Anthropogenic and natural land use and land cover changes in tundra environments detected from satellite image time series on Yamal Peninsula, Russia.

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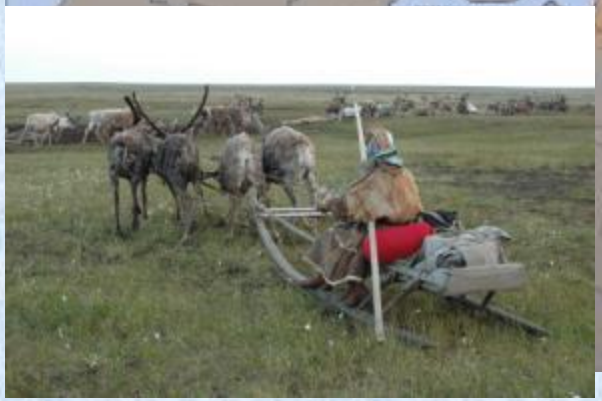
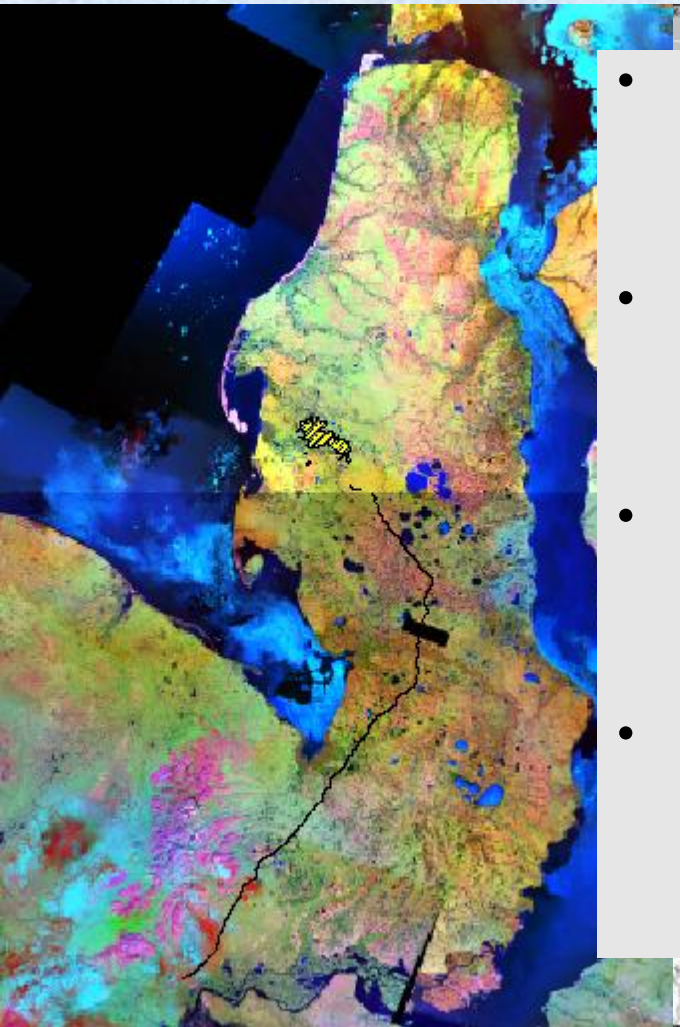
MAIN REINDEER HERDING AREAS IN SCANDINAVIA AND THE RUSSIAN NORTH



