Application of space-based technologies and models to address land-cover/land-use change problems on the Yamal Peninsula, Russia

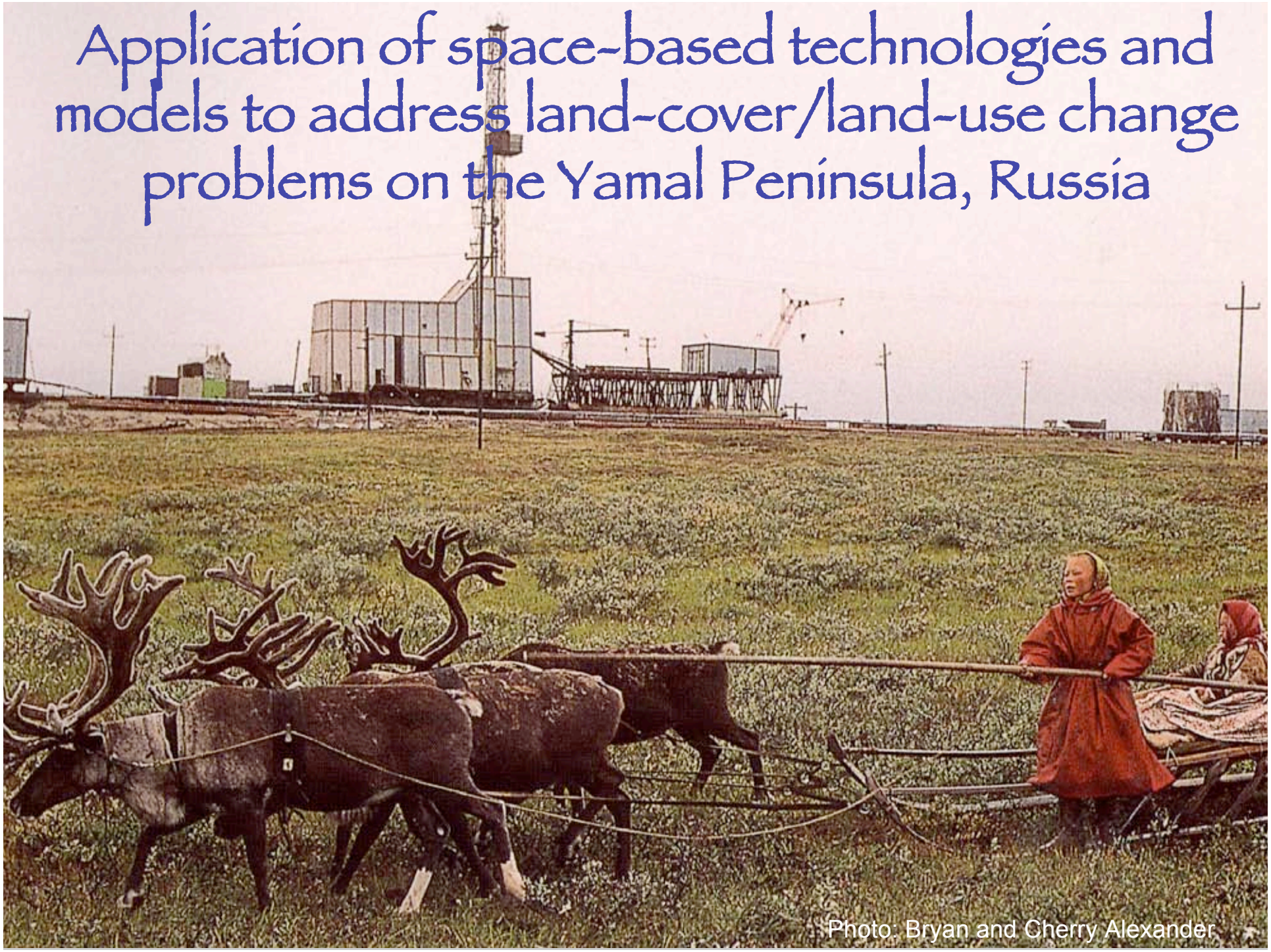

Photo: Bryan and Cherry Alexander

Greening of the Arctic
An IPY Initiative

Authors

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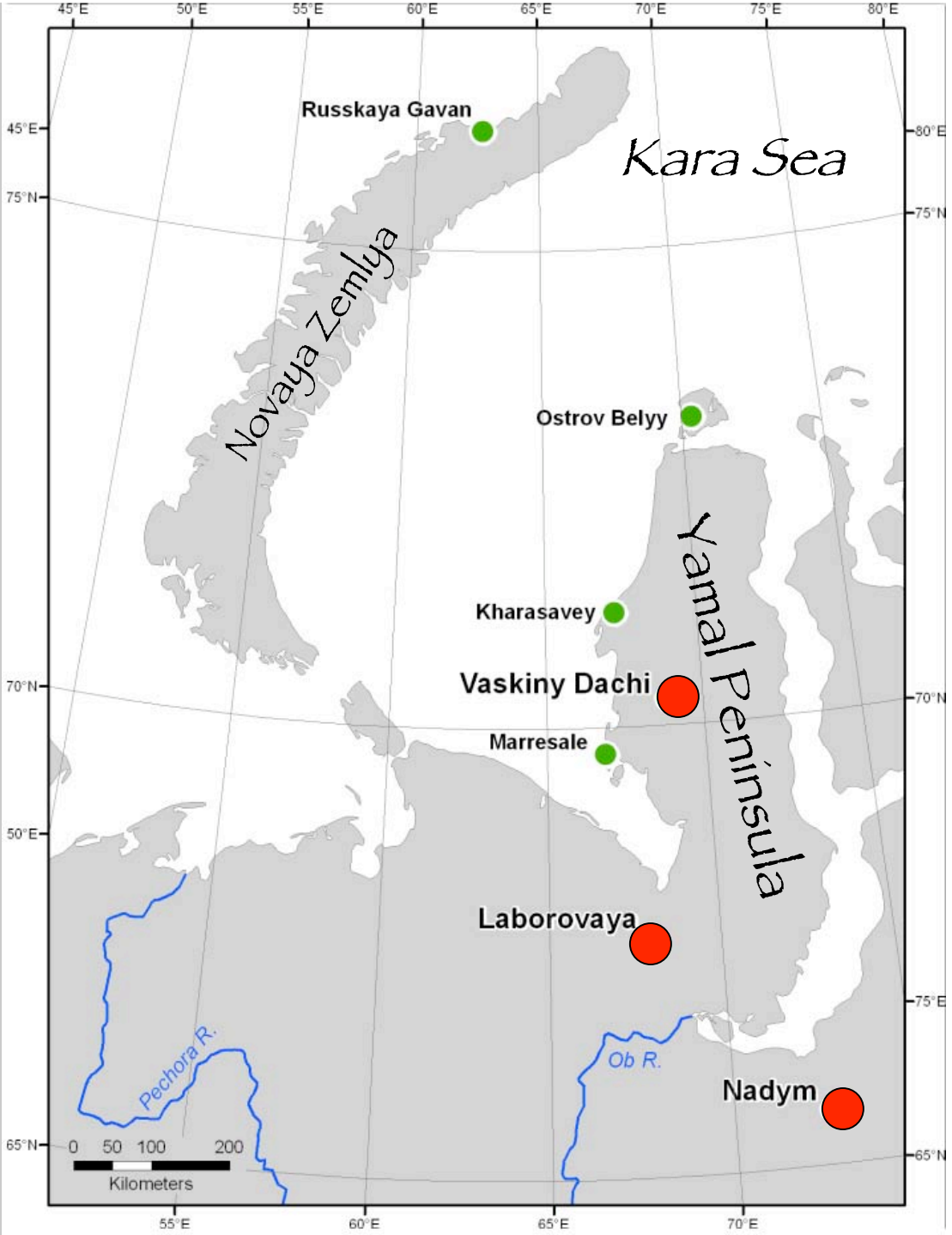
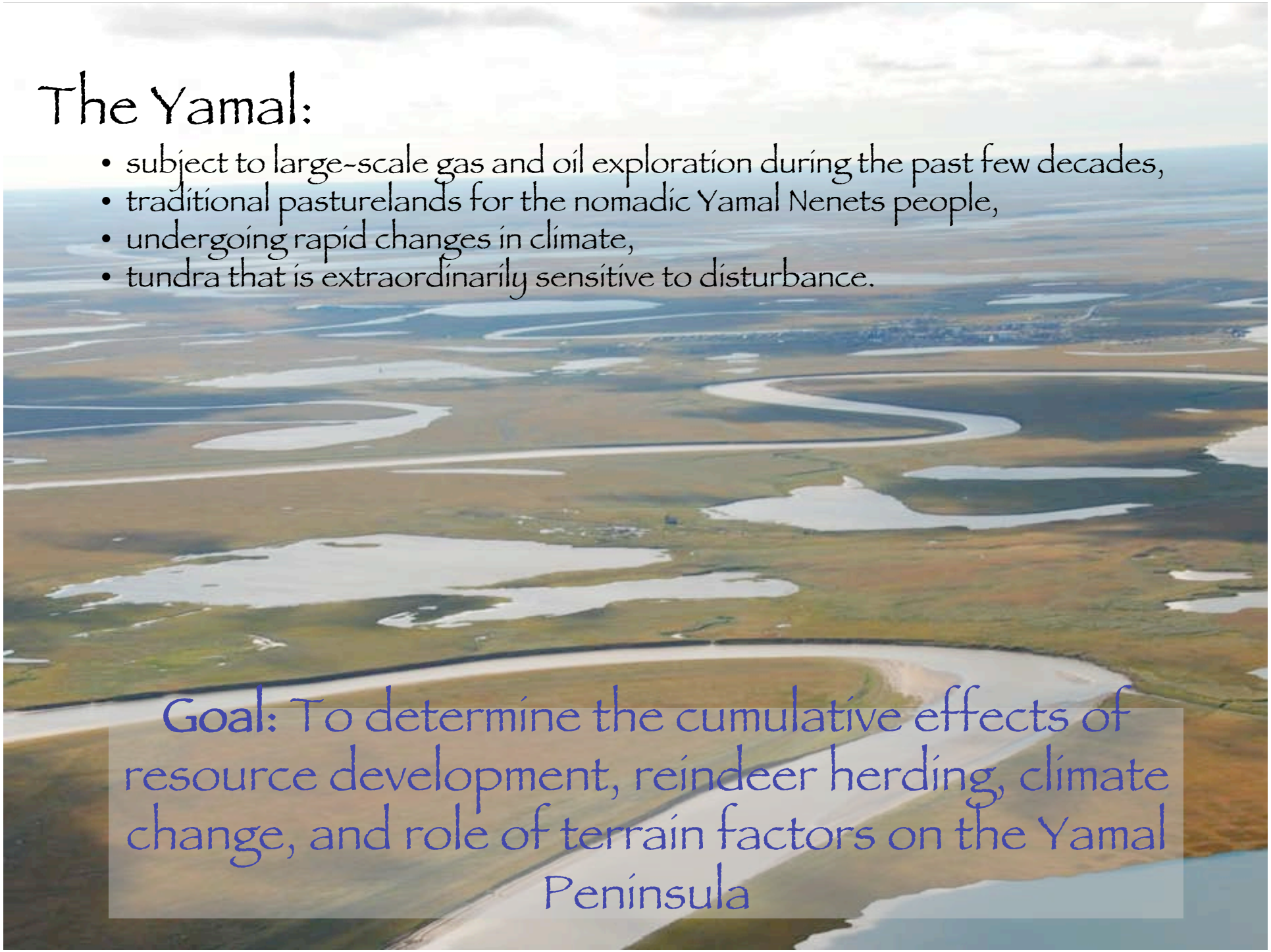
The project is part of the Greening of the Arctic project of the International Polar Year and the Northern Eurasia Earth Science Partnership Initiative (NEESPI).

