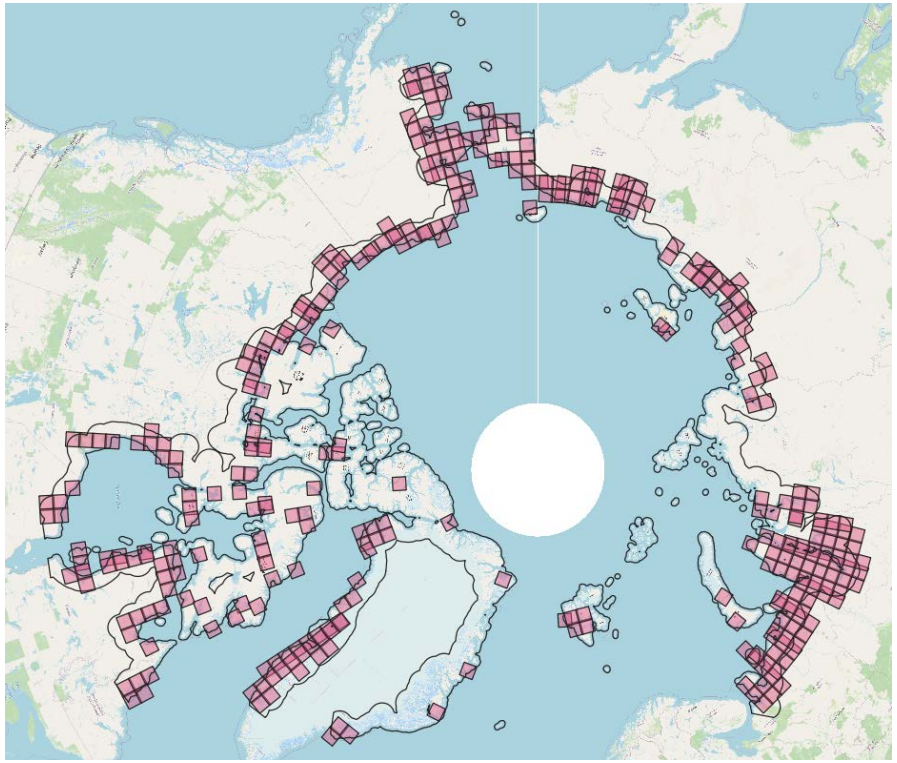
Deep Learning result

Fully automatic scheme not applicable

Bartsch, Pointer, Ingeman-Nielsen & Lu (2020), RS

- More than 2400 Sentinel-2 acquisitions at granule extent (2016-2020) processed
- At least one Sentinel-1 acquisition per granule

- 366 Granules with infrastructure and permafrost

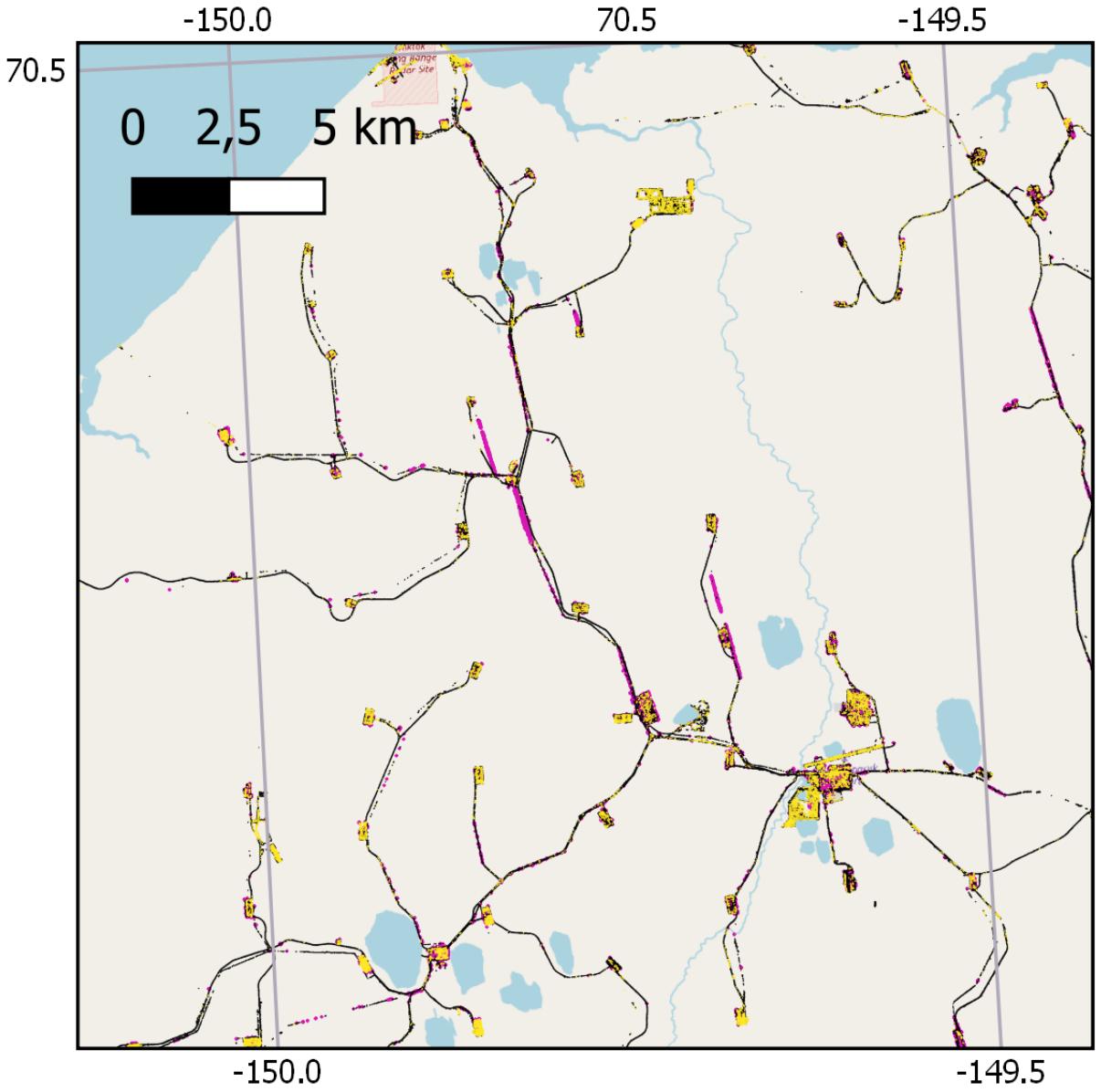


Sentinel-1/2 derived Arctic Coastal Human Impact dataset (SACHI)
https://zenodo.org/record/492591

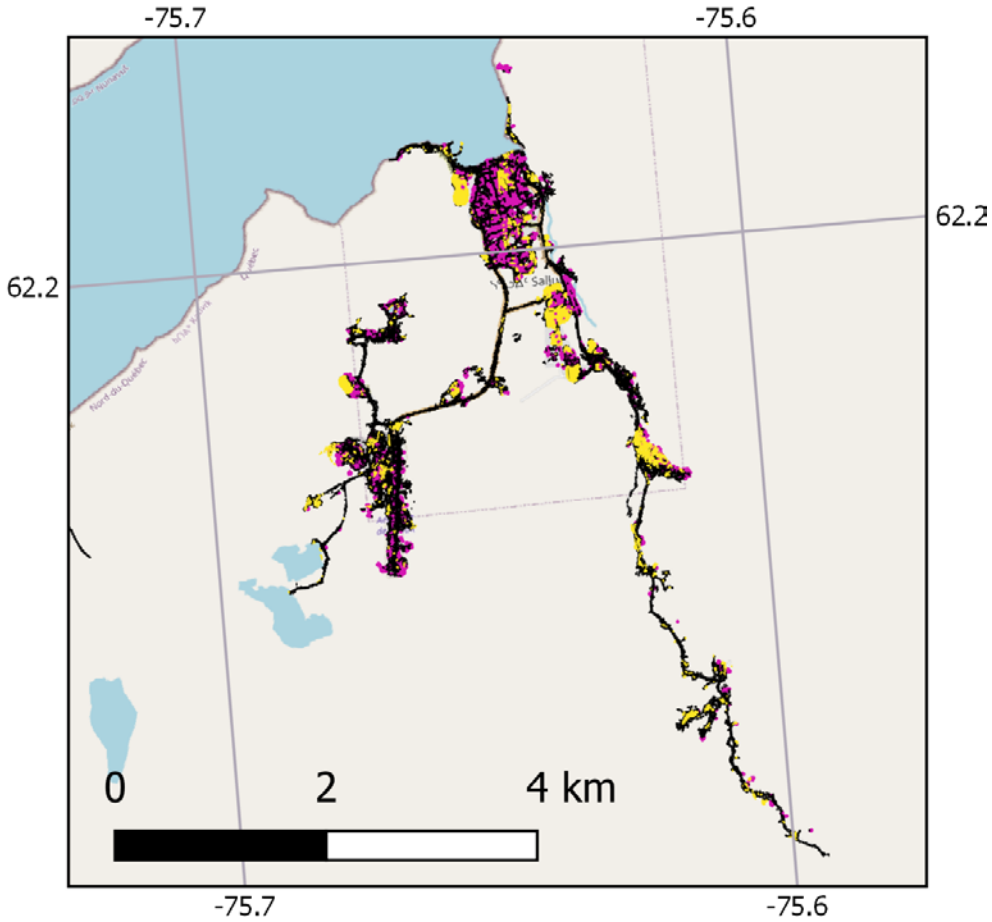
It consists of three shape files:
1. SACHI.shp - all identified objects with infrastructure/impact classes and auxiliary information (permafrost status and trends, nightlight radiance, vegetation zone, Normalized Difference Vegetation Index trends from Landsat, settlements names)
2. SACHI_100km_buffer - Buffer polygon (analyses extent)
3. SACHI_granules_acquisition_dates - processed Sentinel-2 granule extent polygons with dates of all used input data