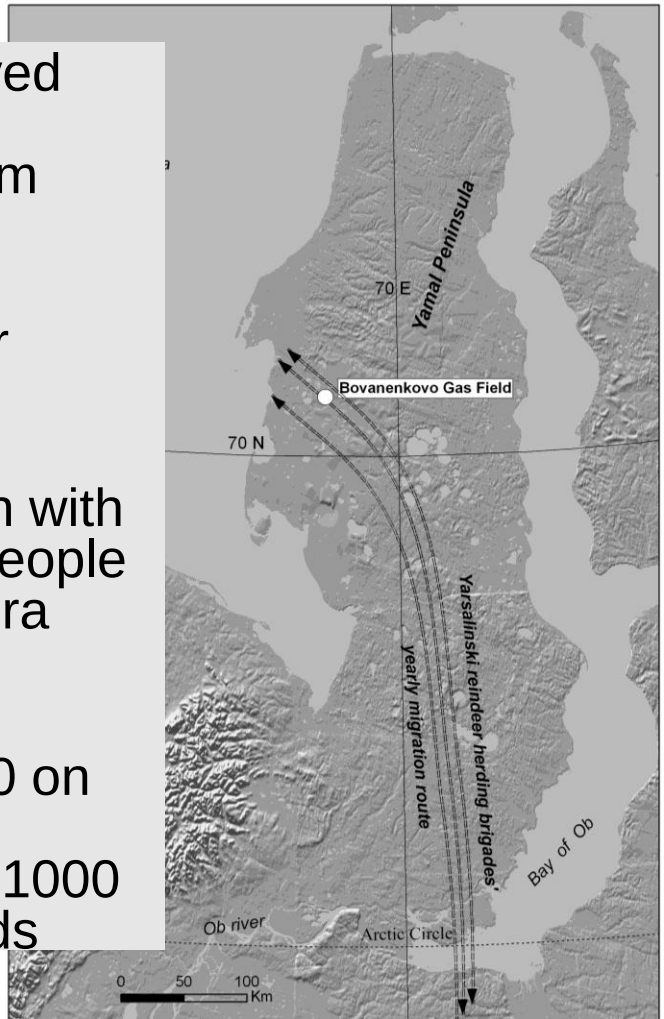
Svalbard
Franz Josef Land
Severnaya Zemlya
Bear Island
Barents Sea
Kara Sea
Novaya Zemlya
NORDLAND
TROMS
FINNMARK
NORR-BOTTEN
LAPLAND
VÄSTER-BOTTEN
OULU
Murmansk
MURMANSK OBLAST
TAYMYR AUTONOMOUS OKRUG
Dudinka
Norilsk
Bovanenkovo
Naryan-Mar
NENETS AUTONOMOUS OKRUG
Salekhard
YAMAL-NENETS AUTONOMOUS OKRUG
REPUBLIC OF KOMI
KHANTY-MANSIYSK AUTONOMOUS OKRUG
Syktyvkar
Khanty-Mansiysk
Reindeer herding areas

Research area location

- Bovanenkovo ”supergiant” gas field, In Central Yamal peninsula, Russia



- Reindeer herding survived best (from soviet arctic indigenous peoples) from Soviet period
- Traditional migration between summer-winter pastures (up to 1400 km/year)
- The only Russian region with significant increase of people and reindeer in the tundra since Soviet Union
- Now close to 600 000 animals, almost 300 000 on the Yamal Peninsula, managed by more than 1000 fully nomadic households



- Bovanenkovo gas field was found in 1971
-1987-1988 construction phase began
- Extensive offroad traffic untill mid 1990’s
- Road network build in mid 1990’s

- 1) What are the combined environmental and social impacts of gas activities on reindeer rangelands in Bovanenkovo region?
- 2) How can remote sensing be combined with other forms of ecological, social, geographical and local knowledge data?
- 3) Monitor the changes and build up remote sensing based chronology of industrial development in the Bovanenkovo gas field
- 4) Which natural land cover changes appears in the region

Remote sensing imagery

Satellite Sensor	Acquired	Resolution
LANDSAT MSS	28 July1984	70 m
LANDSAT TM	7 August 1988	30 m
SPOT	29 July 1993	19 m
SPOT	19 July 1998	20 m
ASTER VNIR	21 July 2001	15 m
Quickbird-2 Panchromatic	15 July 2004	0.63 m
Quickbird-2 Multispectral	15 July 2004	2.4 m
GeoEye	15 August 2009	1.65 m
LANDSAT + ETM/7	19 July 2010	30 m
LANDSAT TM	14 July 2011	30 m

