Lesson 4
Social-ecological effects of oil and gas development in the Arctic

Comparison of the Prudhoe Bay, Alaska, and Bovanenkova, Russia, regions

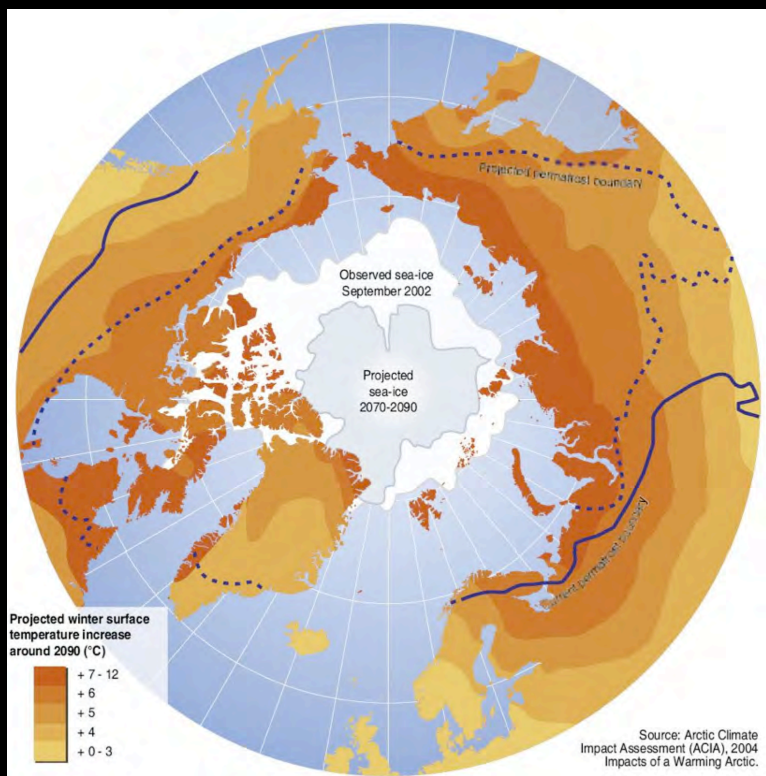
Photos: Courtesy of Pam Miller and Bryan and Cherry Alexander