SACHI class values:
1=linear transport infrastructure,
2=buildings (and other constructions such as bridges),
3=other impacted area (includes gravel pads, mining sites)

Prudoe Bay Oil field, Alaska



Salluit, Canada



SACHI classes

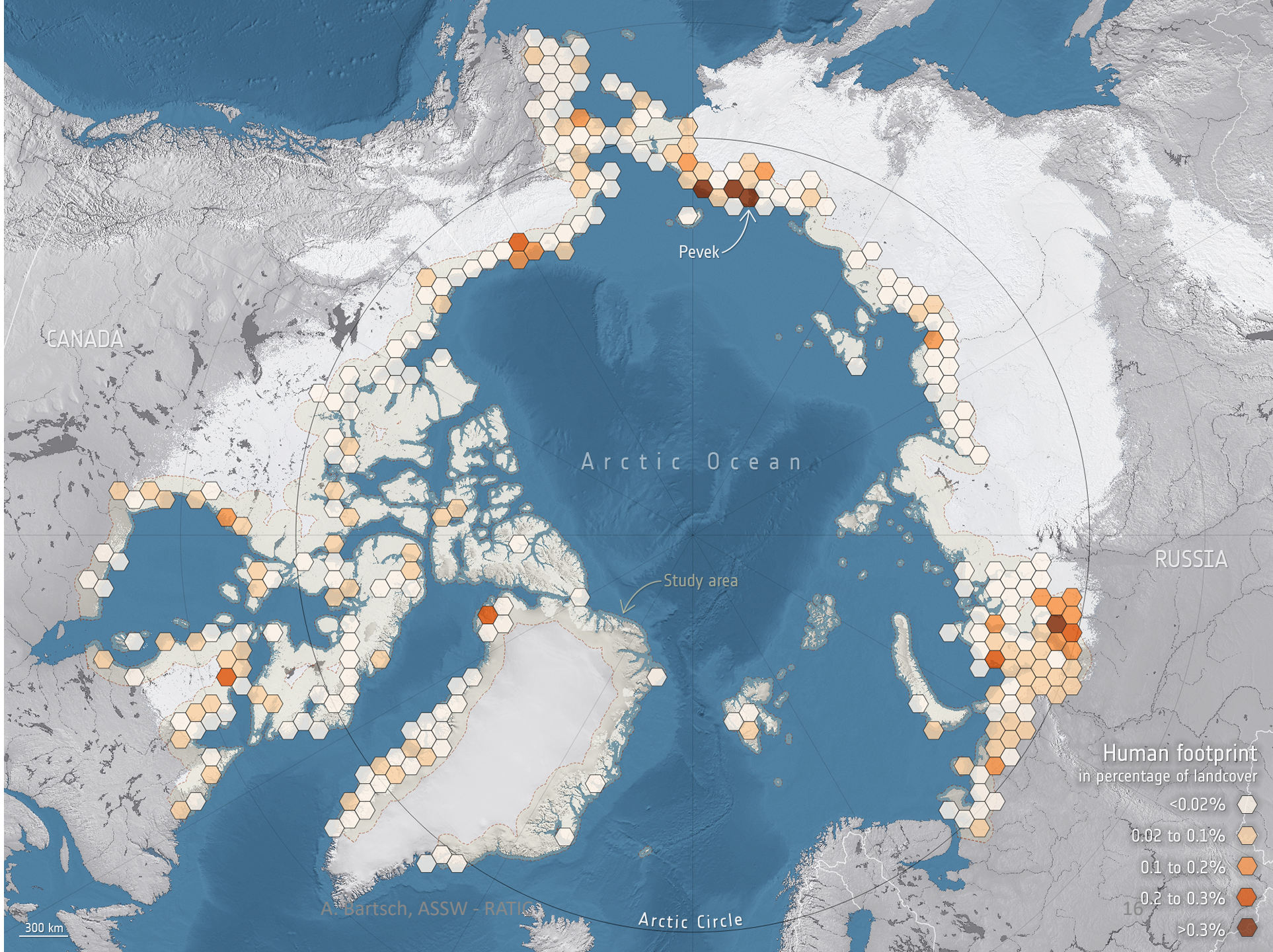
- roads
- buildings and other constructions
- other impacted area

‚Human footprint' – within 100 km of the coast (permafrost areas only)