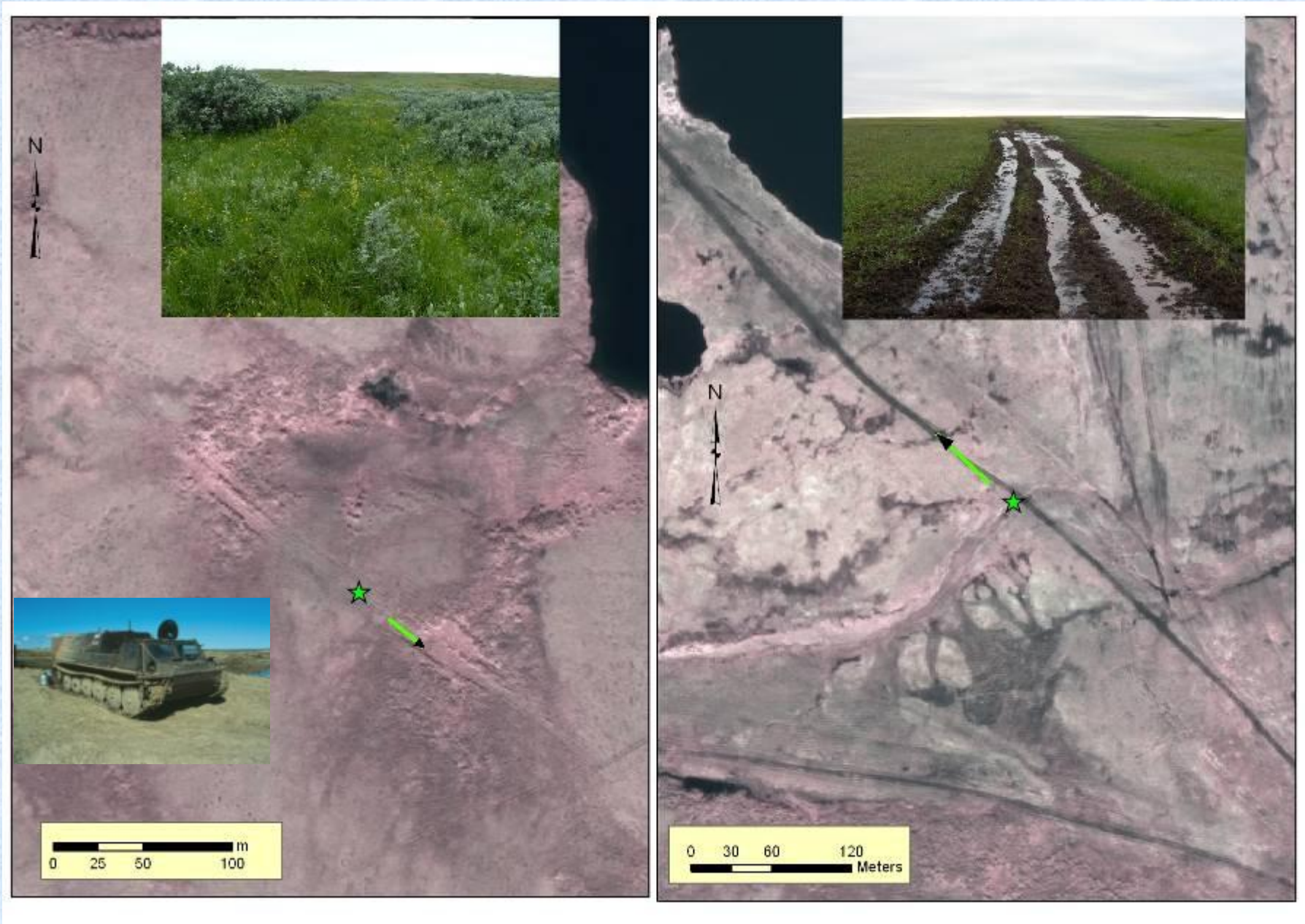
GIS database:

- Road network
- Offroad vehicle tracks
- Pipeline network
- Quarries
- Other infrastructure