Fulbright Lectures by: D.A. Walker
at Masaryk University, Spring Semester, 2011

Overview of lecture

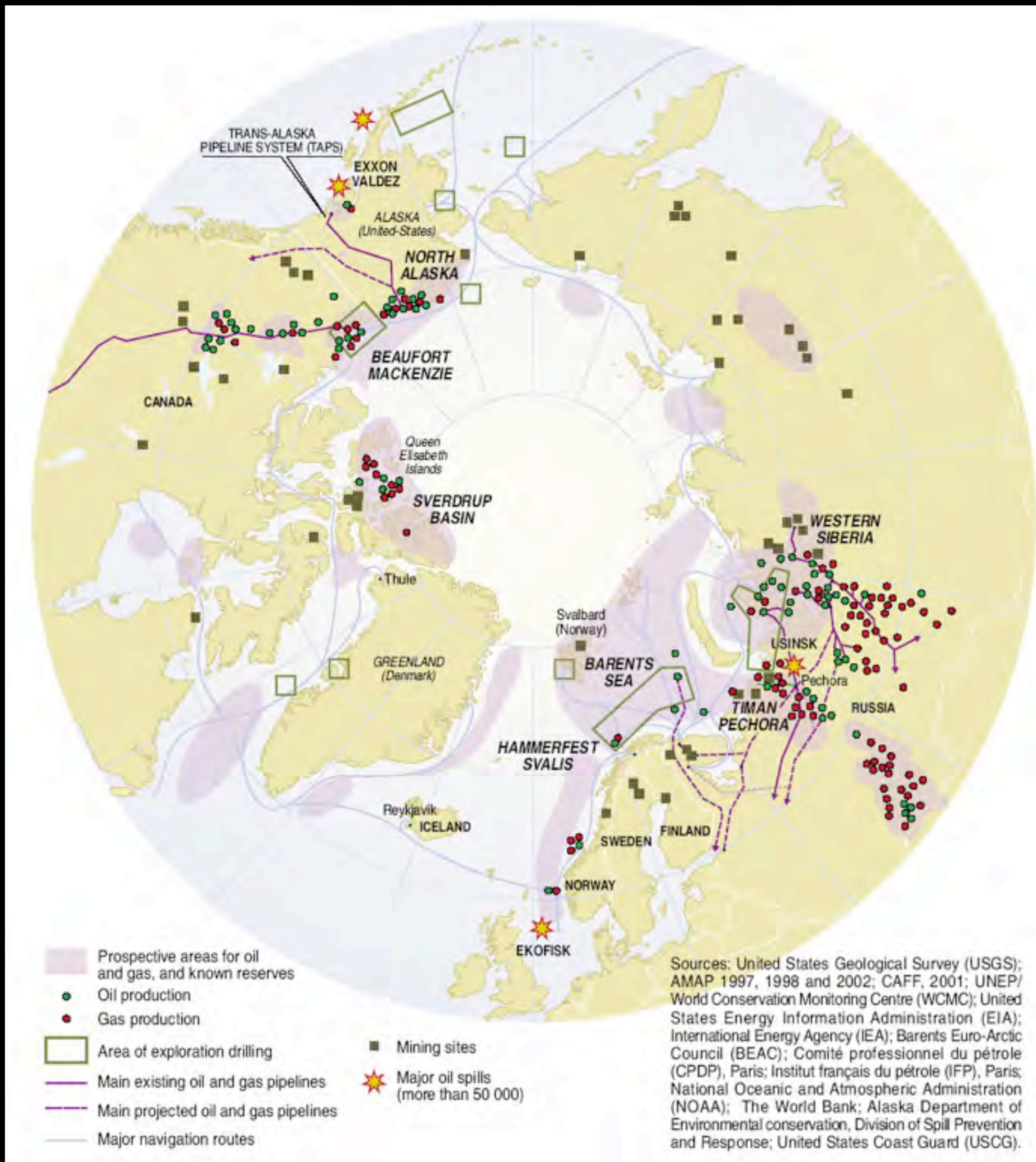
- Expected changes in anthropogenic footprint in the Arctic (UNEP GLOBIO, 2004).
- Review of the National Research Council (NRC) report of the cumulative effects of oil and gas development on the Alaska Arctic Slope.
- Methodology for GIS analysis of historical geobotanical changes in the Prudhoe Bay field, Walker et al. 1986, 1987.
- Socio-ecological effects of gas development on the Yamal Peninsula, Russia: Forbes et al. 2010; Walker et al. 2011.

The Arctic has received a lot of press lately due to climate change and retreating sea ice.



Projected increases in winter temperatures for about 2090 (ACIA 2004).

Sep 2010 sea-ice extent compared to 1979-2000 mean (NSIDC 2011).

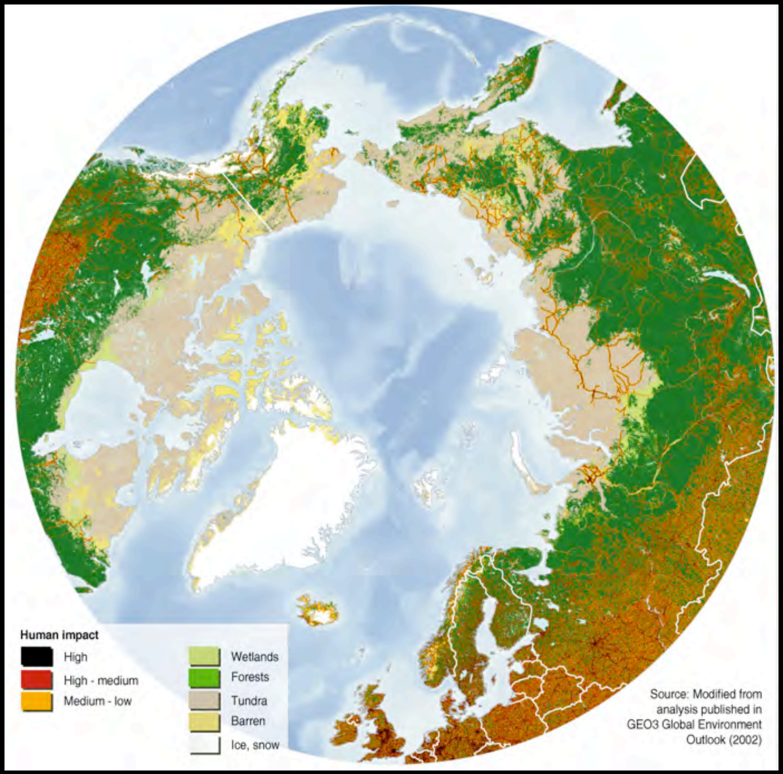


•A related issue for many living in the Arctic is the pressure to develop the natural resources of the Arctic.