Roads, buildings & constructions, mining areas, gravel pads etc

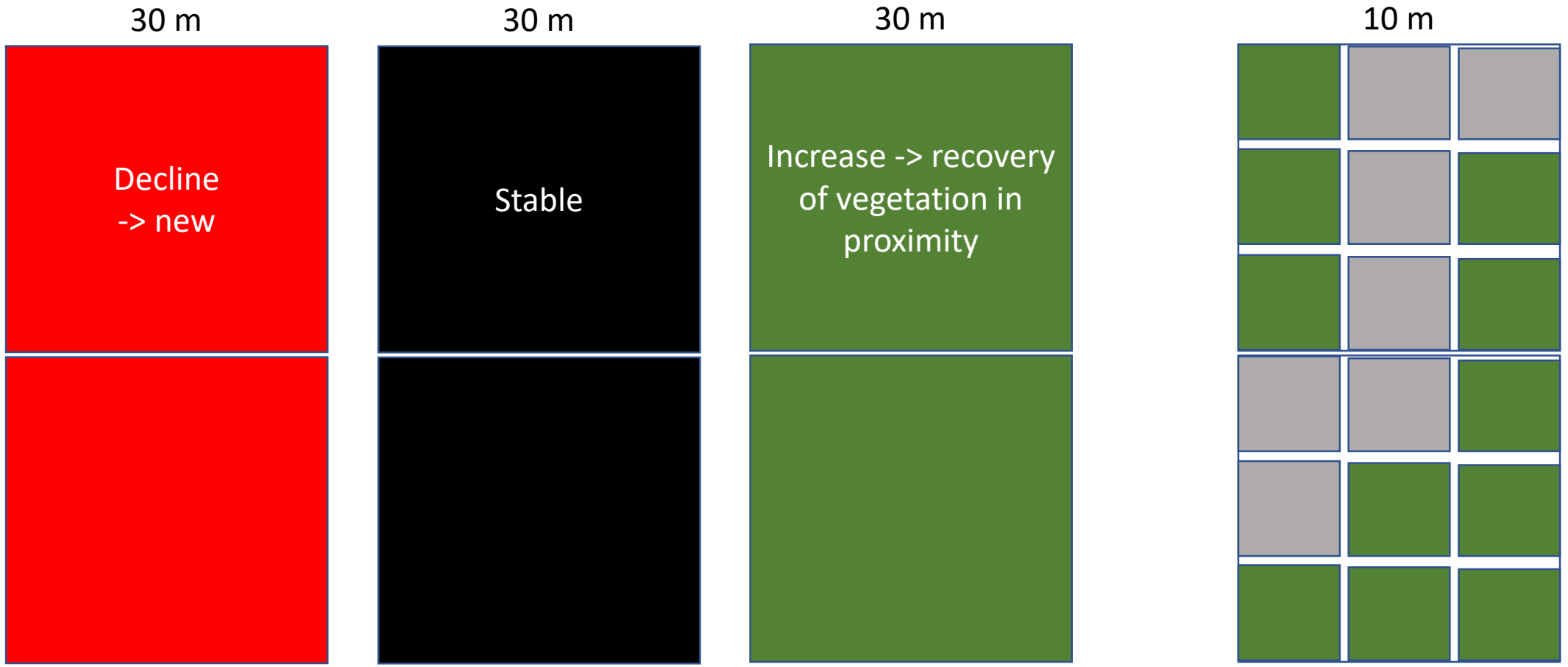
Representing 2016-2019

Graphic: ESA



Vegetation trends –> landcover change

- Landsat 30 m, NDVI – Normalized difference vegetation index, 2000 - 2018



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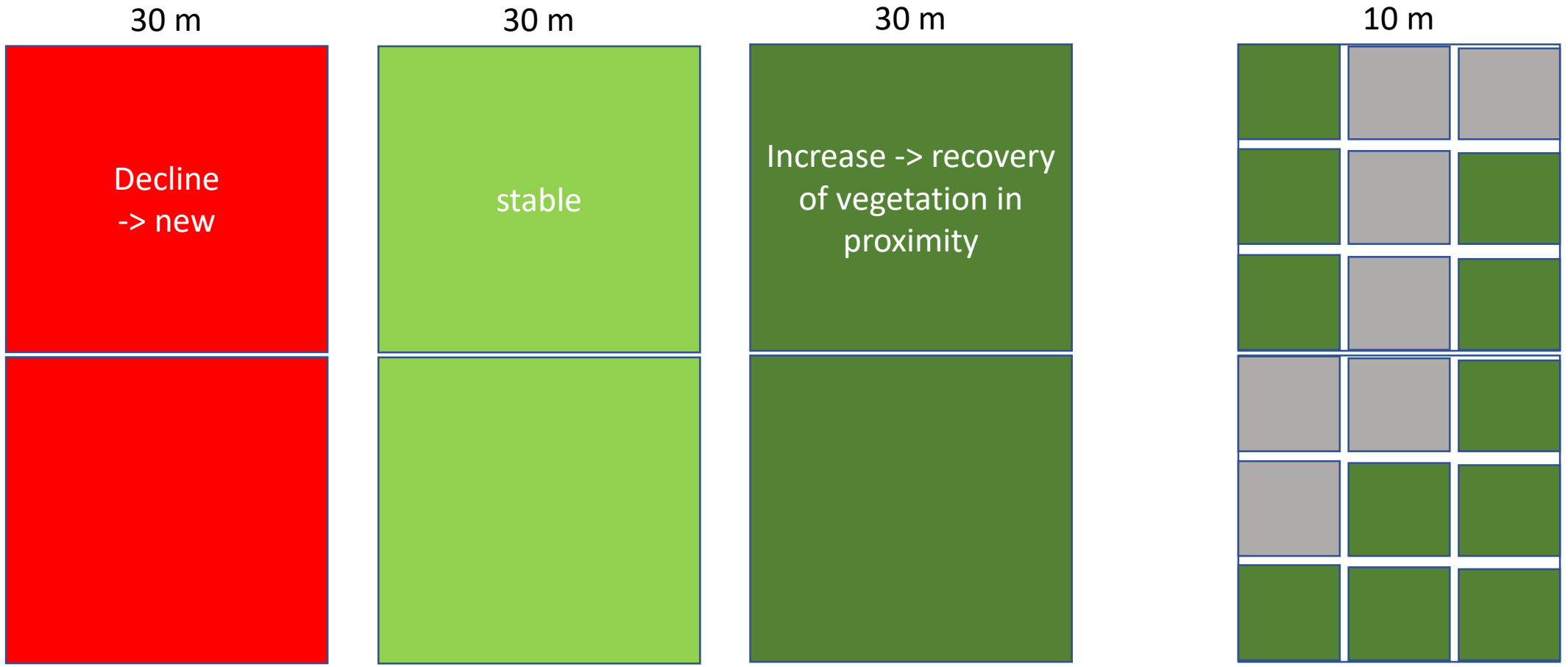
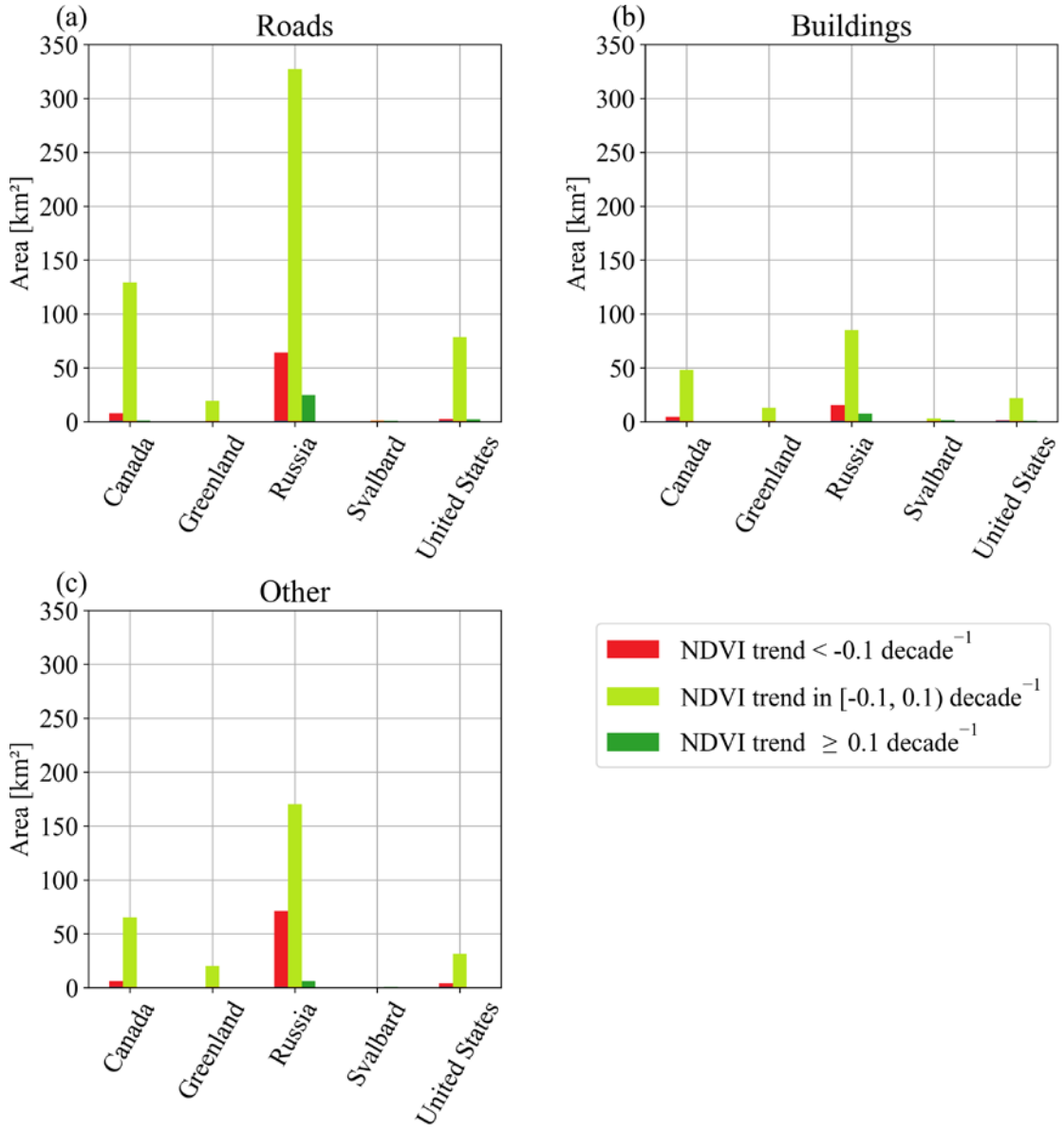
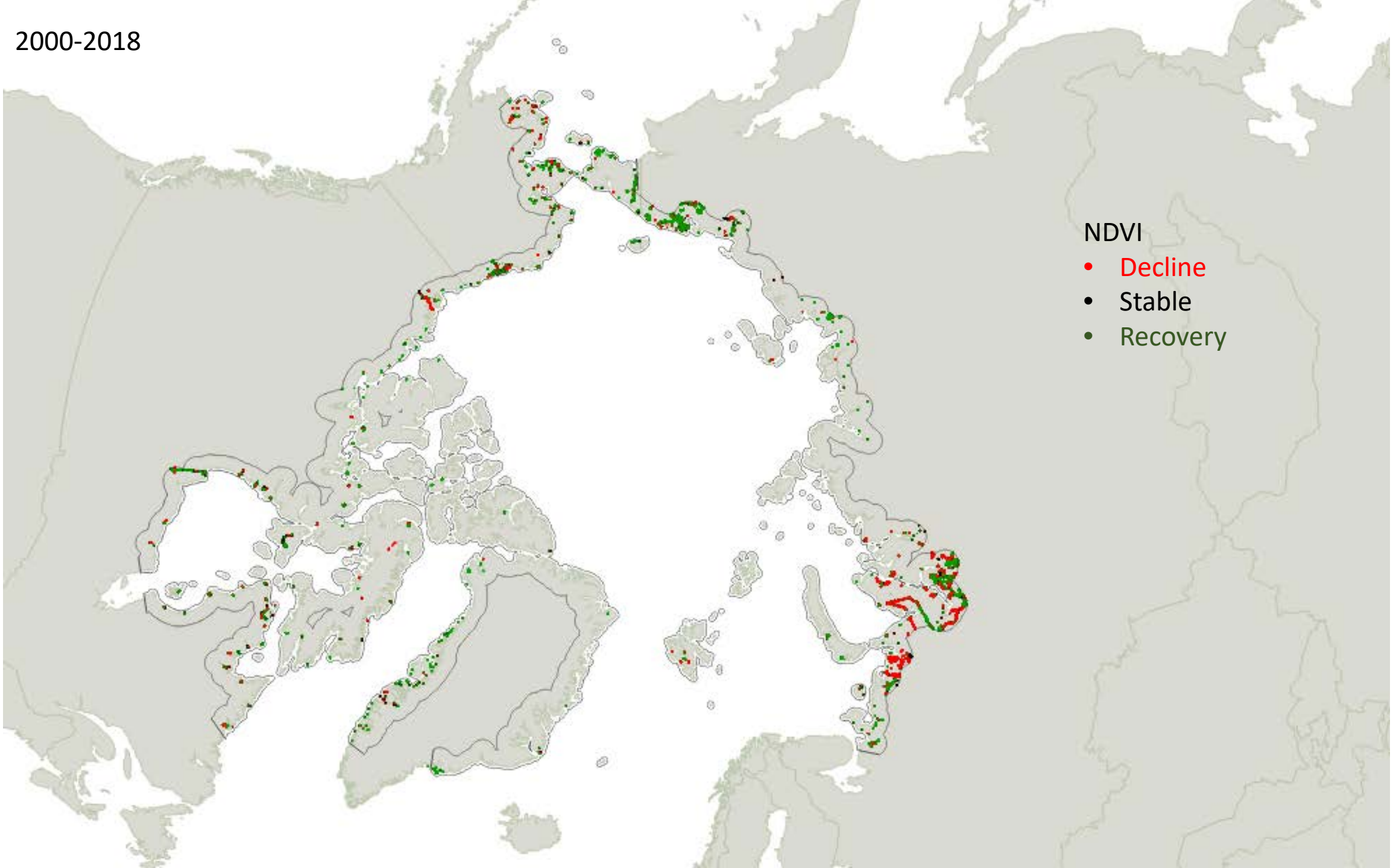