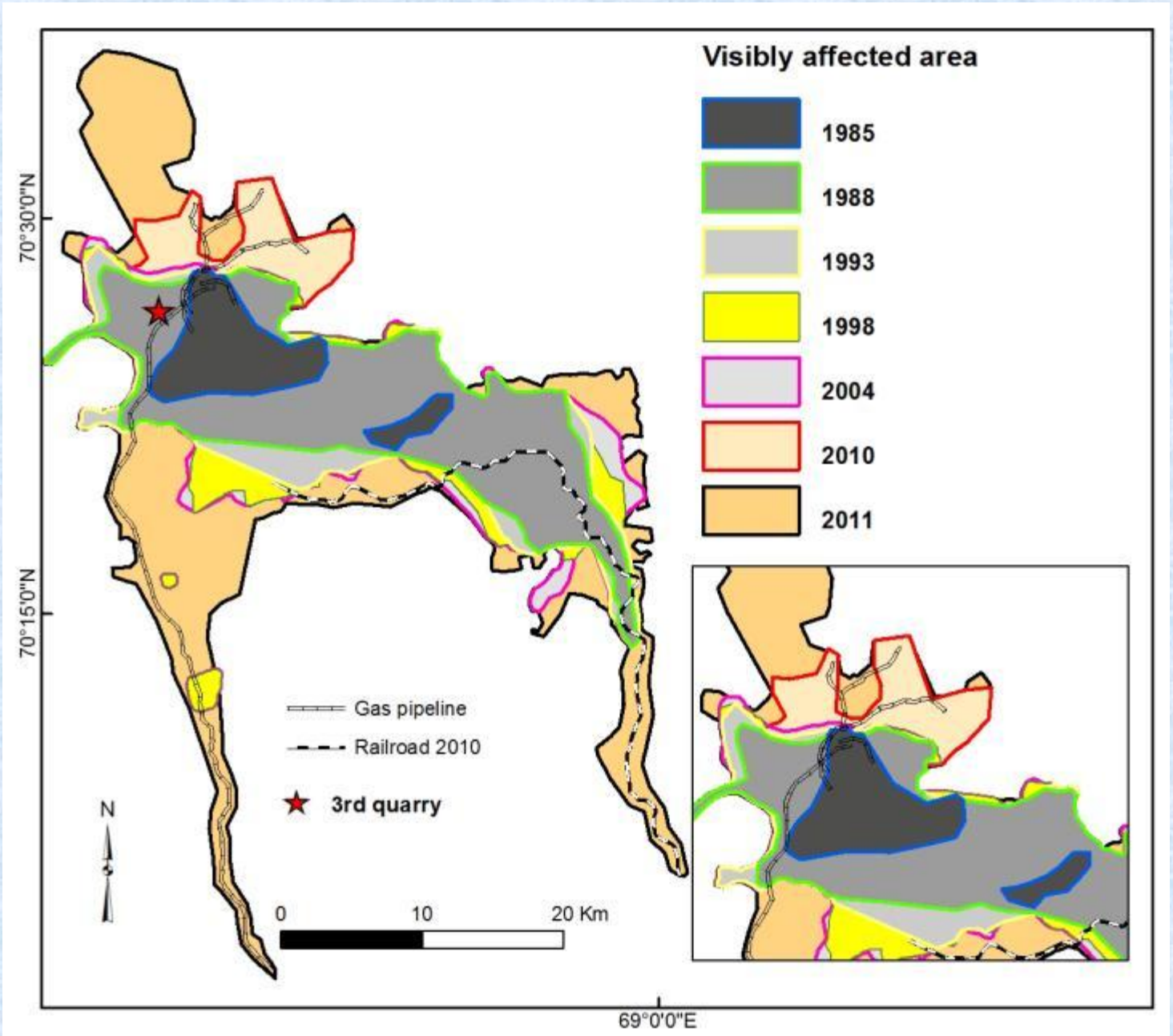
Table 2. Capacity to detect different impacts of hydrocarbon exploration in Bovanenkovo. *Data on soil contamination are from Varandei oil field in