Eurasian Arctic Transect Locations

- 2007 Yamal Expedition
  - Nadym
  - Laborovaya
  - Vaskiny Dachi
- Planned 2008-2009



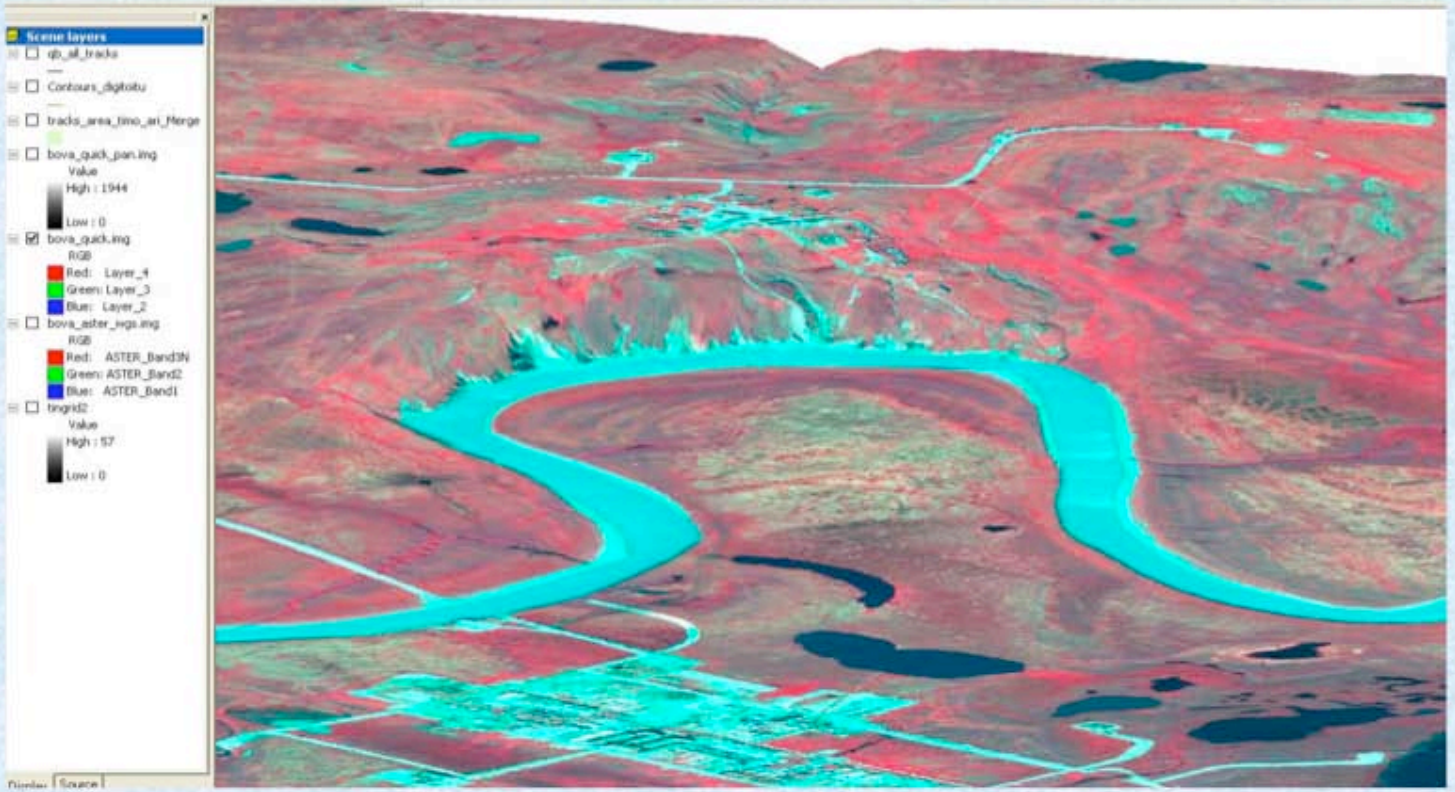


The Yamal:

- subject to large-scale gas and oil exploration during the past few decades,
- traditional pasturelands for the nomadic Yamal Nenets people,
- undergoing rapid changes in climate,
- tundra that is extraordinarily sensitive to disturbance.

Goal: To determine the cumulative effects of resource development, reindeer herding, climate change, and role of terrain factors on the Yamal Peninsula

Remote sensing of land-use /land-cover change in the Bovanenkovo gas field on the Yamal peninsula, Russia



Workshop:

Yamal Land-Cover Land-Use Change Workshop

Moskova, 28-30 January 2008

Timo Kumpula

Department Of Geography

University of Joensuu

Detectability of impacts with different sensors

- Quickbird best available sensor for most gas field impacts.
- Better than ground surveys for detecting off-road vehicle trails.

Detectivity / Impact	Field survey	Quickbird-2 Panchromatic	Quickbird-2 Multispectral	ASTER TERRA VNIR	Landsat TM	Landsat MSS
Soil contamination, oil & chemicals	x	–	–	–	–	–
Removal of top soil and vegetation	xxx	xxx	xxx	xx	x	x
Quarries	xxx	xxx	xxx	xxx	xx	x
Garbage						
- metal	xx	–	–	–	–	–
- glass	x	–	–	–	–	–
- concrete	xxx	x	x	–	–	–
- wood	xxx	x	–	–	–	–
Pipelines	xxx	xx	x	–	–	–
Powerlines	xxx	xx	x	–	–	–
Roads	xxx	xxx	xxx	xxx	x	x
Offroad tracks	xx	xxx	xx	xx	x	x
Winter roads	xx	xx	xx	xx	x	–
Drill towers	xxx	xxx	xx	x	–	–
Barracks	xxx	xxx	xx	x	–	–
Trucks/Vehicles	xxx	xx	x	–	–	–
Changes in hydrology	xxx	xxx	xx	xx	x	x

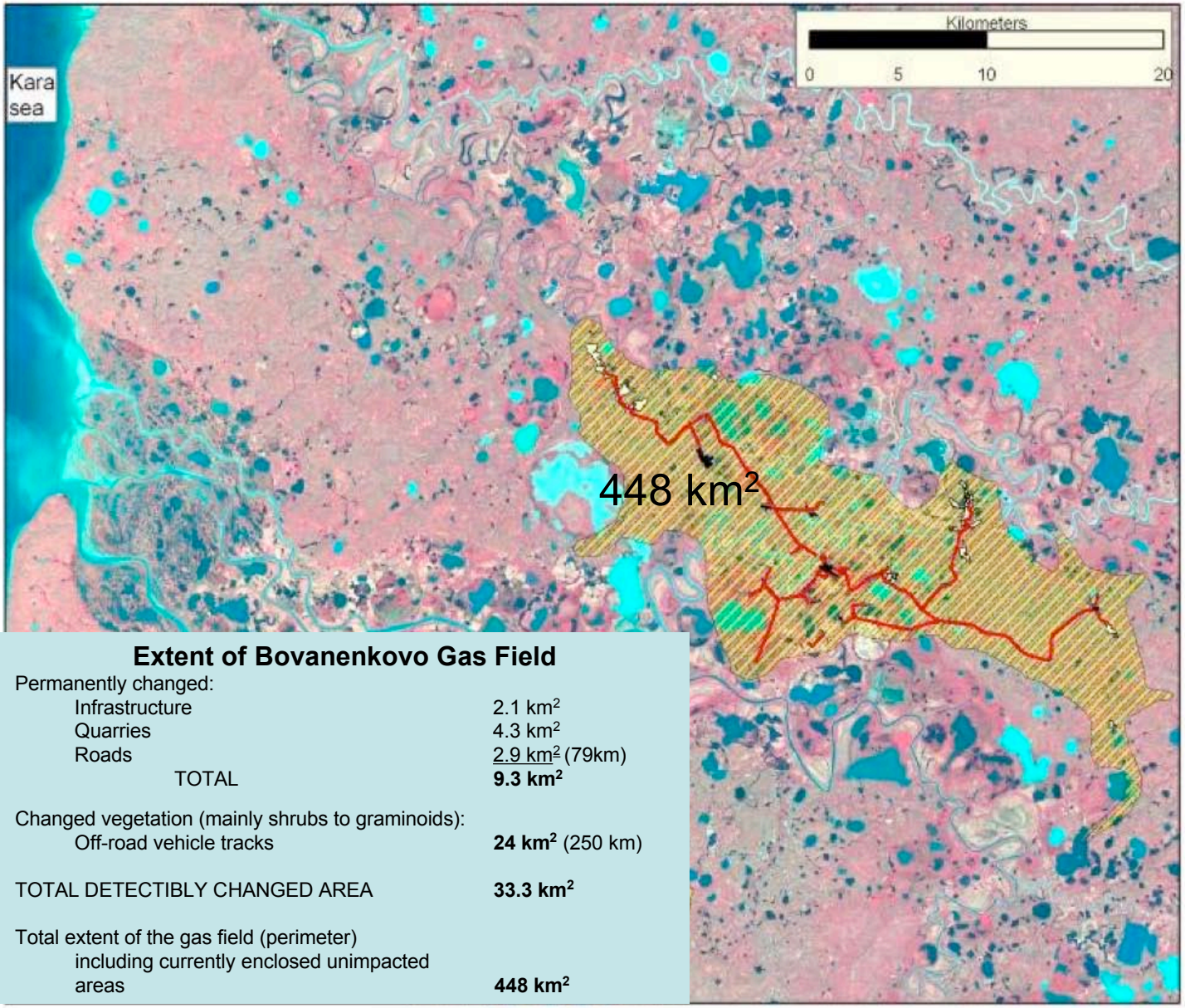
T. Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