The cumulative impacts of issues related to natural resource development are viewed by the Nenets people of the Yamal Peninsula in Russia as a greater threat to their livelihood than climate change.

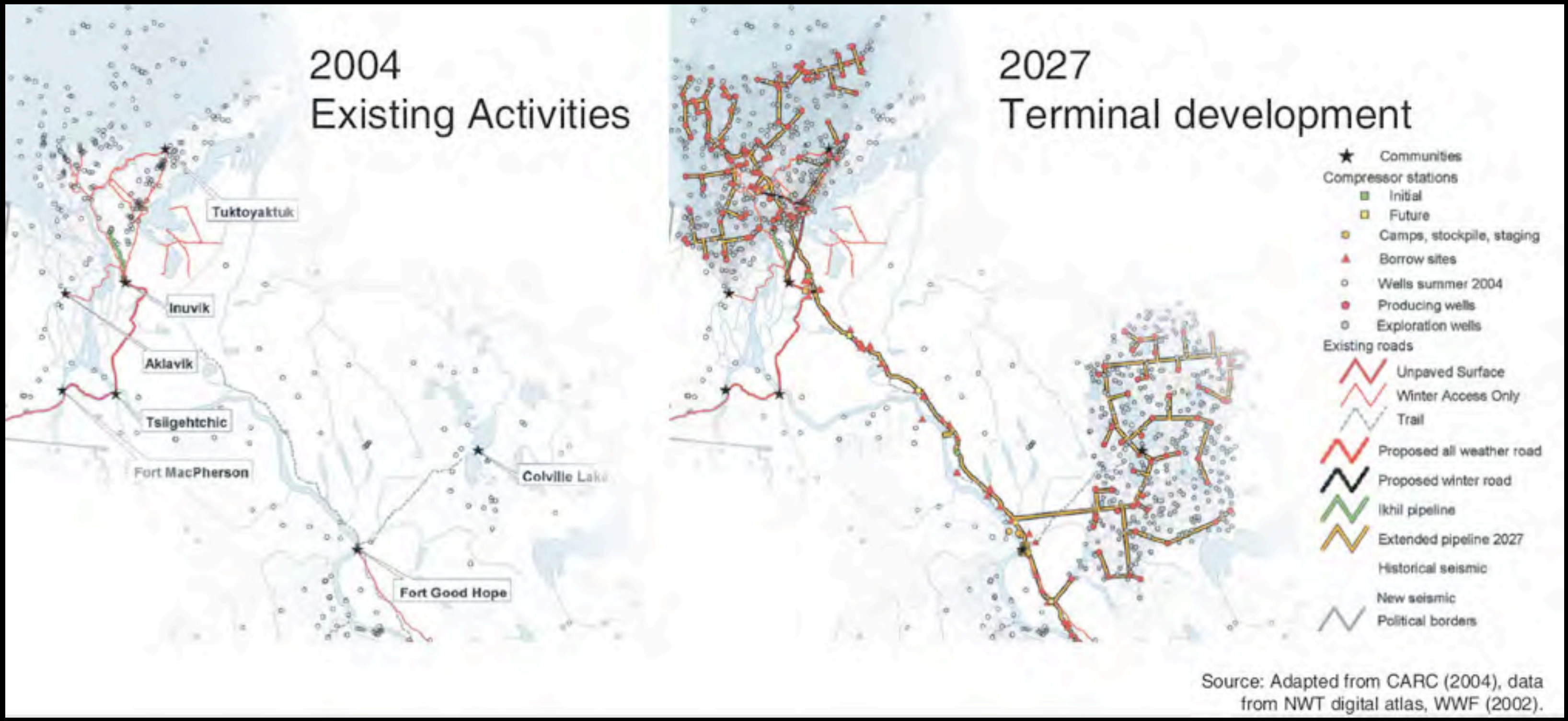
GLOBIO, Vital Arctic Graphics: http://www.grida.no/publications/vg/arctic/