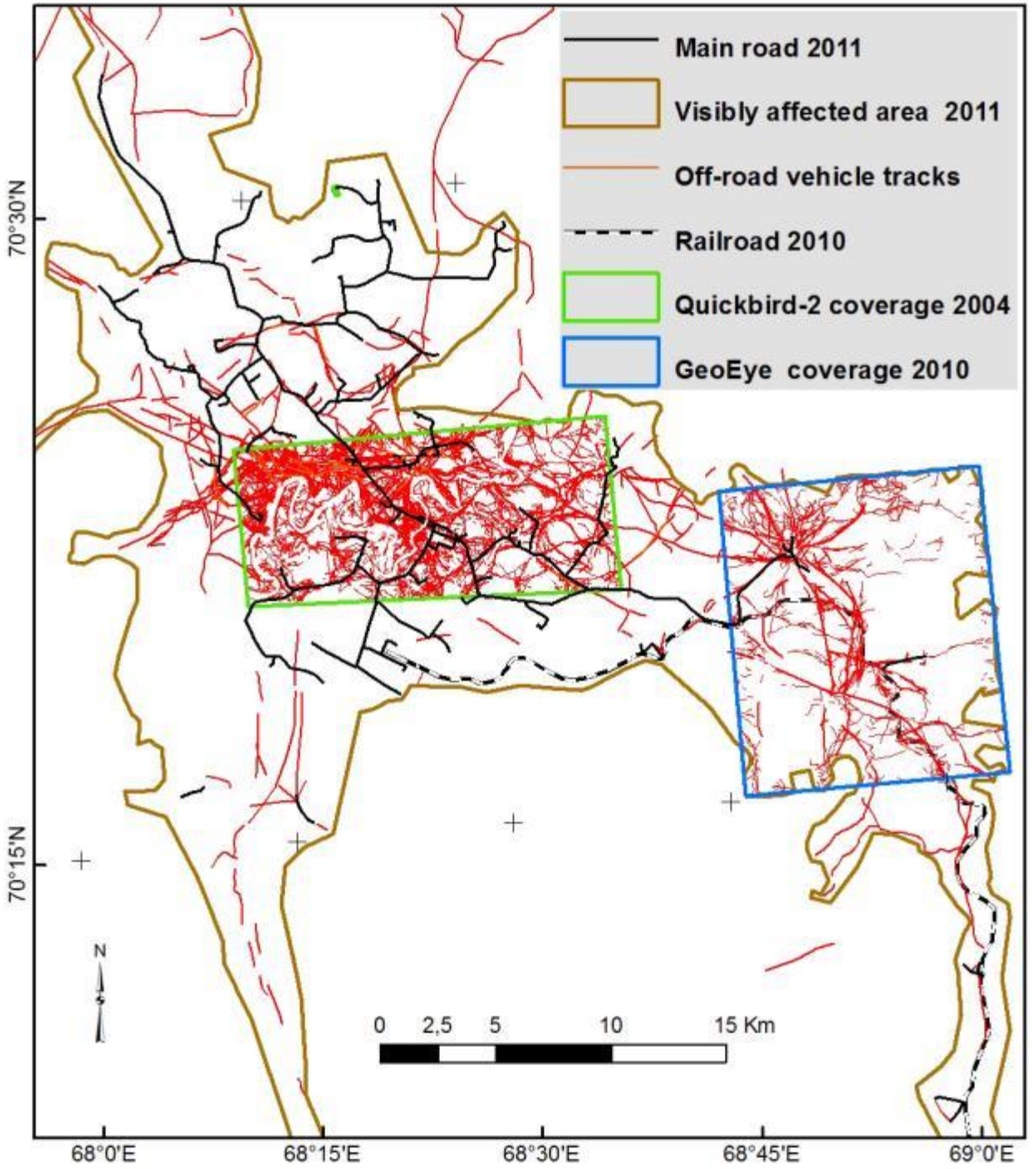
Impact	Socio-cultural survey	Ground truthing	Quickbird-2 Panchromatic	Quickbird-2 Multispectral	ASTER TERRA VNIR	Spot Panch.	Spot Multispec.	Landsat ETM7	Landsat TM
Small scale < 0,09 ha									
Soil contamination*	xx	xx	–	–	–	–	–	–	–
Removal of top soil and vegetation	xxx	xxx	xxx	xx	x	x	x	–	–
Industrial waste:									
- metal	xx	xx	x	–	–	–	–	–	–
- glass	xx	x	–	–	–	–	–	–	–
- concrete	xxx	xxx	xx	x	–	–	–	–	–
- wood	xxx	xxx	x	–	–	–	–	–	–
Single off-road vehicle track	xx	xx	xxx	xx	x	x	x	–	–
Vegetation changes:									
- shrubs to graminoids	x	xx	x	xx	x	–	–	–	–
- peatland to graminoids	x	xxx	x	xx	x	–	–	–	–
- revegetated barren ground	x	xxx	x	xx	x	–	–	–	–
Pipelines	xxx	xxx	xxx	xx	x	–	–	–	–
Powerlines	xxx	xxx	xx	x	–	–	–	–	–
Drilling towers	xxx	xxx	xxx	xx	x	x	–	–	–
Trucks/Vehicles	xxx	xxx	xx	x	–	–	–	–	–
Medium scale > 0.1 ha - < 1 ha									
Roads	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xx	xx
Multiple off-road tracks	xx	xx	xxx	xx	xx	xx	xx	x	x
Concrete paved yards and roads	xxx	xxx	xxx	xx	xx	xx	xx	x	x
Vegetation changes:									
- shrubs to graminoids	xx	xx	x	xx	x	–	x	x	x
- peatland to graminoids	xx	xxx	x	xx	x	–	x	x	x
- revegetated barren ground	xx	xxx	x	xx	x	–	x	x	x
Barren ground on industrial sites	xxx	xxx	xxx	xxx	xx	xx	xx	x	x
Revegetated areas	x	xx	x	xx	x	x	x	x	x
Barracks & built up areas	xxx	xxx	xxx	xx	xx	xx	xx	x	x
Winter roads	xxx	xx	xxx	xxx	xx	xx	x	x	x
Large scale > 1 ha									
Removal of top soil and vegetation	xxx	xxx	xxx	xxx	xx	xx	xx	xx	xx
Vegetation changes:									
- shrubs to graminoids	xxx	xxx	x	xxx	xx	xx	xx	xx	xx
- peatland to graminoids	xxx	xxx	x	xx	xx	xx	xx	xx	xx
- revegetated barren ground	xxx	xxx	x	xxx	xx	xx	xx	xx	xx
Production and worker settlements	xxx	xxx	xxx	xxx	xx	xx	xx	x	x
Quarries	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xx	xx
Impoundment water bodies	xxx	xx	xxx	xxx	xxx	xxx	xxx	xx	xx