GIS and remote sensing approach to catalog impacts

Bovanenko gas field

Petroleum exploration related activity

- Main road network
- Zone of effected area
- Sand quarries
- Active infrastructure



GIS database collection

- **Visual interpretation of impacts**
- **Develop digital elevation model from 1:100,000 maps**
- **Digitize boundaries**
  - **Roads**
  - **Pipeline network**
  - **Off-road vehicle trails**
  - **Infrastructure**
  - **Quarries**

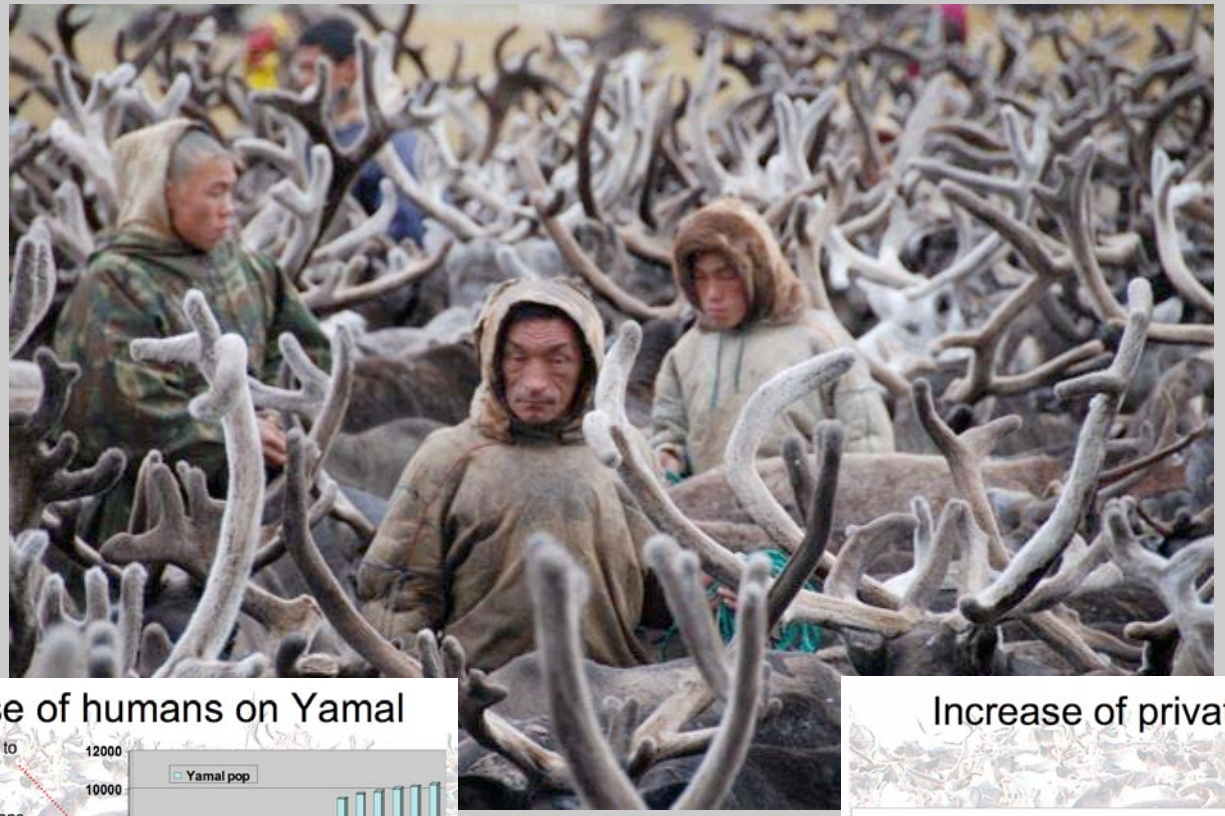
Digitized from:
Quickbird-2 image 15.7.2004 (2.4 m resolution)
Aster Terra VNIR image 21.7.2001 (15 m resolution)

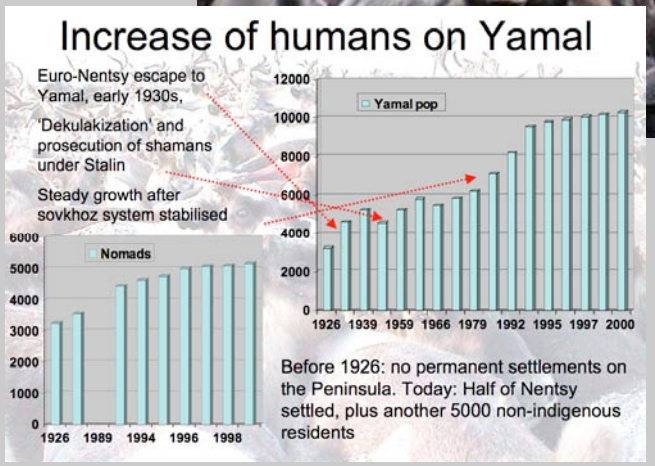
Background image:
Landsat TM 07.08.1988

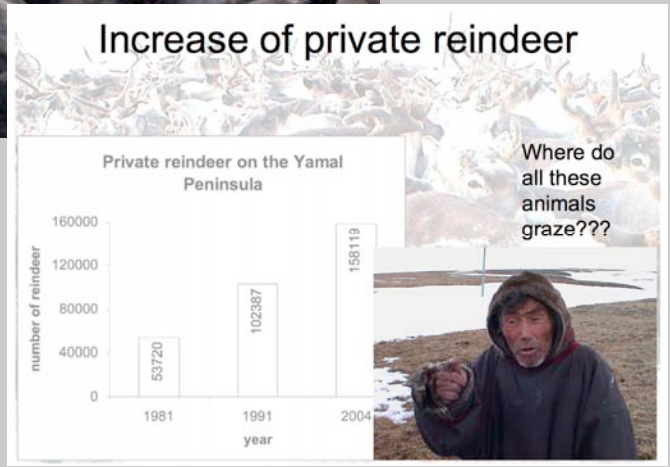
Extent of Bovanenkovo Gas Field

Permanently changed:	
Infrastructure	2.1 km²
Quarries	4.3 km²
Roads	2.9 km² (79km)
TOTAL	**9.3 km²**
Changed vegetation (mainly shrubs to graminoids):	
Off-road vehicle tracks	**24 km²** (250 km)
TOTAL DETECTIBLY CHANGED AREA	**33.3 km²**
Total extent of the gas field (perimeter) including currently enclosed unimpacted areas	**448 km²**

Nenets people and their reindeer







Florian Stammler: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Effects of reindeer herding

- Overgrazing
- Grassification
- Wind erosion

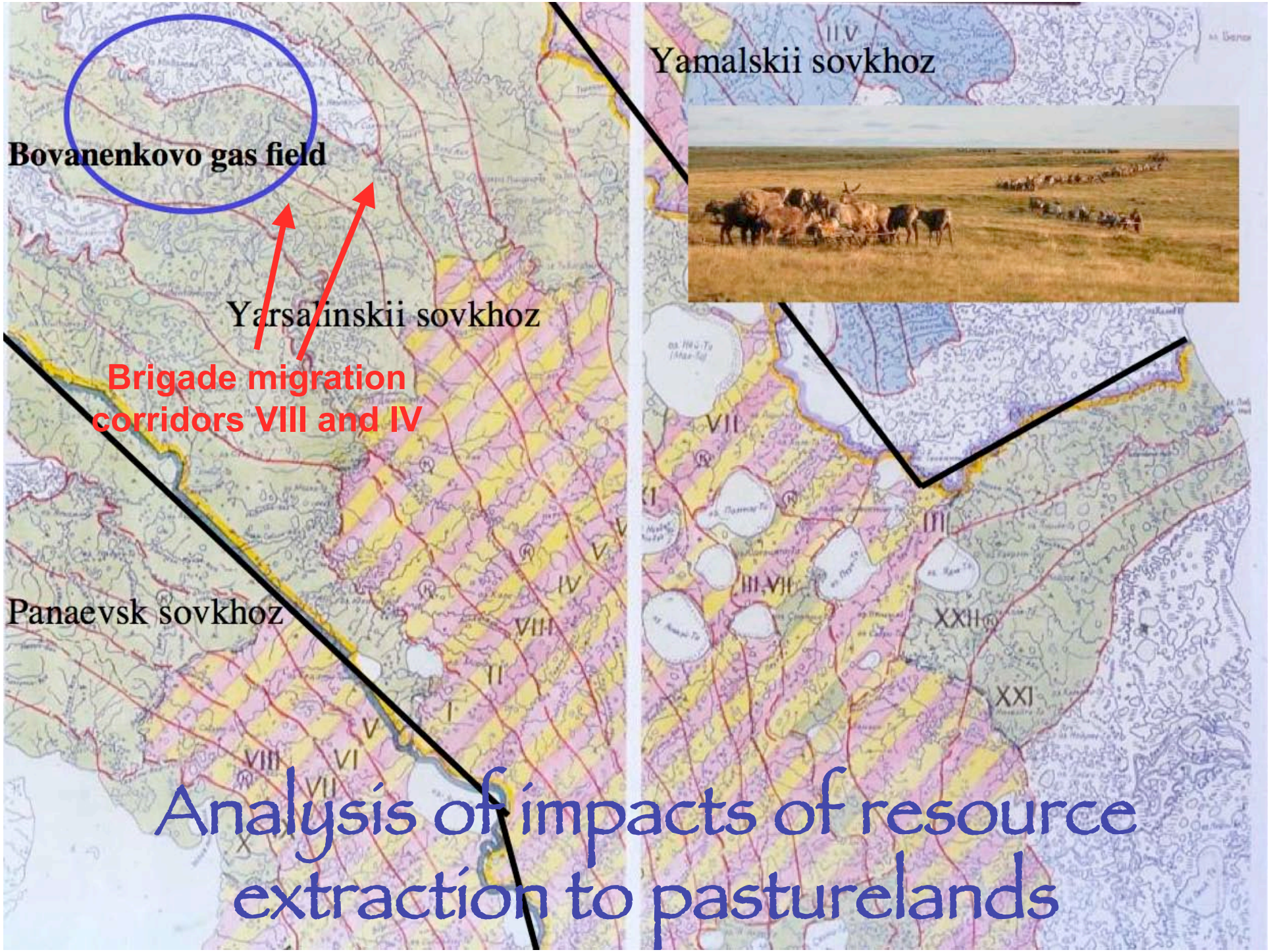
Photos: Bruce Forbes.