2000-2018



Annett Bartsch, Georg Pointner, Ingmar Nitze, Aleksandra Efimova, Dan Jakober, Sarah Ley, Elin Högström, Guido Grosse, Peter Schweitzer (2021): Expanding infrastructure and growing anthropogenic impacts along Arctic coasts. Environmental Research Letters. https://doi.org/10.1088/1748-9326/ac3176

2000-2018



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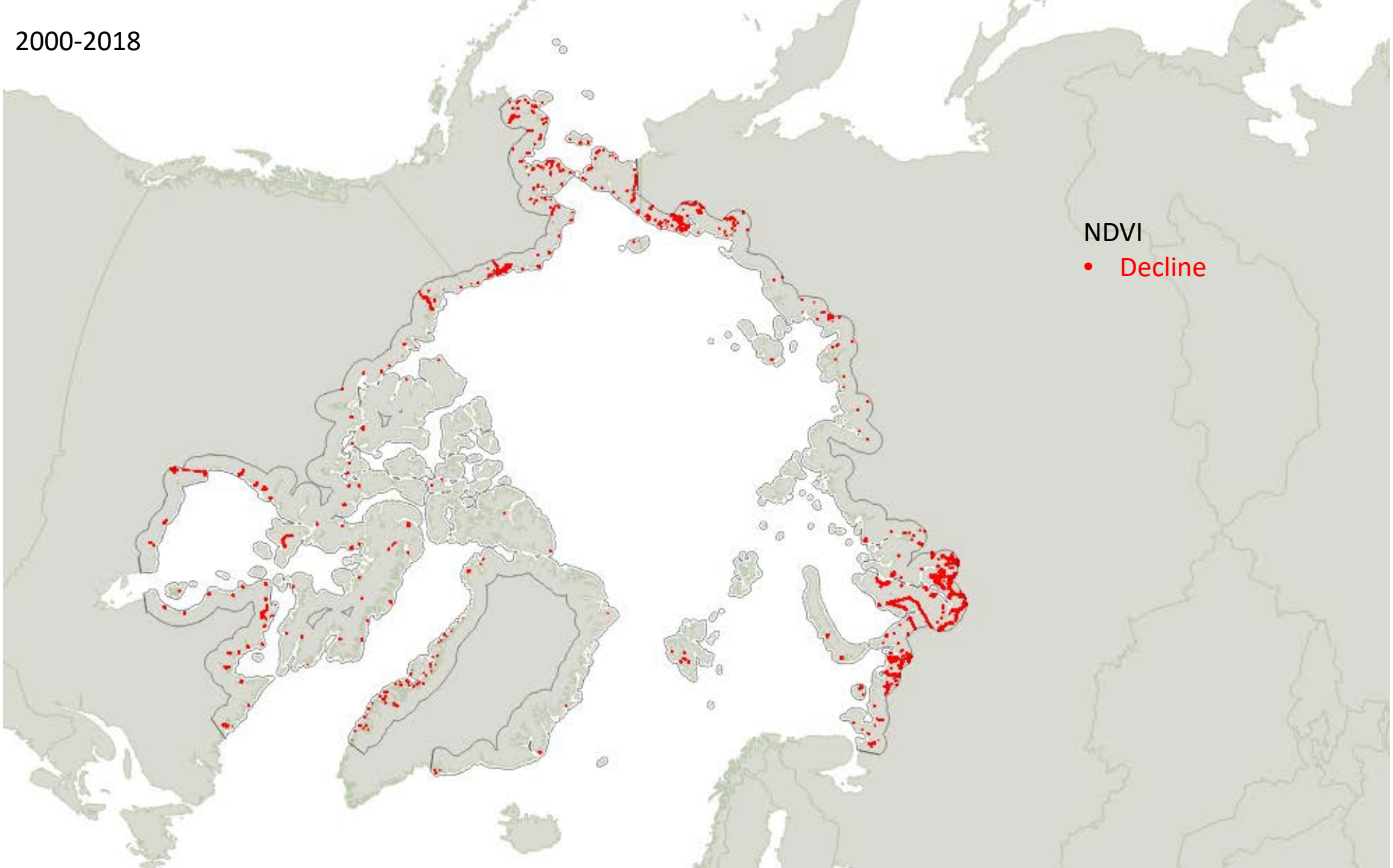
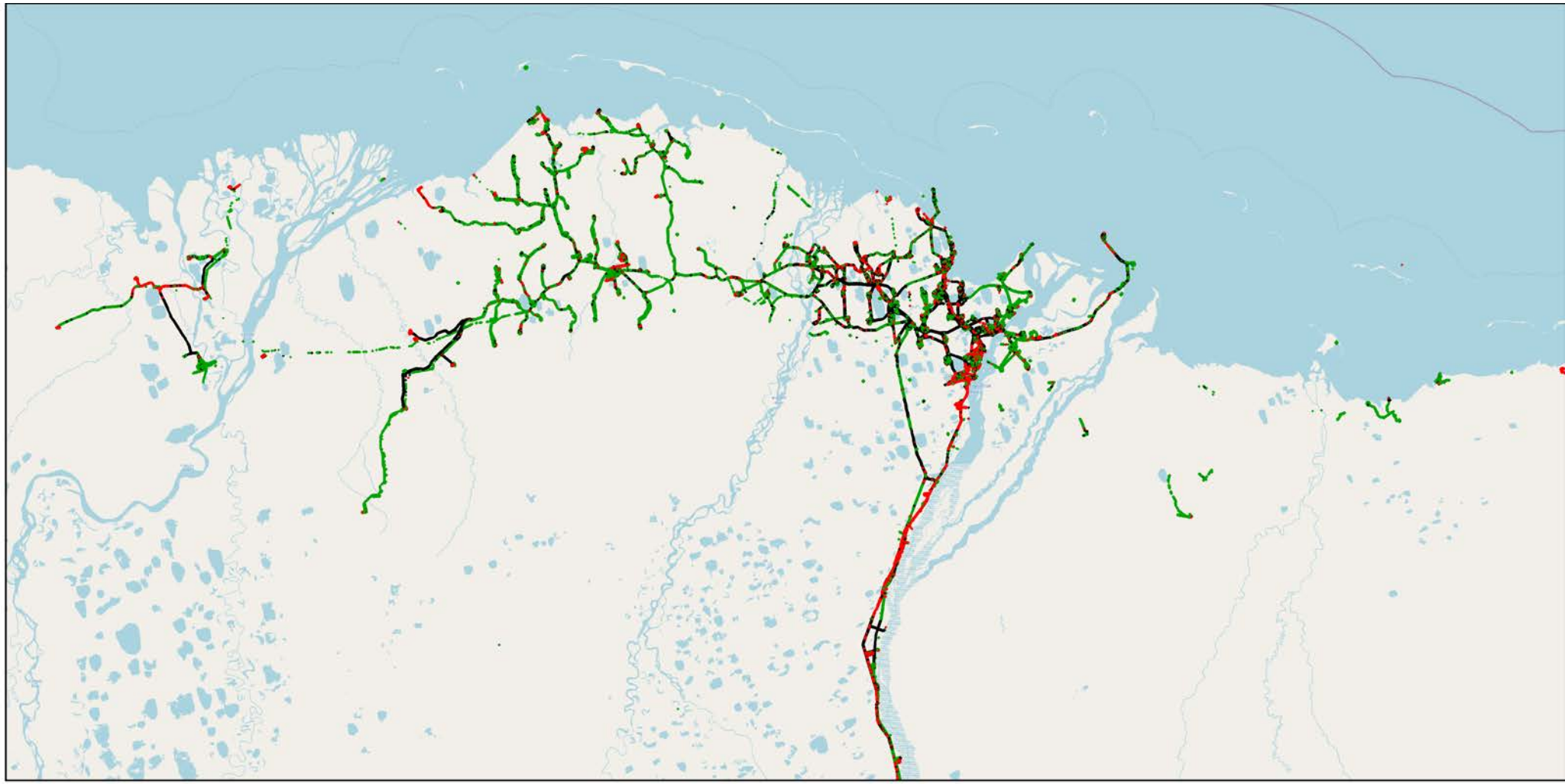