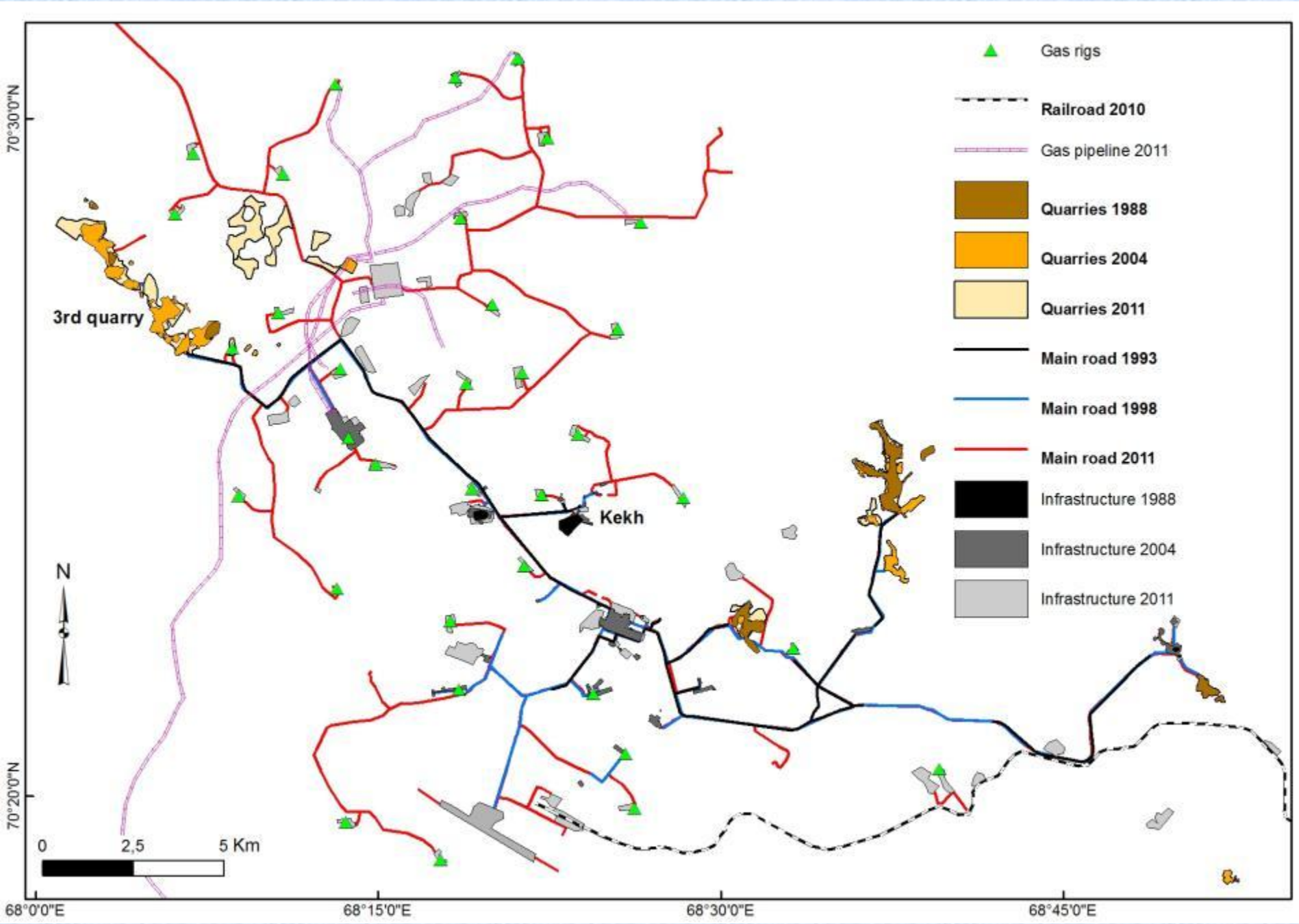
Kumpula, et. al. (2010). (*Arctic*) **Kumpula et al. (2012) (*Remote sensing)***