Quantification of wind deflated areas with satellite imagery: T. Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008

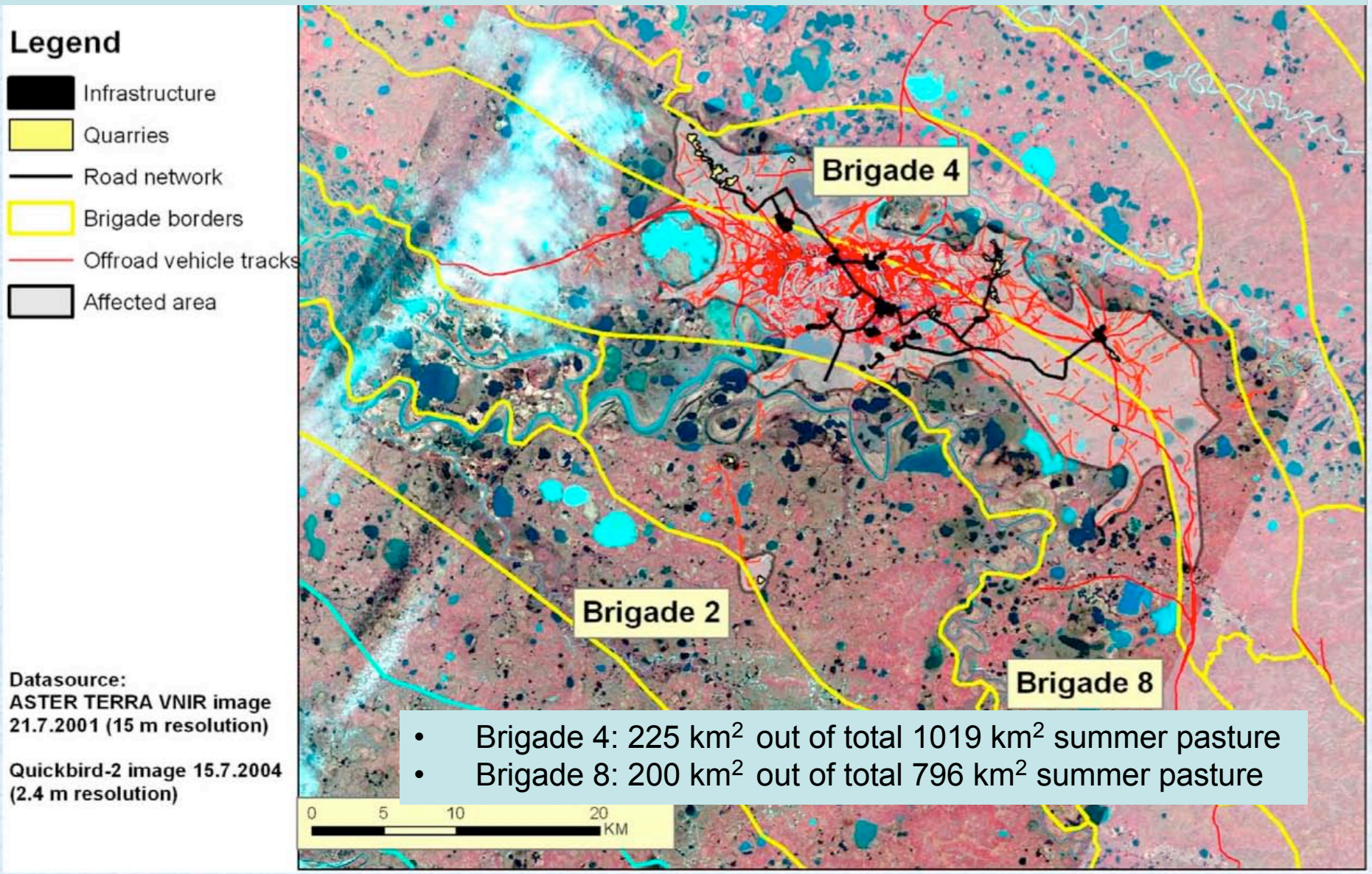
Combining remote sensing and traditional knowledge

"…in addition to taking part in daily life and seeing with our own eyes exactly how the animals are managed we … do more formal semi-structured interviews. Some of these are recorded on either digital tape or film, or both. In these cases we have medium or very high resolution satellite imagery of the areas we are discussing to focus on specific places and features that the herders can recognize easily."

Photo and quote: Bruce Forbes


Bovanenkovo gas field
Yarsalinskii sovkhoz
Brigade migration corridors VIII and IV
Panaevsk sovkhoz
Yamalskii sovkhoz
Analysis of impacts of resource extraction to pasturelands

Impacts of Bovanenkovo gas field to summer pasture of Brigades 4 and 8

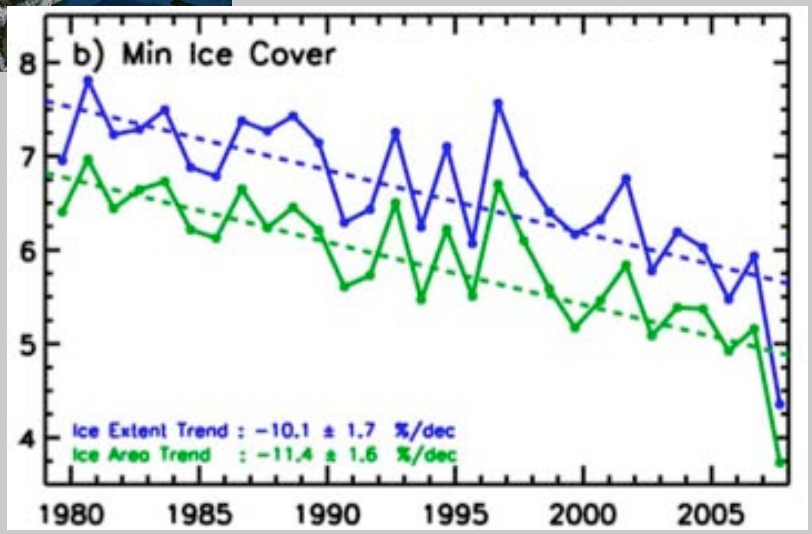


- Brigade 4: 225 km^2 out of total 1019 km^2 summer pasture
- Brigade 8: 200 km^2 out of total 796 km^2 summer pasture

Analysis of sea-ice, land surface temperature and NDVI trends: Arctic seas and associated land masses

Is the trend in sea-ice affecting Arctic vegetation ?

Since 1980, perennial sea ice extent in the Arctic has declined at the rate of 10.1% per decade, and area trend is -11.4% decade

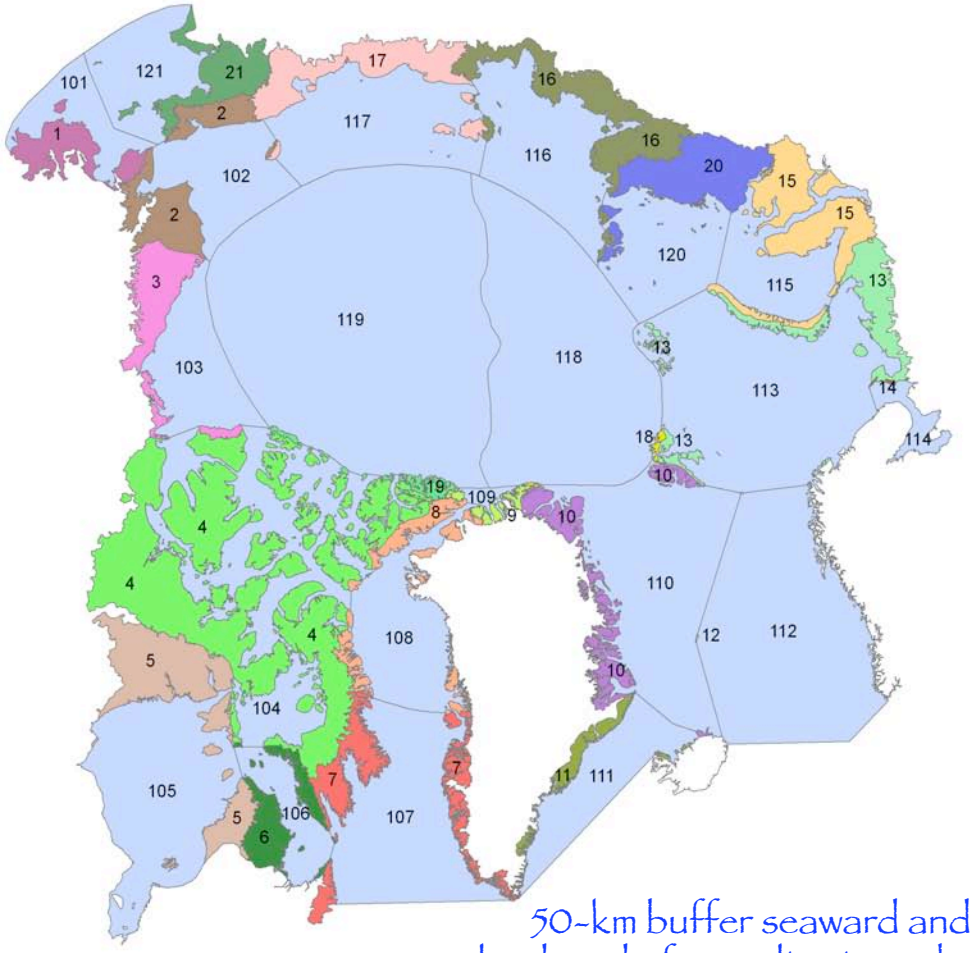


Comiso et al.: 2008, *Geophysical Research Letters*, 35: L01703.