Present and projected (2032) impacted areas in the Arctic (UNEP 2004)



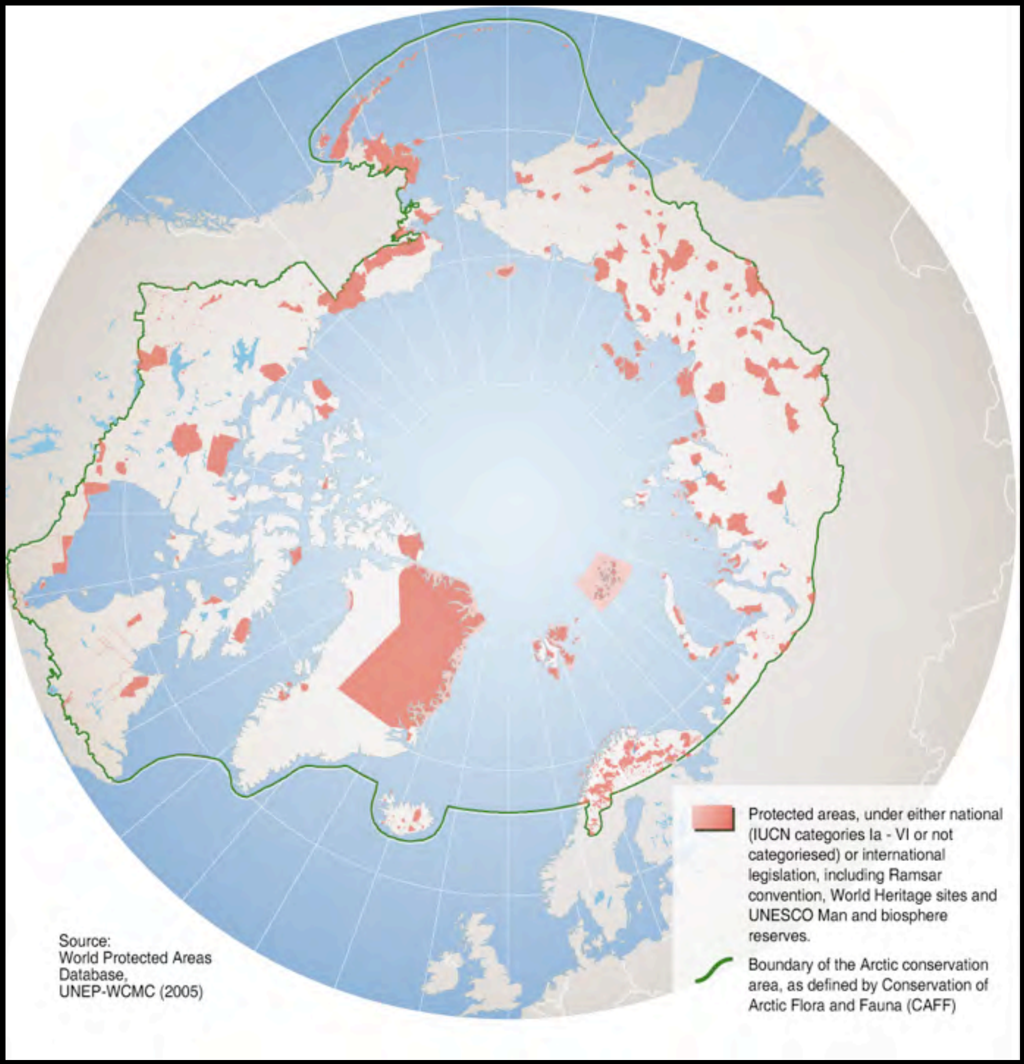
- *Some estimates (UNEP, 2001) project that perhaps as much as 80 percent of the Arctic land area will become impacted by development by 2050 if current trends continue.*

Projected development in the Mackenzie River corridor, Canada



- Example of the types of change that are imminent in many gas basins of the Arctic.