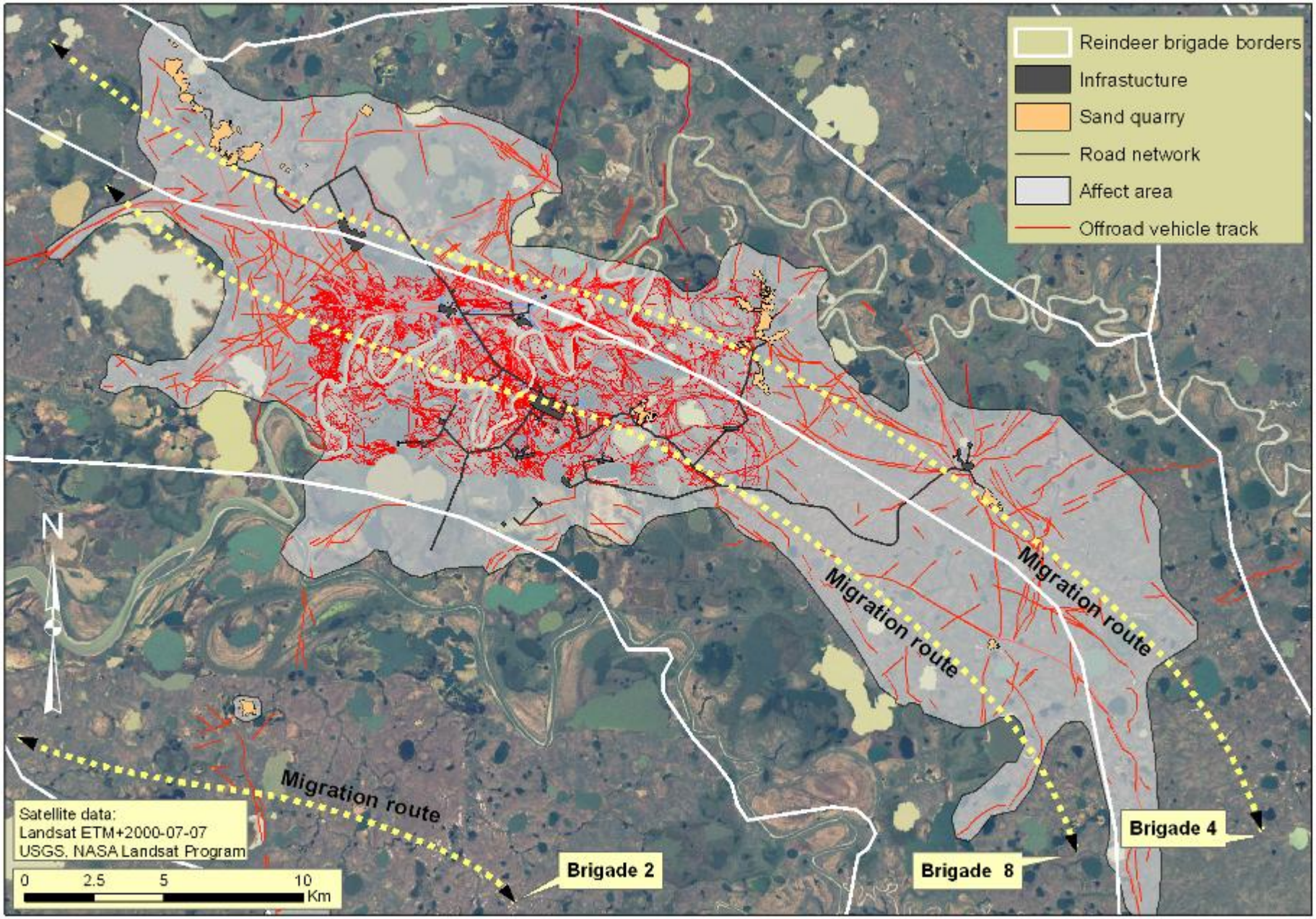


Pajunen, A. (2010). Willow-characterised shrub vegetation in tundra and its relation to abiotic, biotic and anthropogenic factors. *Acta Universitaes Ouluensis* A 546


Visibly affected area
1985
1988
1993
1998
2004
2010
2011
70°30'0"N
70°15'0"N
69°0'0"E
Gas pipeline
Railroad 2010
3rd quarry
N
0
10
20 Km


Main road 2011
Visibly affected area 2011
Off-road vehicle tracks
Railroad 2010
Quickbird-2 coverage 2004
GeoEye coverage 2010
70°30'N
70°15'N
68°0'E
68°15'E
68°30'E
68°45'E
69°0'E
N
0 2,5 5 10 15 Km


Gas rigs
Railroad 2010
Gas pipeline 2011
Quarries 1988
Quarries 2004
Quarries 2011
Main road 1993
Main road 1998
Main road 2011
Infrastructure 1988
Infrastructure 2004
Infrastructure 2011
3rd quarry
Kekh
N
0
2,5
5 Km
70°30'0"N
70°20'0"N
68°0'0"E
68°15'0"E
68°30'0"E
68°45'0"E



Forbes, Stammler, Kumpula, Meschtyb, Pajunen & Kaarlejärvi (2009).