Division of Arctic Ocean and associated land masses according to Russian Arctic Atlas

101 & 1* East Bering Sea
102 & 2 Chukchi Sea
103 & 3 Beaufort Sea
104 & 4 Canadian Arch. Straits
105 & 5 Hudson Bay
106 & 6 Hudson Strait
107 & 7 Davis Strait
108 & 8 Baffin Sea
109 & 9 Lincoln Sea
110 & 10 Greenland Sea
111 & 11 Denmark Strait
112 & 12 Norwegian Sea
113 & 13 Barents Sea
114 & 14 White Sea
115 & 15* West Kara Sea
116 & 16 Laptev Sea
117 & 17 East Siberian Sea
118 & 18 Russian Arctic Basin
119 & 19 American Arctic Basin
120 & 20* East Kara Sea
121 & 21* West Bering Sea

*Treshnikov basin divided for purposes of this study



50-km buffer seaward and landward of coastline in each sea

Bhatt et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Polar stereographic projection (J. Comiso)
Map by M. Raynolds, March 2008

Pan Arctic Variability

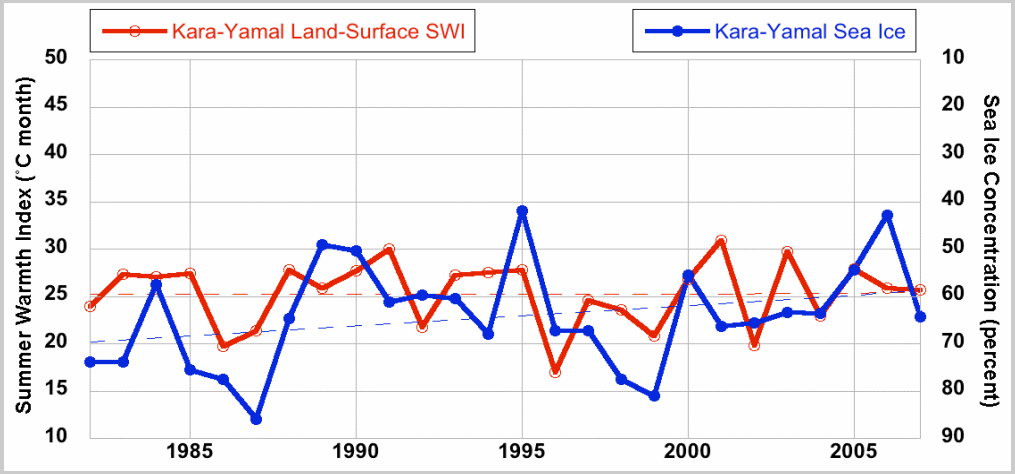
- **Mid July Sea Ice percentage cover**
- **Summer warmth index (SWI)**
- **Max NDVI**
- **Integrated NDVI**

Bhatt, Walker, Raynolds, Comiso: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Sea-ice and temperature trends in Kara/Yamal region of Russia and Beaufort Sea

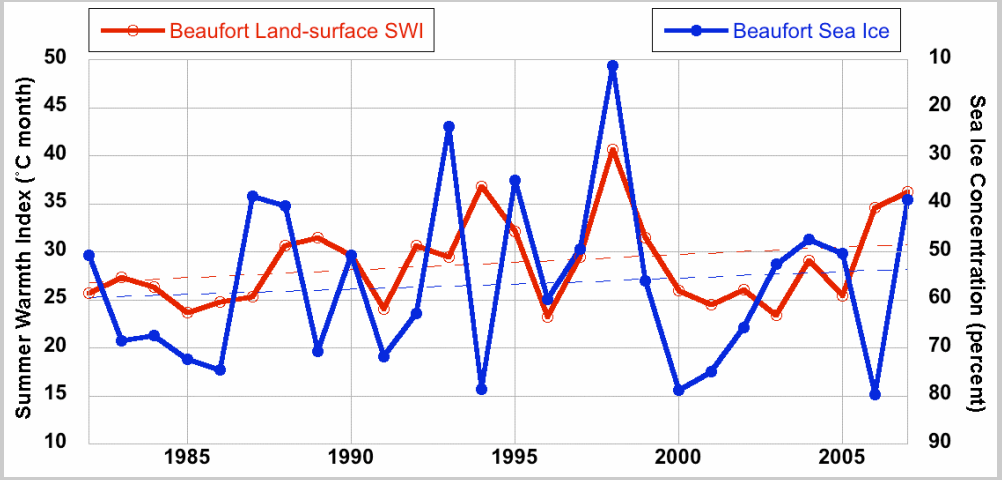
Kara/Yamal

- Negative sea-ice trend but nearly flat temperature trend



Beaufort

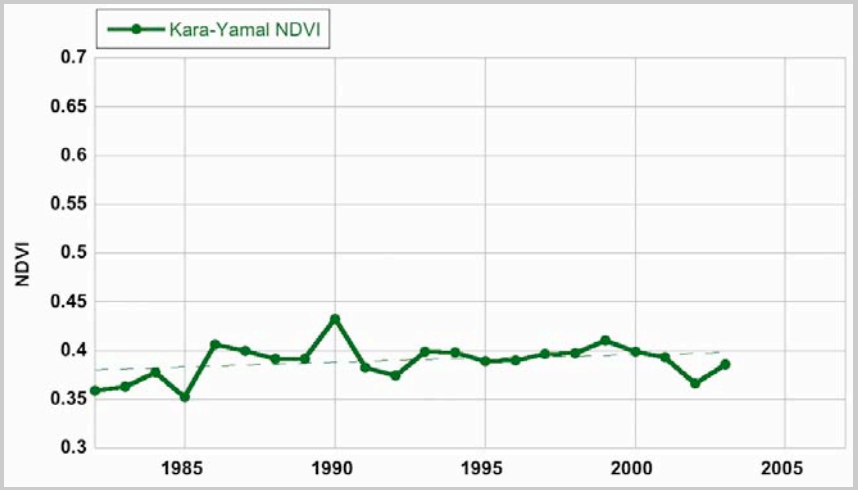
- Negative sea-ice trend correlated with positive temperature trend;
- High year-to-year variability



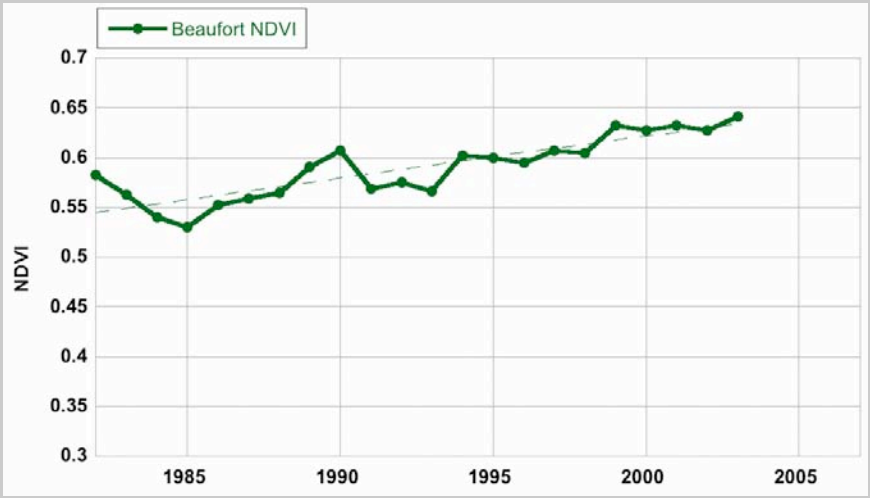
Bhatt et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

NDVI trends in Kara/Yamal region of Russia and Beaufort Sea

Kara/Yamal



Beaufort



- Much lower NDVI on the Yamal is likely due to sandy wind-blown nutrient-poor soils, and grazing by reindeer.
- Greater change in Beaufort Region (+0.04 vs. +0.0085 NDVI units/decade) most likely due to more positive trend in ground surface temperatures in the Beaufort region during the period of record.

Bhatt et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

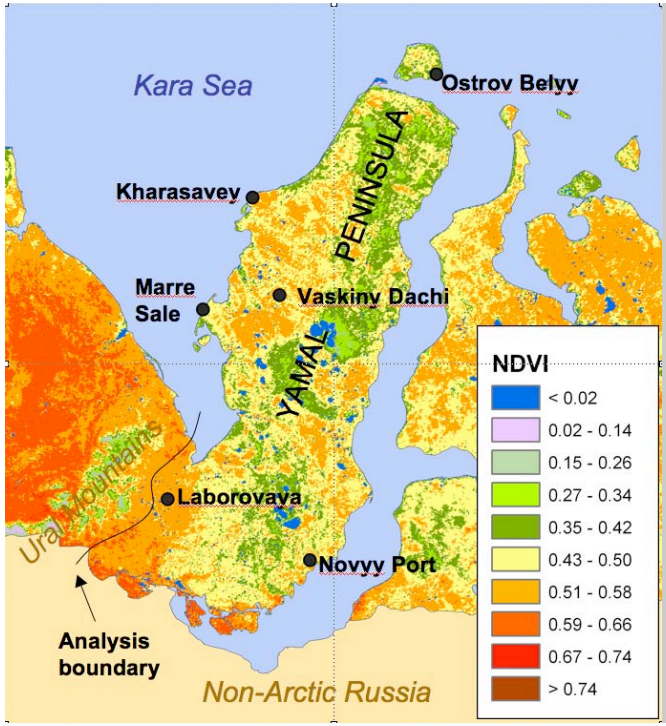
Correlations between climate indices SWI, sea ice, & integrated NDVI

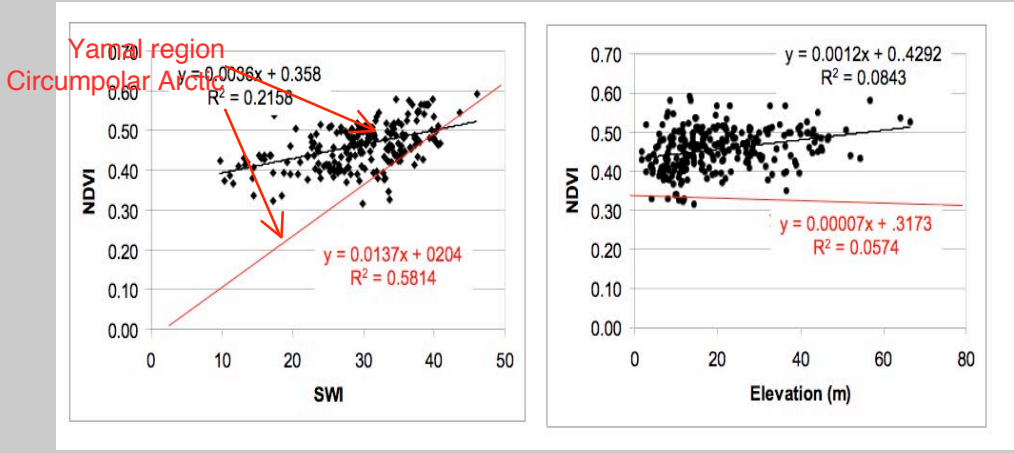
50-km zones with climate indices during preceding winter (DJFM)