2000-2018

PBO

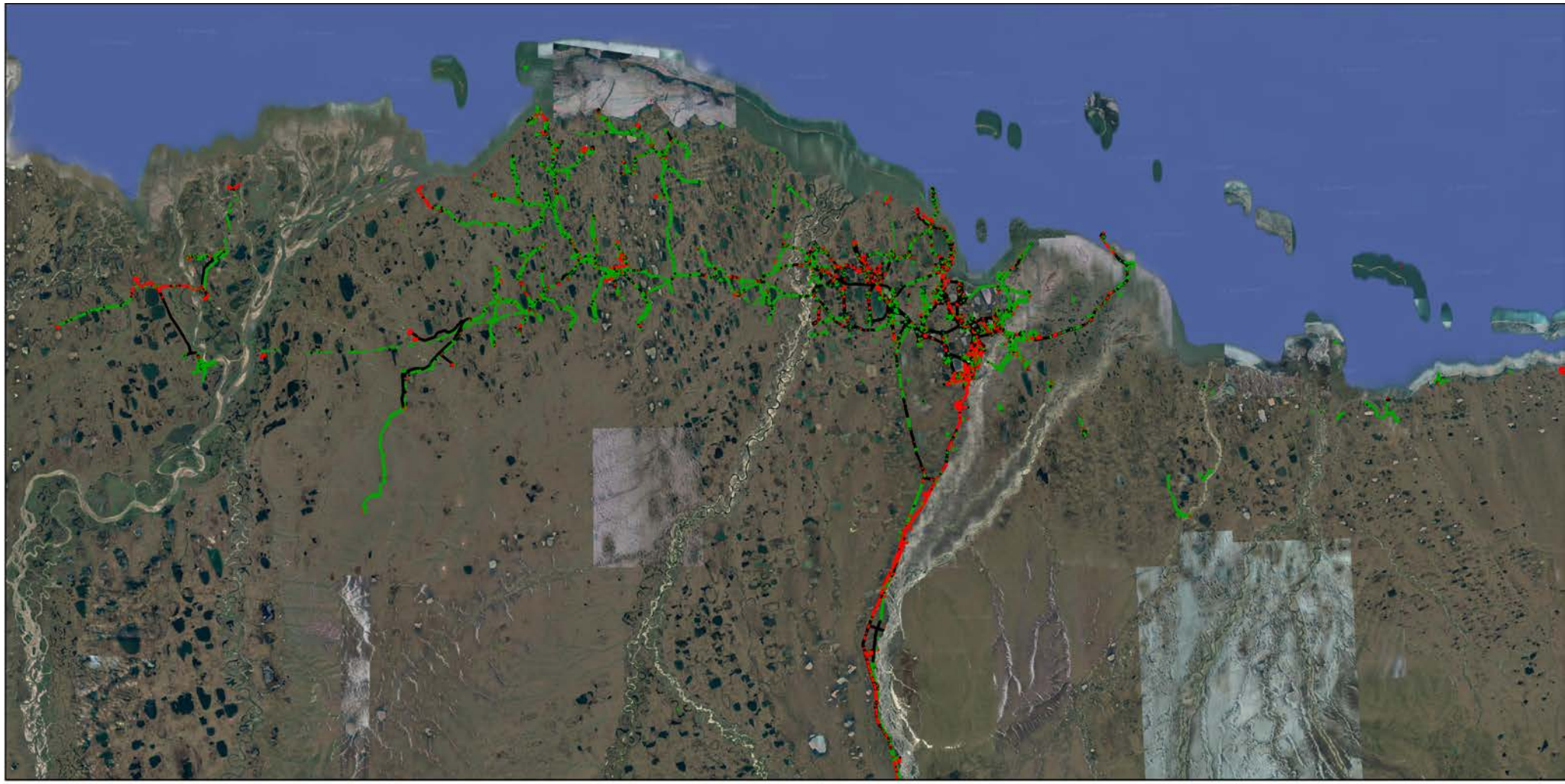


Background:
OpenStreetMap

0 10 20 km

2000-2018

PBO



Google Hybrid background map

0 10 20 km

2000-2018

Near
Pevek,
Russia

Red Dog
mine,
Alaska

Connecting places of interest for mining or oil/gas

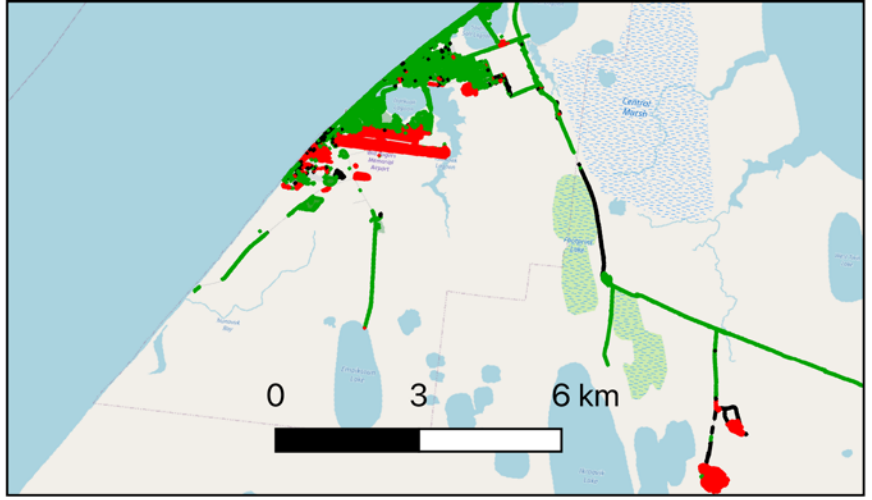
Expansion of mining areas

2000-2018

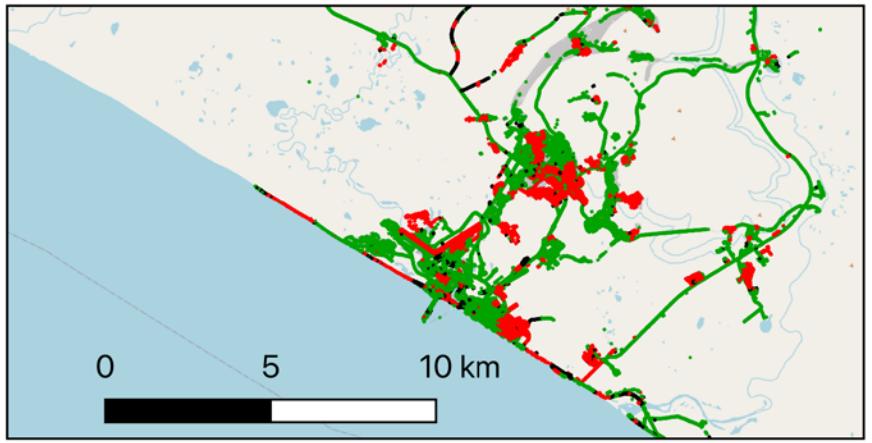
Connecting to the ‘outside’

New or extended airports

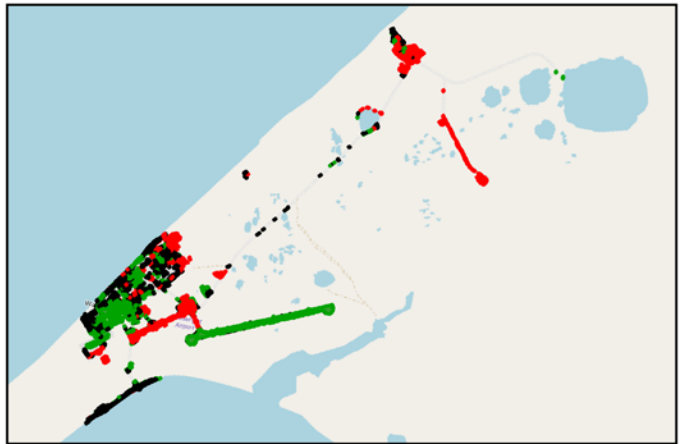
In some cases growth of settlements or other human impact in the proximity