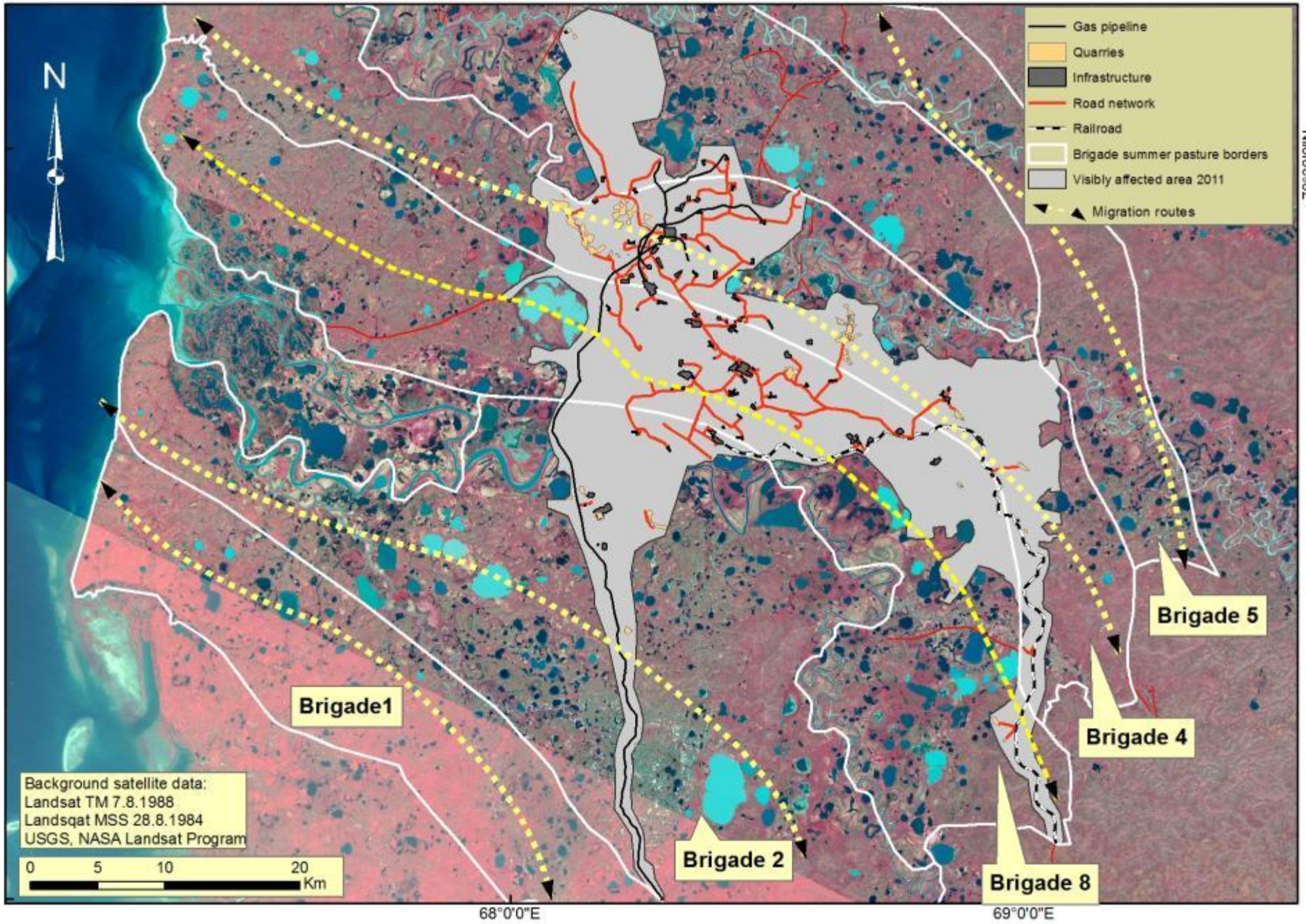

N
Gas pipeline
Quarries
Infrastructure
Road network
Railroad
Brigade summer pasture borders
Visibly affected area 2011
Migration routes
Brigade1
Brigade 2
Brigade 4
Brigade 5
Brigade 8
Background satellite data:
Landsat TM 7.8.1988
Landsqat MSS 28.8.1984
USGS, NASA Landsat Program
0 5 10 20
Km
68°0'0"E
69°0'0"E

Table 3. Estimations of the spatial extent of industrial impacts. Satellite images used are Landsat MSS/TM/ETM, SPOT, ASTER VNIR, Quickbird-2 and GeoEye.

Satellite/year	MSS	TM	SPOT	SPOT	ASTER	Quicbird-2	GeoEye/ETM	TM
Form of activity	**1984**	**1988**	**1993**	**1998**	**2001**	**2004**	**2010**	**2011**
Buildings & yards km^2		0.4	0.6	1.9	1.9	2.1	5.4	9.8
Main roads length km		2	49	80	81	81	154	212
Road area coverage km^2		0.6	1.8	2.9	3	3	5.8	8.0
Sand quarries km^2		1.8	3.5	3.5	3.5	4.3	6.6	9
Pipeline right of way km						16	16	103
Pipeline corridor km^2						0.6	0.6	4.4
Railroad km								59
Railroad area coverage km^2								3.6
Off-road track length km	38	348	380	410	590	2,400	2,989	3,136
Off-road track area coverage km^2	3	14	16	17	24	44	49	54
Disturbed vegetation 1988–2011 km^2		1.9						0.3
Airport km^2								1
Visibly affected area km^2	70	320	375	420	440	451	509	836
Permanently changed area km^2		2.8	5.9	8.4	8.3	8.9	18.4	36.1

Kumpula et al. (2012) ***Remote sensing***

Impacts of Bovanenkovo gas field to brigades 2, 4 and 8 of Yarsalinski sovhoz:

Brigade 4:

- Summer pasture July-August 1019 km^2
- 300 km^2 in Bovanenko gas field affected area

Brigade 8:

- Summer pasture July-August 796 km^2
- 295 km^2 in Bovanenko gas affected area

	Brigade 4	Brigade 8	Brigade 2
area affected 2004 km^2	225	200	29
area affected 2010 km^2	228	240	29
area affected 2011 km^2	300	295	147
Area of summer pasture km^2	1019	796	1208