Bold values indicate significance at 90% level or greater

Correlation	SWI				Sea Ice				Integrated NDVI			
	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI	NAO	AO	PDO	NPI
Barents	**0.38**	0.3	0	.14	-0.2	-0.3	**0.42**	-.20	.11	0.20	-.24	.23
Kara-Yamal	0.27	.12	0	.14	**-.54**	**-.57**	**0.48**	**-.34**	0	.14	-.29	**.40**
Kara-East	- 0.2	**-.40**	-.14	-.2	0	0	0	0	0	-.13	0	.16
Laptev	0.33	.19	-.31	.15	**-.56**	**-.53**	**0.43**	-.17	**0.60**	**0.41**	**-.41**	.27
E.Siberian	0.14	.33	**-.43**	.32	-.27	**-.56**	**0.49**	-.26	0.19	**0.45**	**-.63**	**.49**
Chukchi	-0.1	.12	-.28	**.37**	.19	-.26	0.20	-.11	-.17	0	-.26	.25
W. Bering	0.0	0	-.26	.13	-.11	-.24	0.14	0	0	0	-.22	0
E. Bering	0.0	0	-.11	.22	0	-.25	0.10	0	0	0	0	.15
Beaufort	**0.48**	**.40**	0	.11	0	0	-.27	.16	-.12	0.10	-.25	.22
Canadian Arch	0.19	.13	0	0	.14	0	0	0	0	.14	-.16	.15
Davis Straits	-0.2	0	0	.15	.18	0	0	-.11	-.31	0	0	.10
Baffin Sea	0.0	0	-.15	.16	0	0	0.15	-.17	0	0	0	.24
Grnland Sea	-0.1	.14	-.10	.19	**.43**	0.26	0	0	.13	0	0	0

Other effects on NDVI





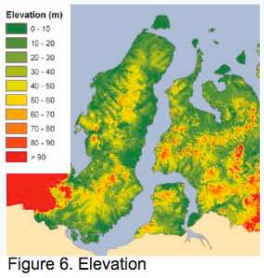


Figure 6. Elevation

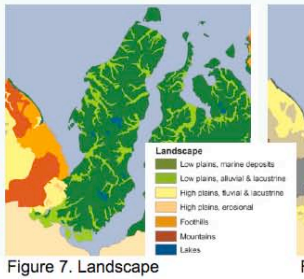


Figure 7. Landscape

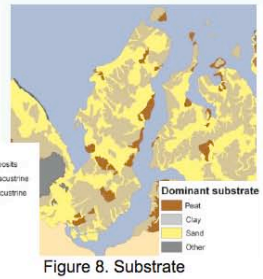


Figure 8. Substrate

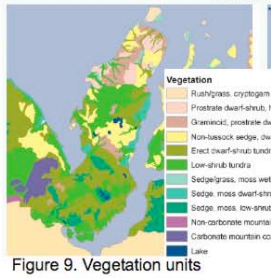


Figure 9. Vegetation units

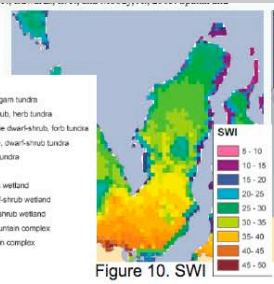


Figure 10. SWI

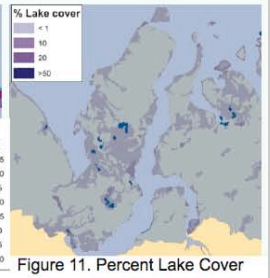


Figure 11. Percent Lake Cover

Results from General Linear Model

	Df	Deviance	Residual Df	Residual Deviance	% Deviance accounted for	Signi-ficance
Null			280	2.06516		
Elevation	0.60322	0.60322	279	1.46194	**29.21**	< 2e-16 ***
Land-schaft	0.40732	0.40732	278	1.05462	**19.72**	< 2e-16 ***
Lithology	0.10083	0.10083	277	0.9538	**4.88**	2.91e-07 ***
Veget-ID	0.08868	0.08868	276	0.86512	**4.29**	3.50e-06 ***
SWI	0.03856	0.03856	275	0.82655	**1.87**	1.12e-04***
Lake area	0.03245	0.03245	274	0.7941	**1.57**	9.34 e-04***
TOTAL					**61.55**	

- Summer warmth explains only 2% of the regional variance in NDVI on the Yamal!
- Elevation, landscape type, vegetation type, and substrate explain 58%.

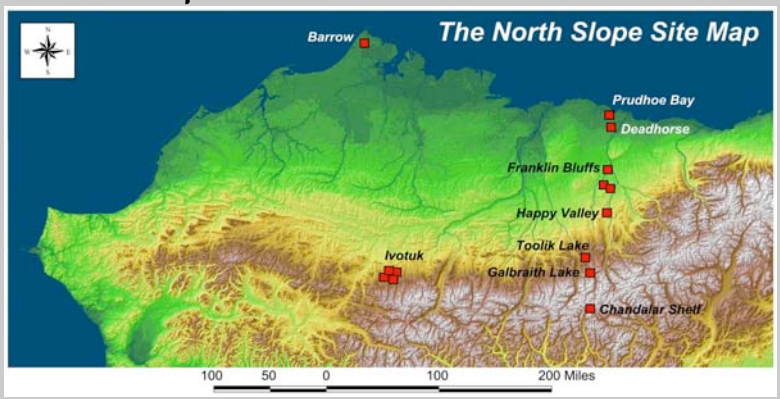
Raynolds et al.: 2008, Yamal LCLUC Workshop, Moscow.

General sea-ice, NDVI, climate trends

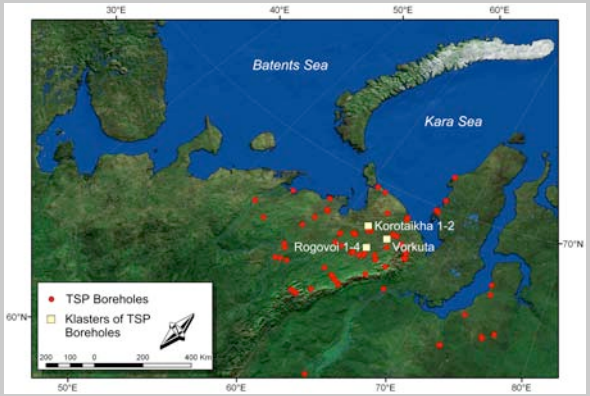
- Summer land-surface temperature, winter sea-ice concentrations, and integrated NDVI are correlated at all spatial scales.
- Preseason large-scale climate forces the sea ice while local circulation patterns play a larger role during the summer.
- Although there is a correlation between NDVI and the summer temperature, summer temperature accounts for only a small proportion of the total variation in NDVI on the Yamal. Other factors such as substrate, vegetation type, and major physiographic boundaries play a much larger role than temperature.

Permafrost temperatures

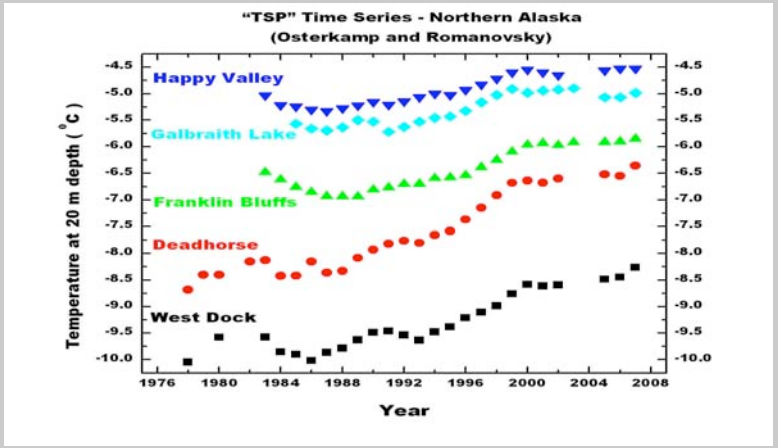
North Slope, Alaska

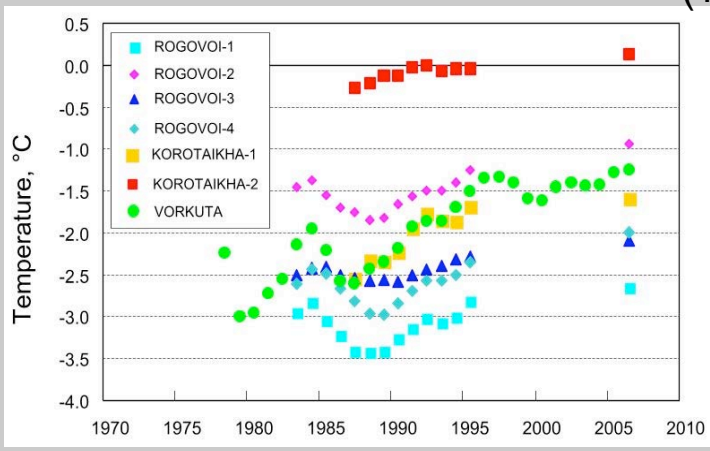


Yamal Region, Russia



- Cooling mid-1980s
- Warming to late 1990s
- Stable 2000 to present
- Strongest warming near the Beaufort coast (+1.5 – +2.0 ˚C)





Russia data from N. Oberman, MIREKO

Romanovsky et al.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

2007 Expedition to Yamal Peninsula Region, Russia

Goals:

- Collection of ground observations to support remote-sensing climate-change studies on the Yamal and circumpolar region.
- Learn about environmental controls on primary production in the region.