Barrow, Alaska

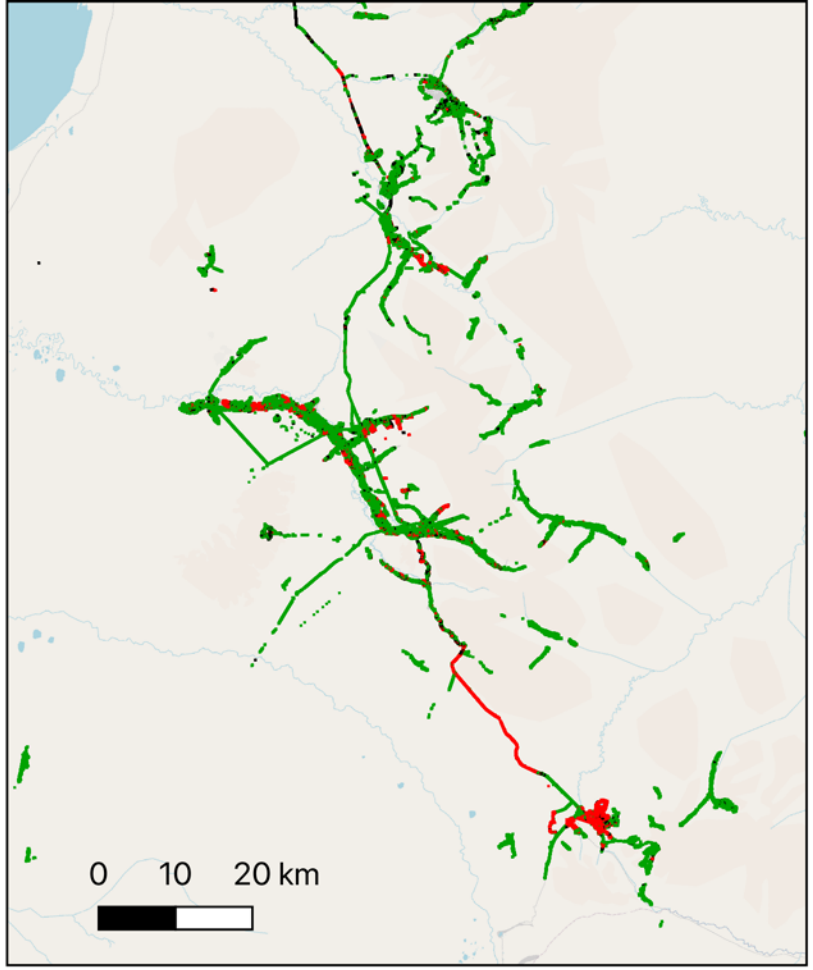


Nome, Alaska

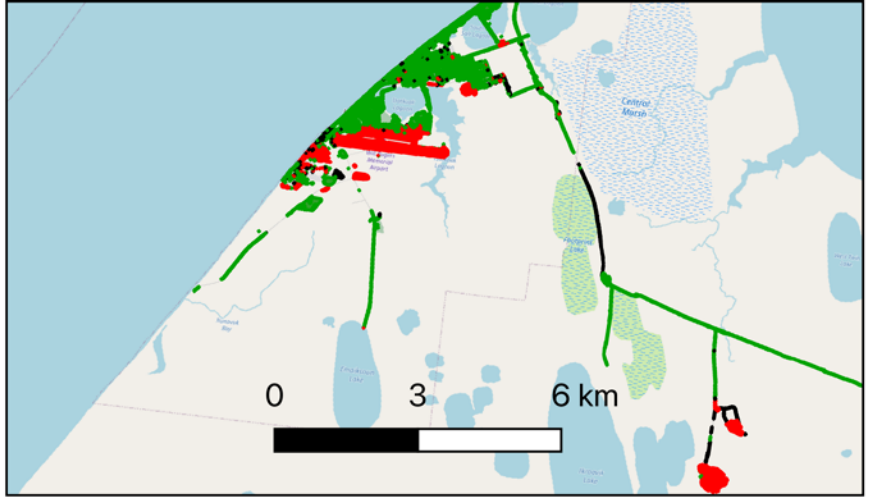


Wainwright, Alaska

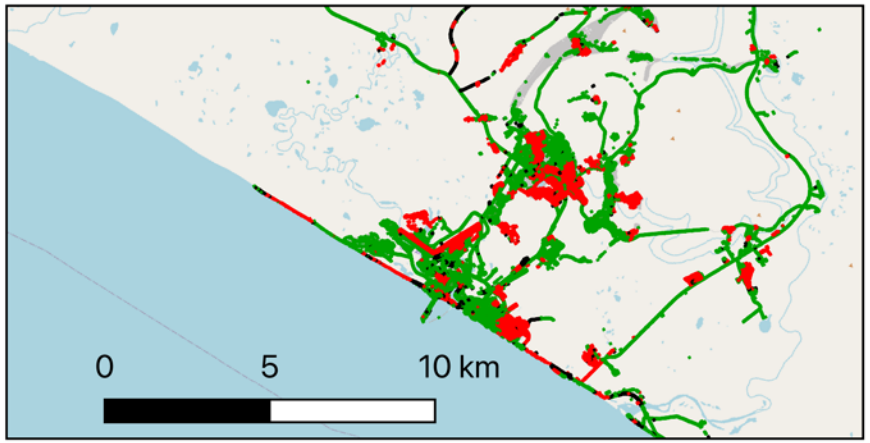
2000-2018



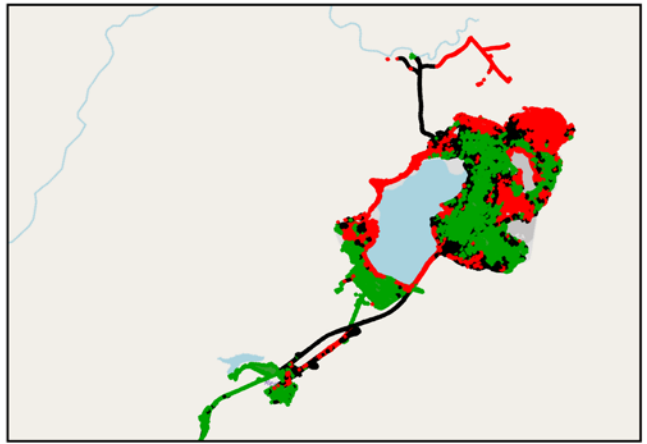
Near Pevek, Russia



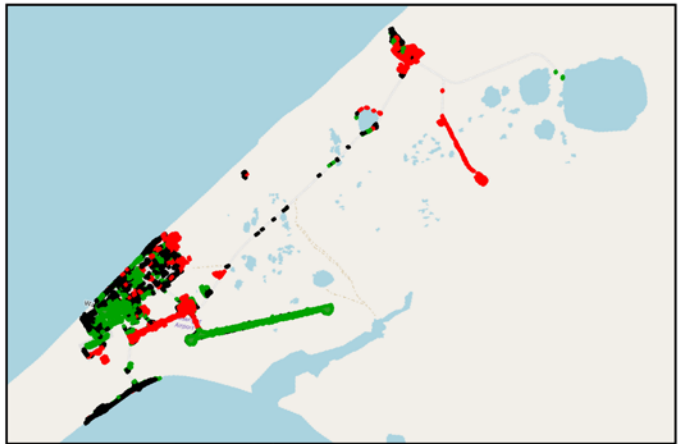
Barrow, Alaska



Nome, Alaska



Red Dog mine, Alaska



Wainwright, Alaska

Changing permafrost

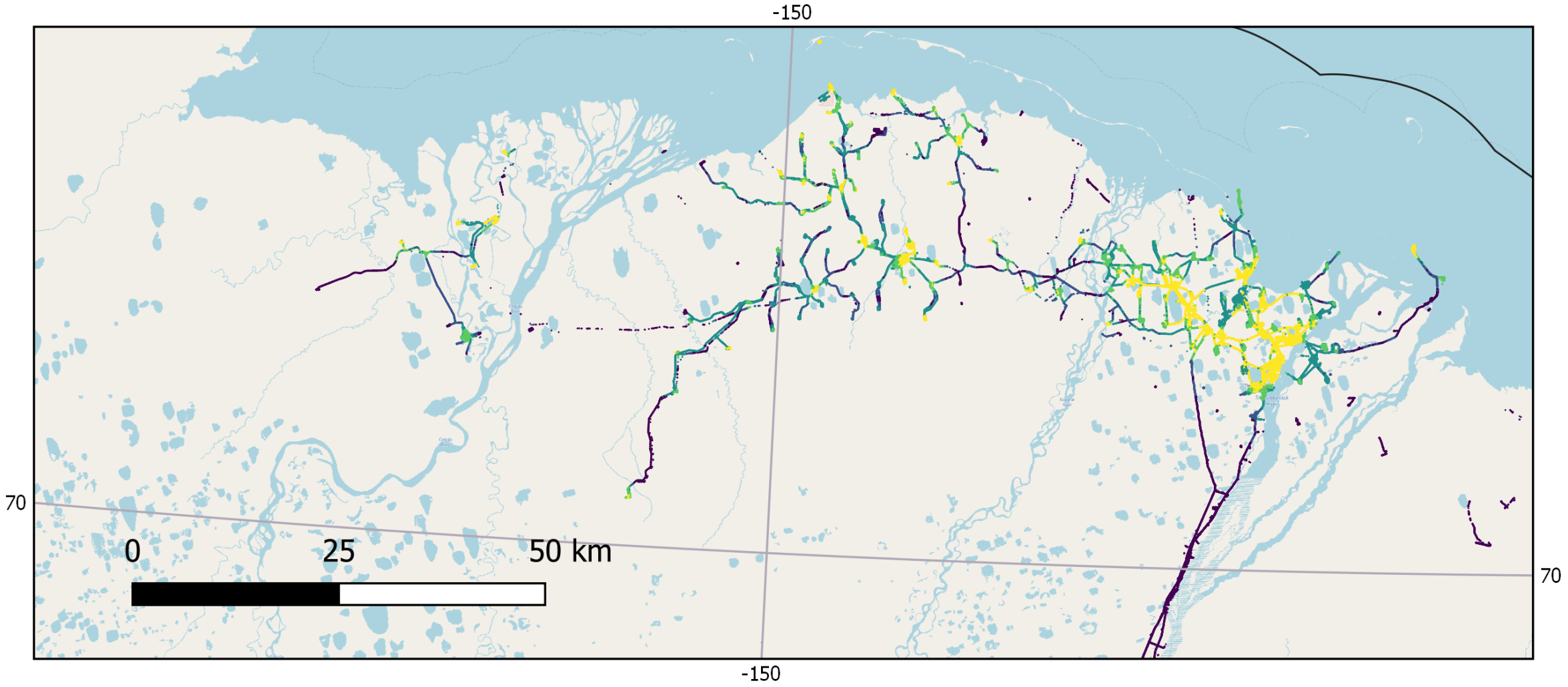
2 m depth

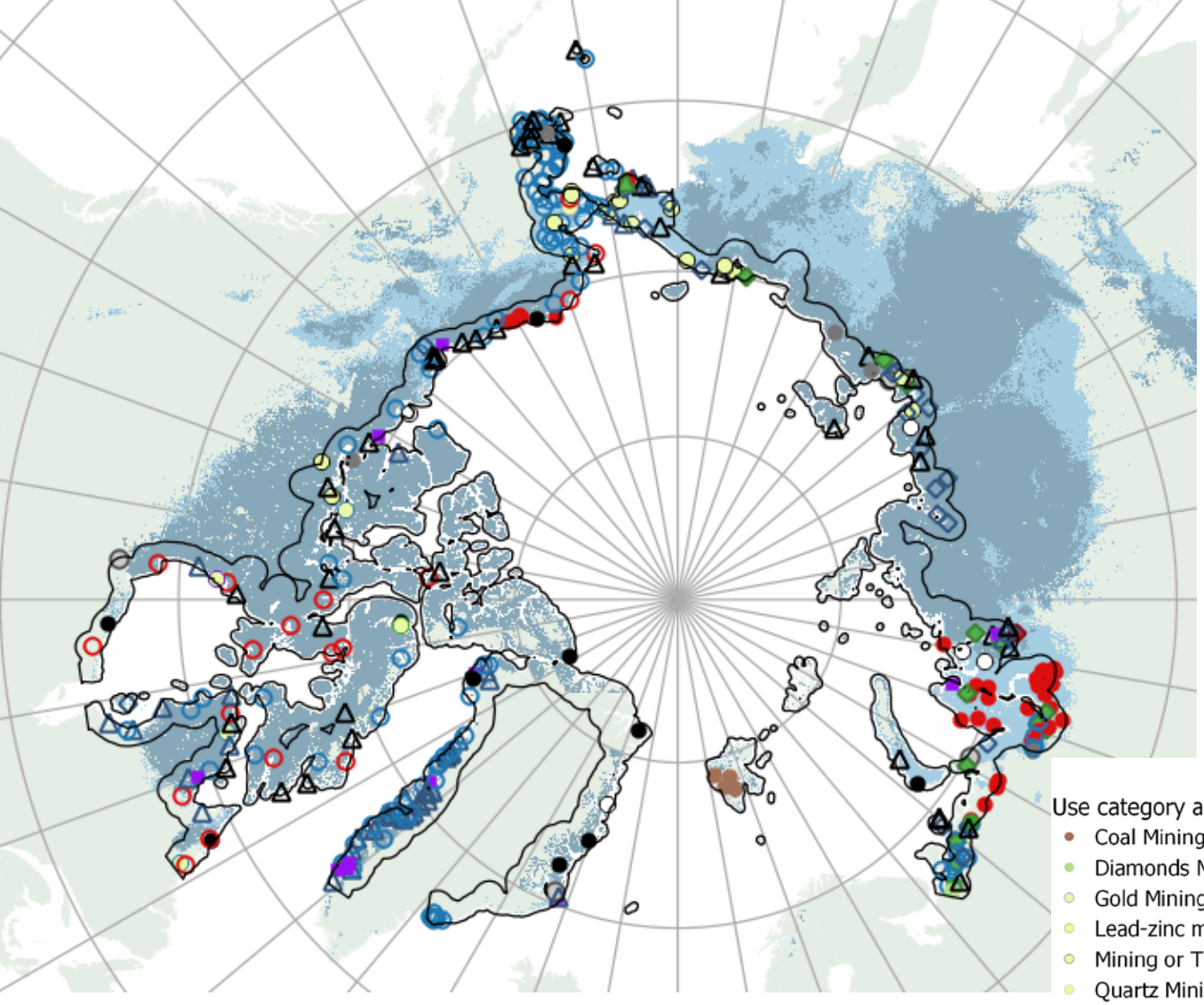
- Combination with e.g. ESA CCI+ Permafrost records
  - 2019 status
  - Trends 1997-2019

- Each point represents the average for a SACHI object

Bartsch, Pointner, Nitze, Efimova, Jakober, Ley, Högström, Grosse, Schweitzer (2021), ERL

Night-time lights 2016 (in $nWcm^{-2}sr^{-1}$; extracted from Elvidge et al. 2021), Alaskan North Slope, PBO





Ground temperature at 2 m depth below zero degree Celsius in

- 2019
- 2050 (extrapolated trend based on 1997-2019)