Protected areas in the Arctic



- Compared to other biomes the Arctic is relatively well protected.
- Areas of primary concern are the coastal areas. Only 7% of the coasts are currently impacted,
- Only 1% are protected. These could be highly threatened by increased tanker traffic, industrial development, and new fisheries.

Alaska North Slope region

- 230,000 km^2 about = Romania or about 3 x Czech Republic.
- Population in 2001 = 7,555.
- Naval Petroleum Reserve 4 (now NPR-A) explored in the 1960s with only minor finds of oil and gas.
- ANWR set aside as wilderness except for 1002 Area.
- Currently producing about 7 billion bbl of oil (7% of the annual domestic U.S. consumption in 2001), mostly on State of Alaska land.

Discovery of oil at Prudhoe Bay

Alaska and Polar Regions Collections, Elmer E. Rasmuson Library, University of Alaska Fairbanks.

- 1967: Discovery of Prudhoe Bay field.

Wildcat oil rig exploring for new oil fields

Alaska and Polar Regions Collections, Elmer E. Rasmuson Library, University of Alaska Fairbanks.

Very similar to the oil rig I worked on in 1969.

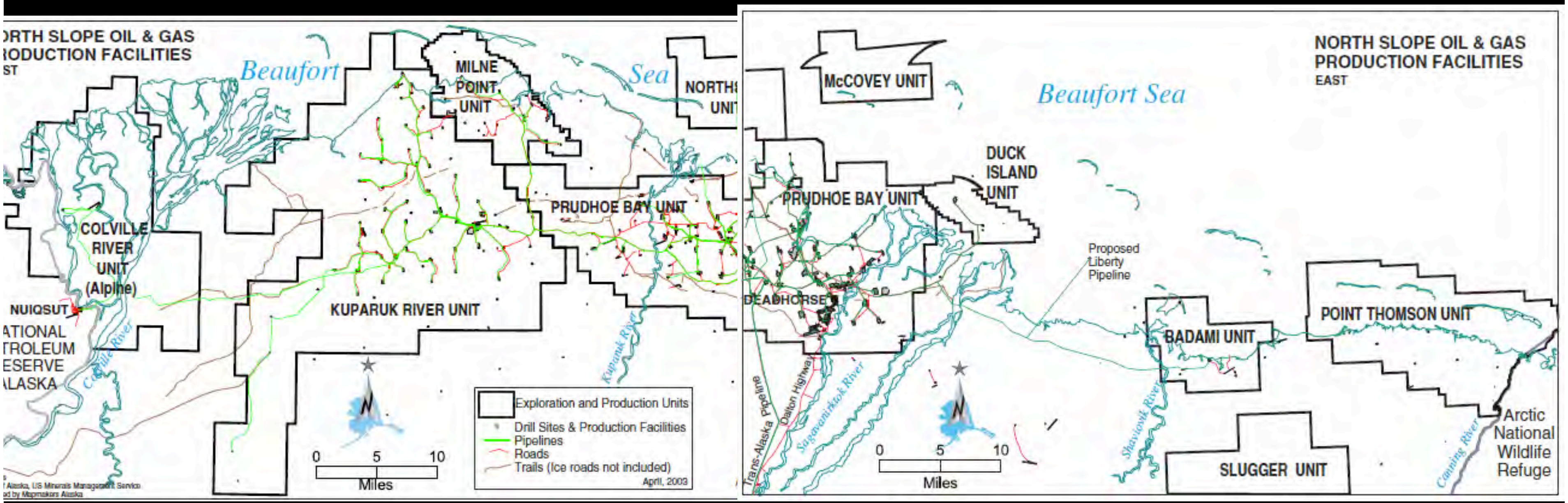
All equipment was initially flown in or towed by tractors over snow and ice roads.

In 1968 there were virtually no roads on the North Slope of Alaska.

Alaska and Polar Regions Collections, Elmer E. Rasmuson Library, University of Alaska Fairbanks.