Members of the Expedition:

Nadym

Laborovaya and Vaskiny Dachi

Logistics:

Data collected:

Soils

Plant Cover

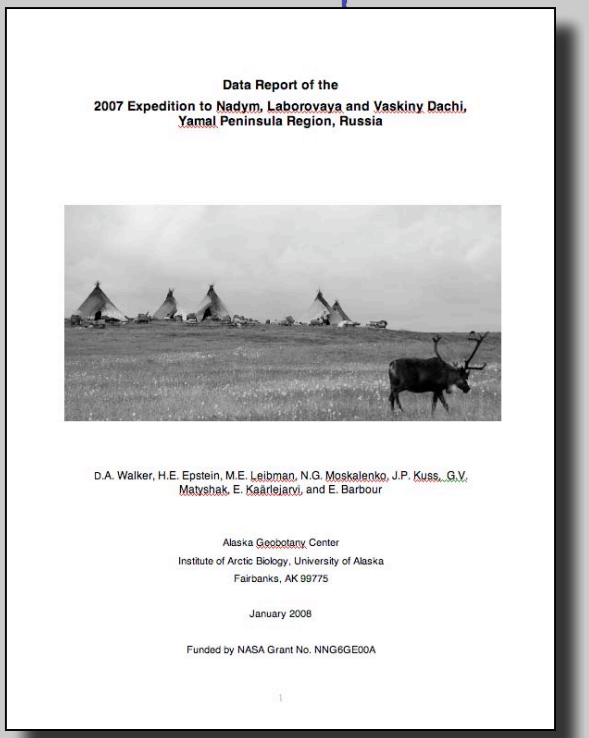
NDVI & LAI

Ground temperatures

Active layer

Plant Biomass

Data Report



Data Report of the
2007 Expedition to Nadym, Laborovaya and Vaskiny Dachi,
Yamal Peninsula Region, Russia

D.A. Walker, H.E. Epstein, M.E. Leibman, N.G. Moskalenko, J.P. Kuss, G.V. Matyshak, E. Kaärlejarvi, and E. Barbour

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Institute of Arctic Biology, University of Alaska
Fairbanks, AK 99775

January 2008

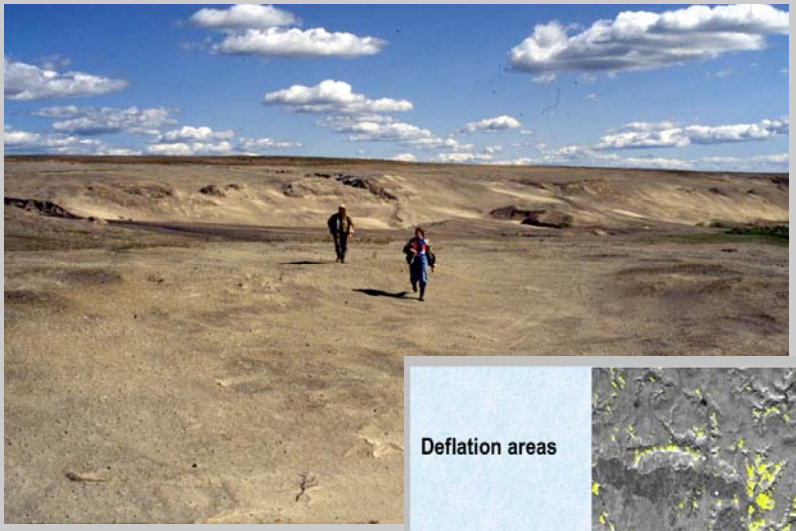
Funded by NASA Grant No. NNG6GE00A

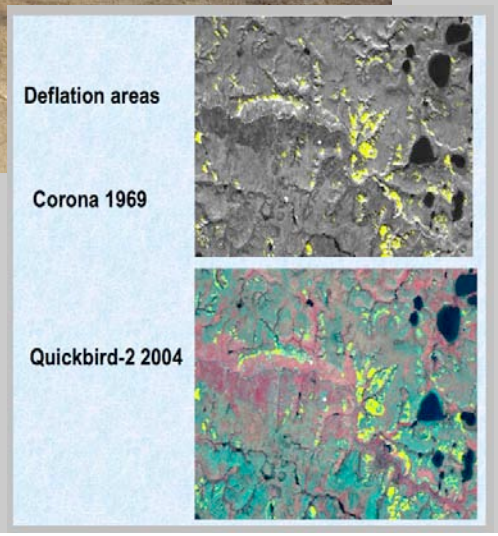
http://www.geobotany.uaf.edu/yamal/documents/yamal_2007_dr080211

Terrain factors that make the Yamal region so sensitive to terrain disturbance

Sandy nutrient poor soils:

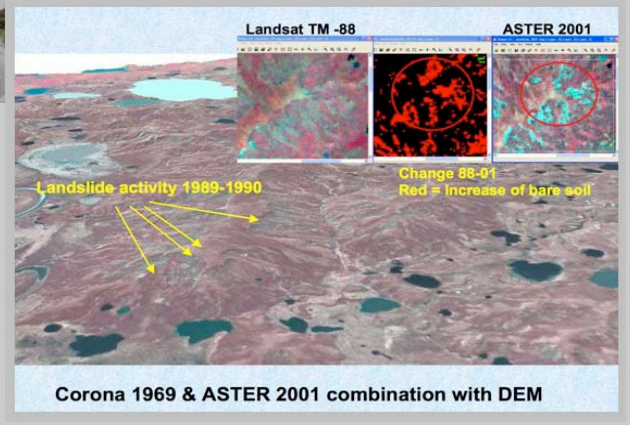
- Highly susceptible to wind erosion.
- Poor plant production, low plant diversity, slow recovery.





Extreme massive ground ice conditions:

- Extreme ice-rich permafrost makes the region very susceptible to landslides.
- For example, in unusually wet year of 1989.



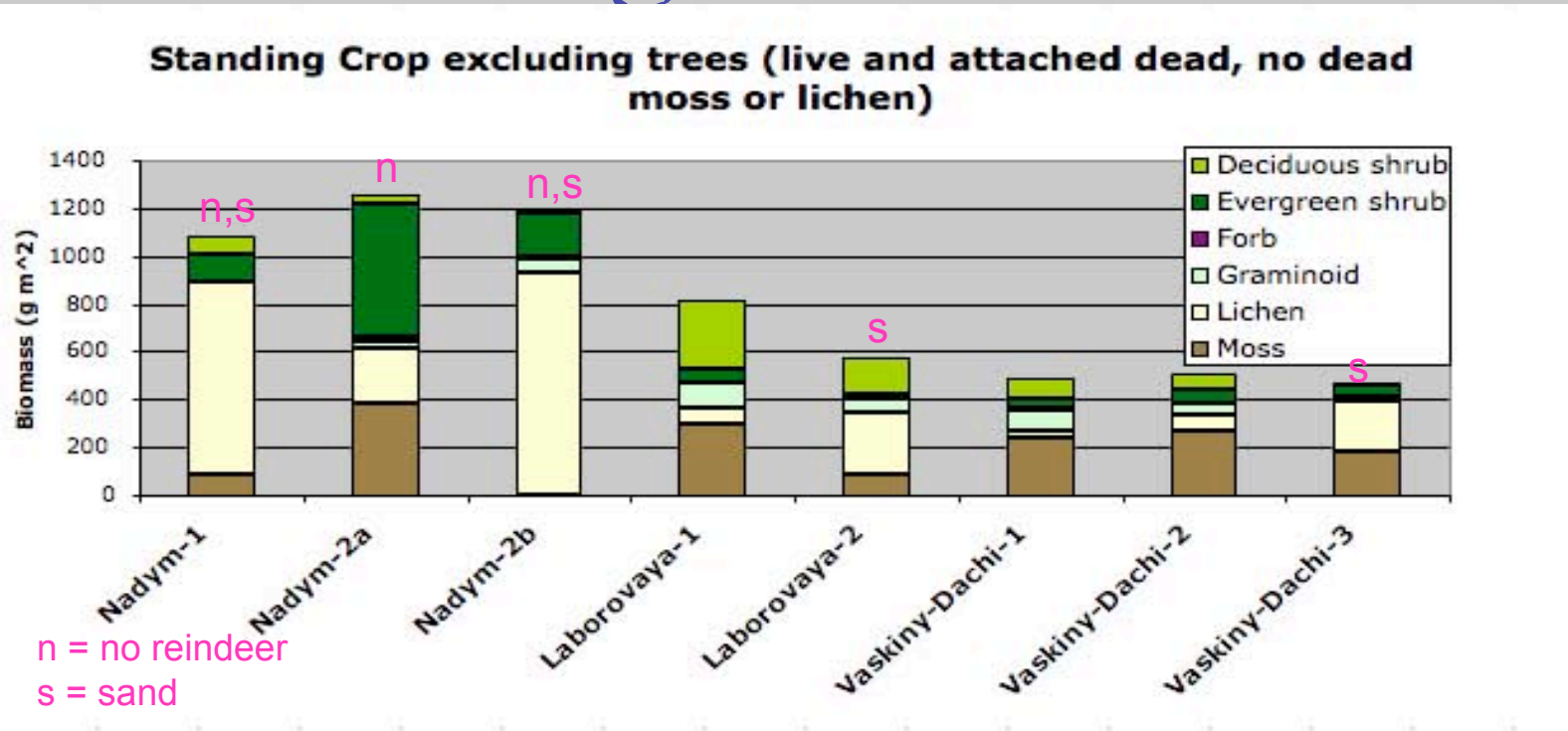
T. Kumpula:
Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Vaskiny Dachi: Unique successional sequences related to Quaternary history, massive ground ice, landslides and soils

- Dense willow thickets develop on old landslides after leaching of salts from clayey marine sediments.

Ukraintseva and Liebman: 2007, 1st North American Landslide Conference, Vail, CO.