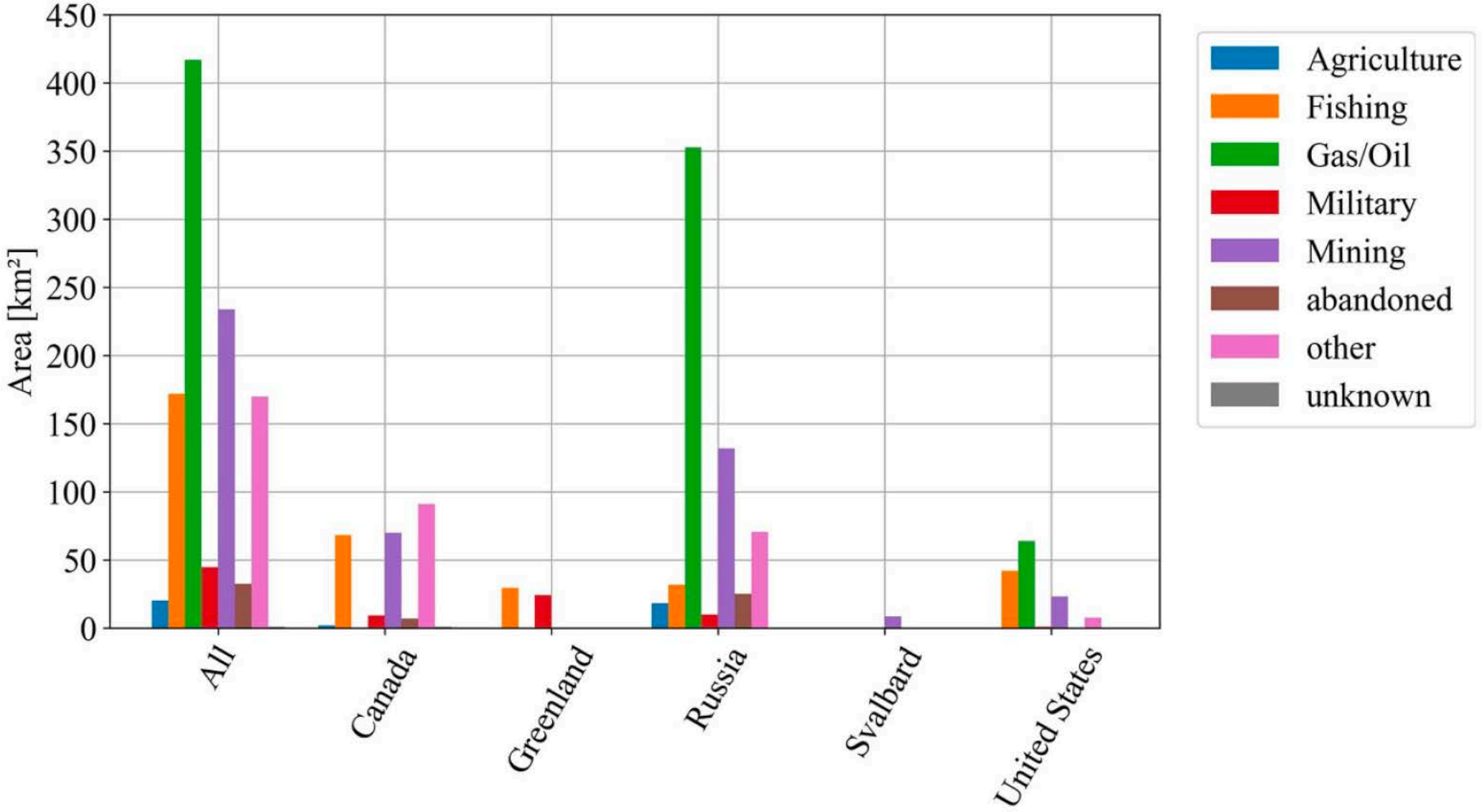
permafrost cci

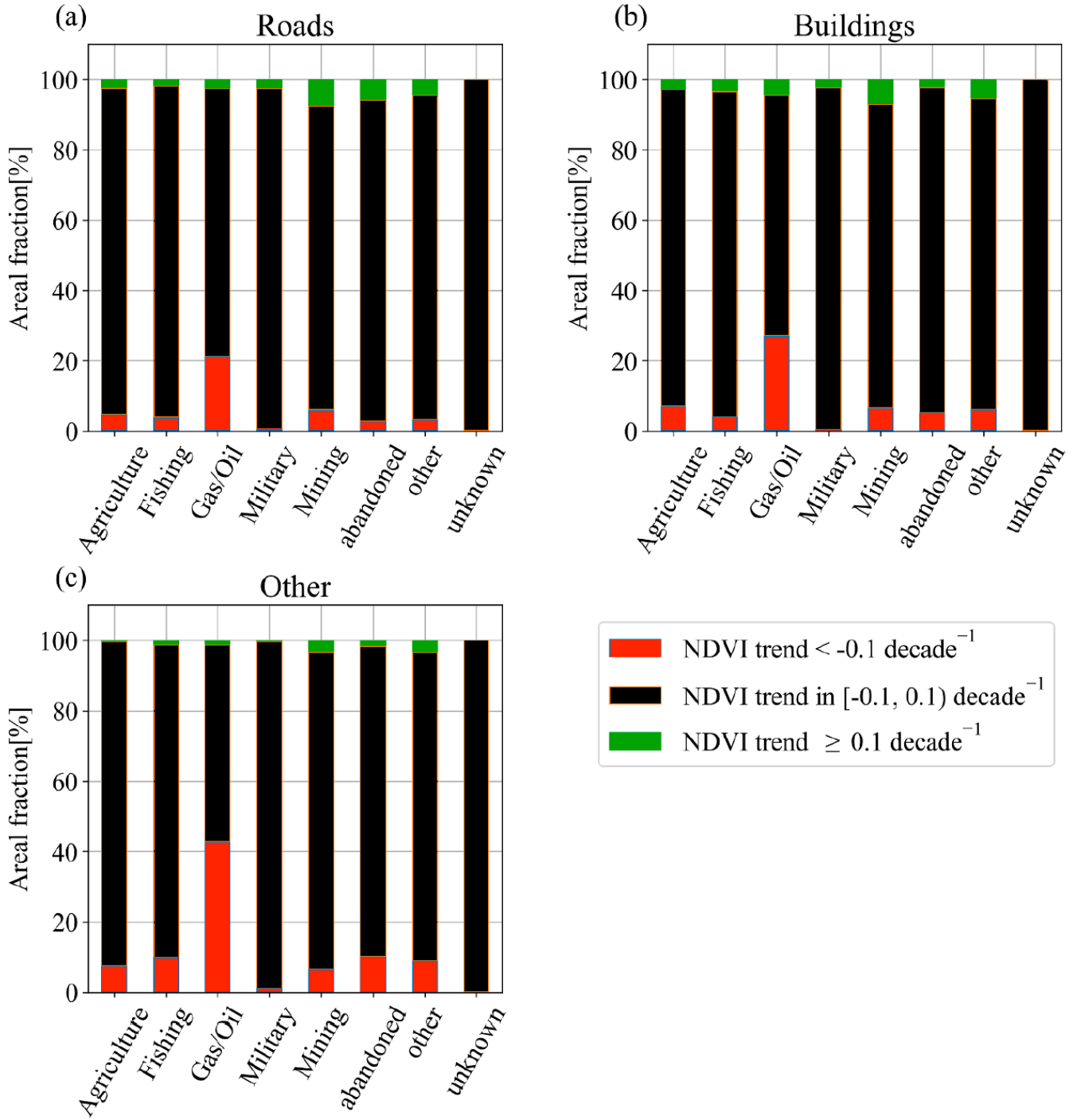
Use categories in discussion within RATIC/IASC T-Mosaic Infrastructure AG

Use category associated with identified settlements and their surroundings
- Coal Mining or Coal Mining & Tourism/ Research Station
- Diamonds Mining
- Gold Mining or Gold & Uranium Mining
- Lead-zinc mining
- Mining or Transport & Mining or Fishing & Mining
- Quartz Mining
- Nickel Mining
- Farming or Foresty
- Herding
- Hunting
- Fishing or Fishing with Farming, Tourism or Nature Reserve
- Fishing, Herding and/or Hunting
- Fishing, Hunting and/or Tourism
- Gas, Herding
- Gas, Oil and/or Tourism
- Military or Military & Tourism or Zink Mine
- Nature Reserve or Research/Weather Station
- Tourism
- Tourism, Transport
- Transport
- unknown
- Historical
- abandoned

Analyses extent
- coastal zone - 100 km

Bartsch, Pointner, Nitze, Efimova, Jakober, Ley, Högström, Grosse, Schweitzer (2021), ERL


Area [km²]
450
400
350
300
250
200
150
100
50
0
All
Canada
Greenland
Russia
Svalbard
United States
Agriculture
Fishing
Gas/Oil
Military
Mining
abandoned
other
unknown


(a)
Roads
(b)
Buildings
(c)
Other
Areal fraction[%]
0
20
40
60
80
100
Agriculture
Fishing
Gas/Oil
Military
Mining
abandoned
other
unknown
NDVI trend < -0.1 decade^{-1}
NDVI trend in [-0.1, 0.1) decade^{-1}
NDVI trend ≥ 0.1 decade^{-1}

Gaps

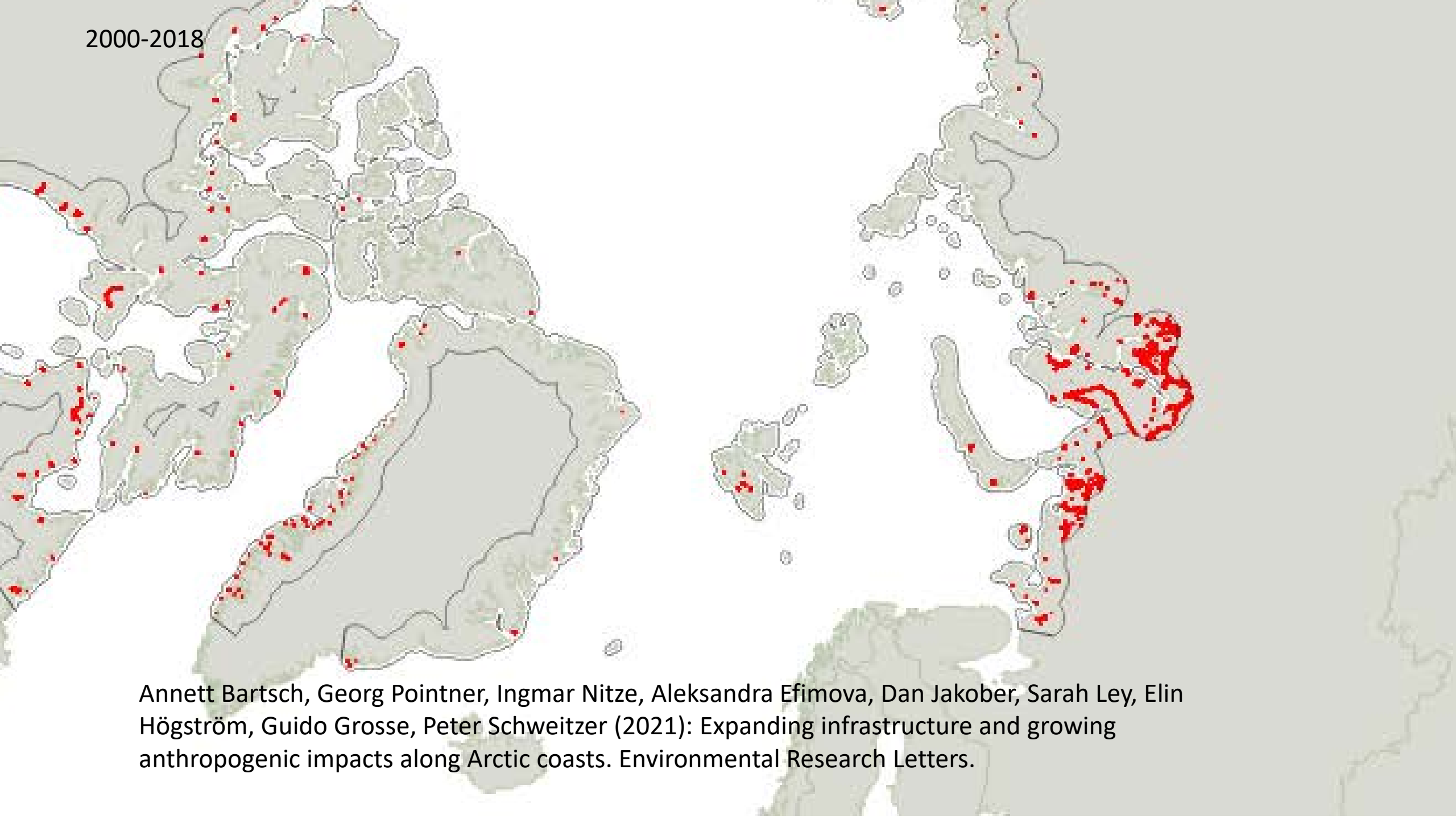
- Other forms of infrastructure existing – social science discussion needed
- Landscapes are altered through vehicle tracks, geophysical surveys
- We need to include also the surroundings to capture the full impact, as available in local studies such as Raynolds et al. (2016), Walker et al. (in press)
- …

Quantities

- *At least 15% correspond to new or increased detectable human impact since 2000*
- *55% of the identified human impacted area will be shifting to above 0°C ground temperature at two meter depth by 2050 if current permafrost warming trends continue at the pace of the last two decades*
- *SACHI contains 8% to 48% more information (human presence) than in OpenStreetMap. 221 (78%) more settlements are identified than in a recently published dataset for this region. 47% percent is not covered in a global night light dataset from 2016*

Conclusions

- *Sentinel-1/2 derived impacted areas provide more detail than any other currently available records for this region.*
- *Several examples for combination with other (coarser) satellite records demonstrate the utility*
- *First consistent account of human presence in the Arctic, but improvements required regarding e.g. classes, uncertainty characterization*



Annett Bartsch, Georg Pointner, Ingmar Nitze, Aleksandra Efimova, Dan Jakober, Sarah Ley, Elin Högström, Guido Grosse, Peter Schweitzer (2021): Expanding infrastructure and growing anthropogenic impacts along Arctic coasts. Environmental Research Letters.