Biomass along the Yamal transect

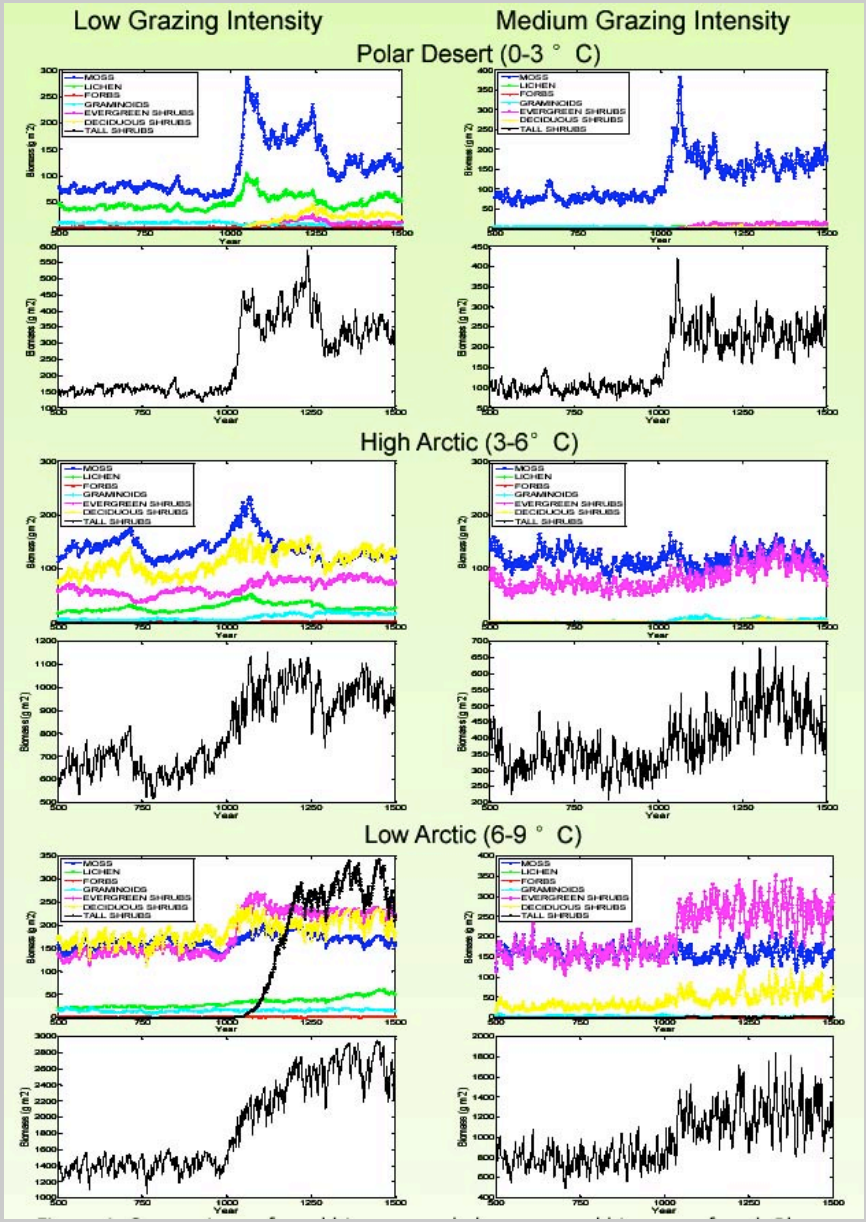


Climate trend:
2000–2300 g m^{-2} at Nadym to about 1000–1300 g m^{-2} at Vaskiny Dachi.

Effect of sandy soils:
- Sandy soils have 250–350 g m^{-2} less biomass than comparable clayey sites
- Much more lichen biomass and less mosses and graminoids.

Effect of reindeer:
- Ungrazed sandy areas near Nadym – over 1000 g m^{-2}
- Less than 250 g m^{-2} in sandy areas where reindeer grazing has occurred annually.

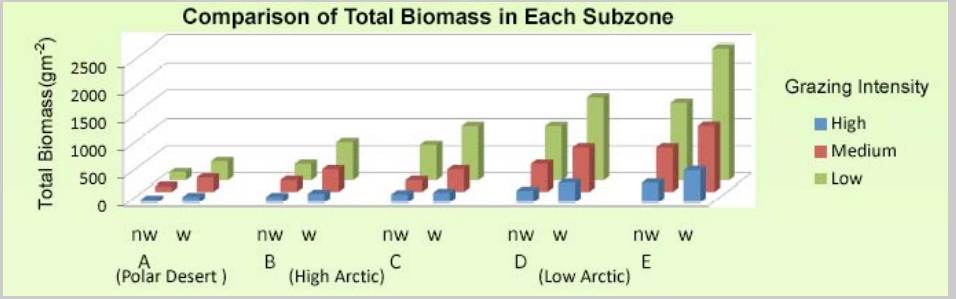
Walker et al:
Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

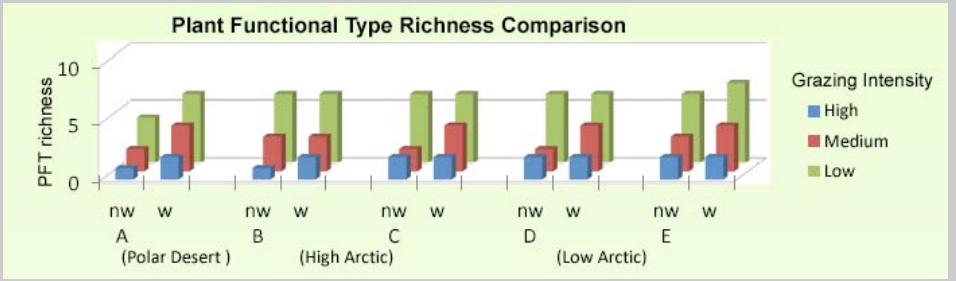


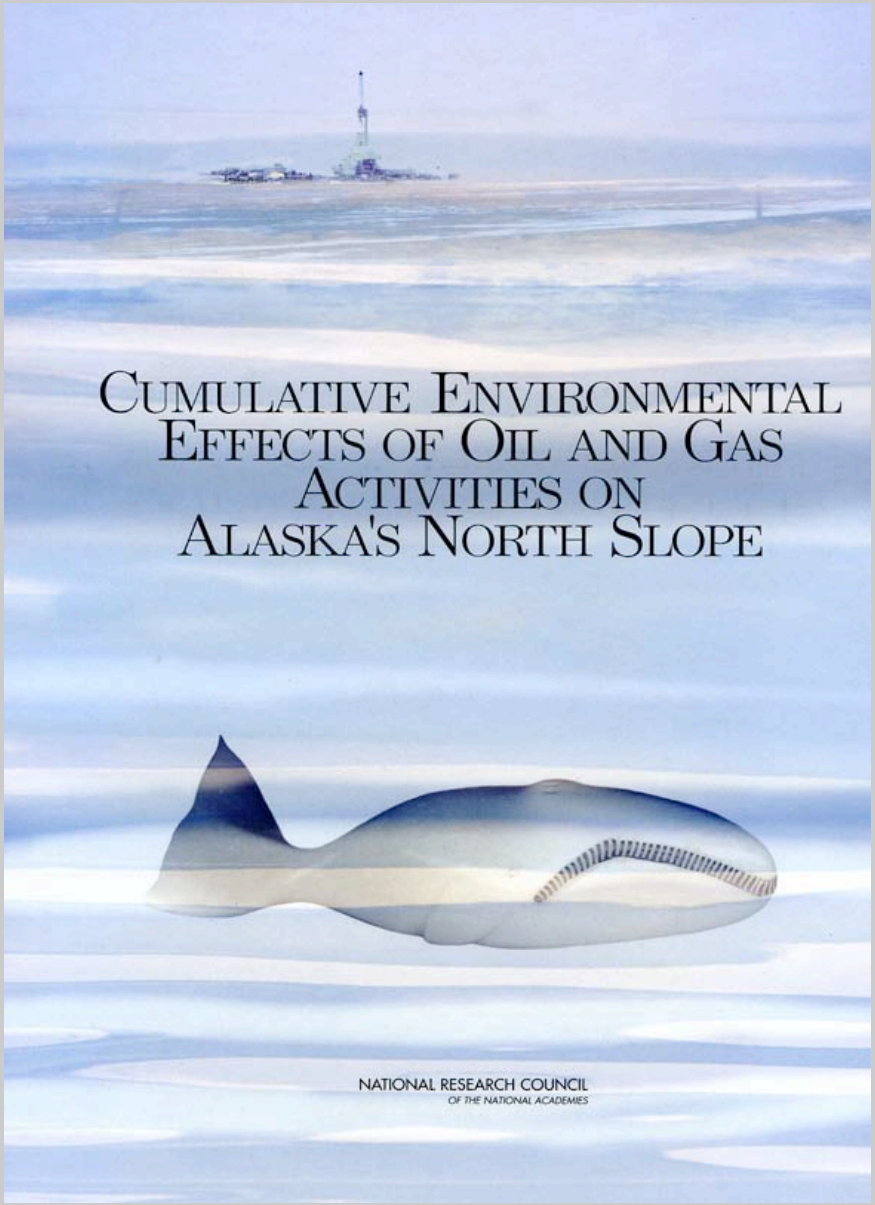
Yu and Epstein: 2008, EGU conference.

Modeled productivity on the Yamal

- ArcVeg model (Epstein et al. 2002)
- Examines succession of biomass for seven Arctic plant functional types.
- Five climate scenarios.
- Warming vs. non-warming treatments.
- Three grazing intensities.
- Next steps will incorporate soil type and disturbance regimes (dust and complete removal of vegetation).







Walker et al.: in progress, in Gutman et al. LCLUC book.

Comparative study with Alaska oil development

Differences:

Resource development:

- Oil vs. gas
- Current state of development: production vs. development phase.
- Regulatory environment: US vs. Russia.

Traditional land-use:

- Subsistence hunting vs. reindeer herding

Climate change:

- More rapid in Beaufort region

Environmental factors:

- Geology: alluvial gravel with loess vs. marine sands and clays
- Permafrost: stable gravels vs. massive ground ice with landslides
- Soils: Nonacidic loess vs. acidic nutrient-poor sands
- Vegetation: Nonacidic species rich vs. acidic species-poor

- **Similarities:–**
- Both are in vast expanses of tundra that were remote and relatively untouched by modern development until the discovery of hydrocarbons.
- Both are affected by combinations of factors related to rapid resource development, traditional land-use issues, climate change, and permafrost-related terrain features that are sensitive to disturbance.
- Both would benefit from land-use planning processes that involve all stake holders.

Conclusions

Resource development:

- Direct (planned) impacts less extensive than indirect impacts.
- Roads and pipelines: serious barriers to migration corridors.
- Effects will increase as new field are developed.

Reindeer herding:

- Land withdrawals by industry, increasing Nenets population, and larger reindeer herds are all increasing pressure on the rangelands.
- Herders view: Threats from industrial development much greater than threats from climate change,but they generally view the gas development positively because of increased economic opportunities.

Climate change:

- Climate change effects are currently hard to document because of lack of long-term ground observations.
- Satellite data suggest that there has been only modest summer land-surface warming and only slight greening changes across the Yamal during the past 24 years.
- Summer temperature controls only small amount of total variation in NDVI on Yamal. Terrain factors are more important.

Landscape factors and terrain sensitivity:

- High potential for extensive landscape effects due to unstable sandy soils, and extremely ice-rich permafrost near the surface.

Comparison with North American Arctic hydrocarbon development:

- Useful insights regarding generality of Yamal observations and lessons to be learned for other areas of Arctic developments.