C-130 Hercules at Prudhoe Bay

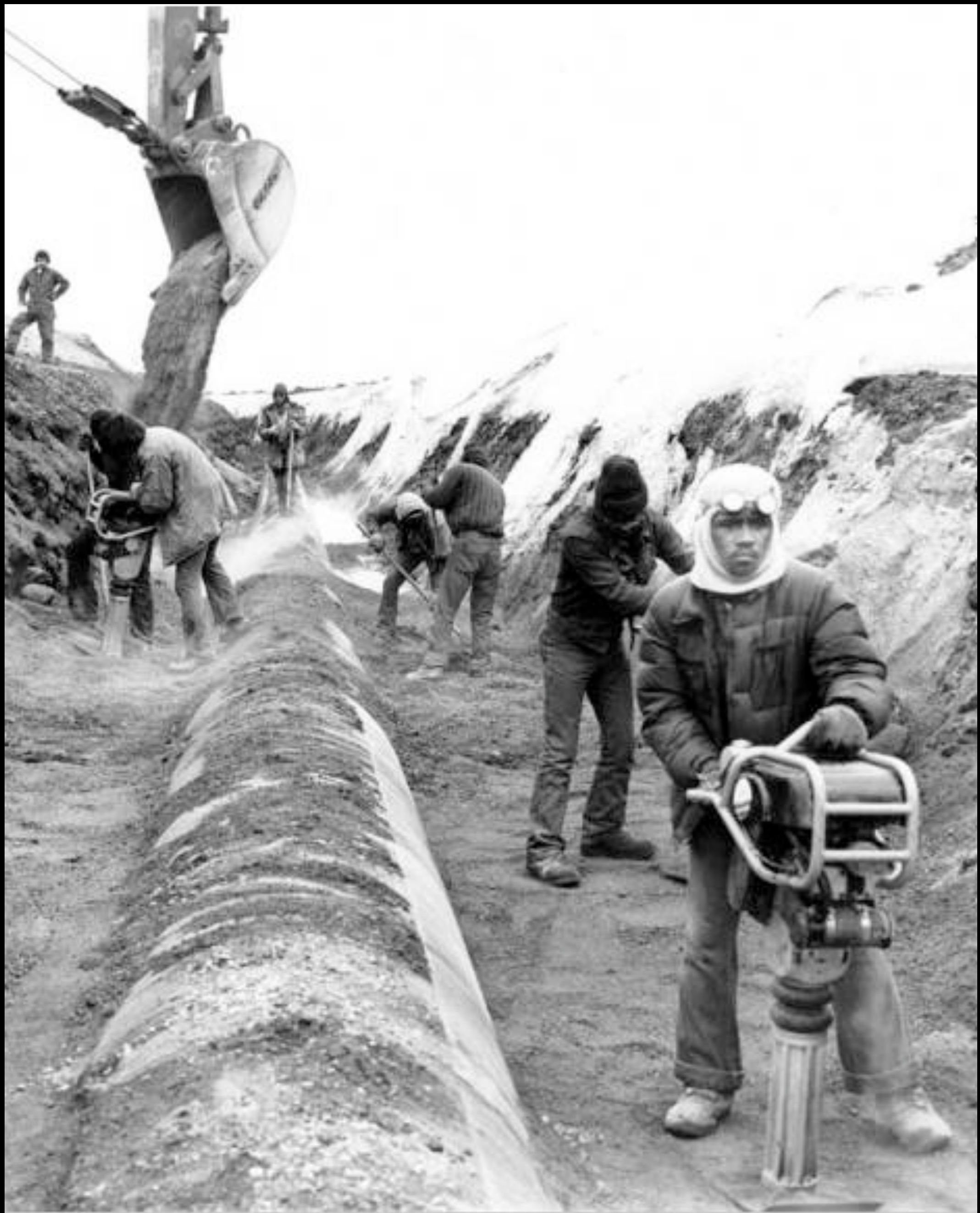
North Slope oil and gas production units, roads and pipelines in 2001.



- 1969: Discovery of Kuparuk, West Sak & Milne Point fields.
- 1971: Alaska Native Claims Settlement Act.
- 1974: Dalton Highway
- 1977: Trans-Alaska Pipeline.
- 1970s-1980s: Rapid expansion of exploration and development.

Trans-Alaska pipeline

- 1287 km.
- Oil takes 12 days to travel from Prudhoe Bay to Valdez.
- Aboveground pipeline mode in areas of ice-rich permafrost.
- Passive refrigeration fins and ammonia cool the permafrost in winter.

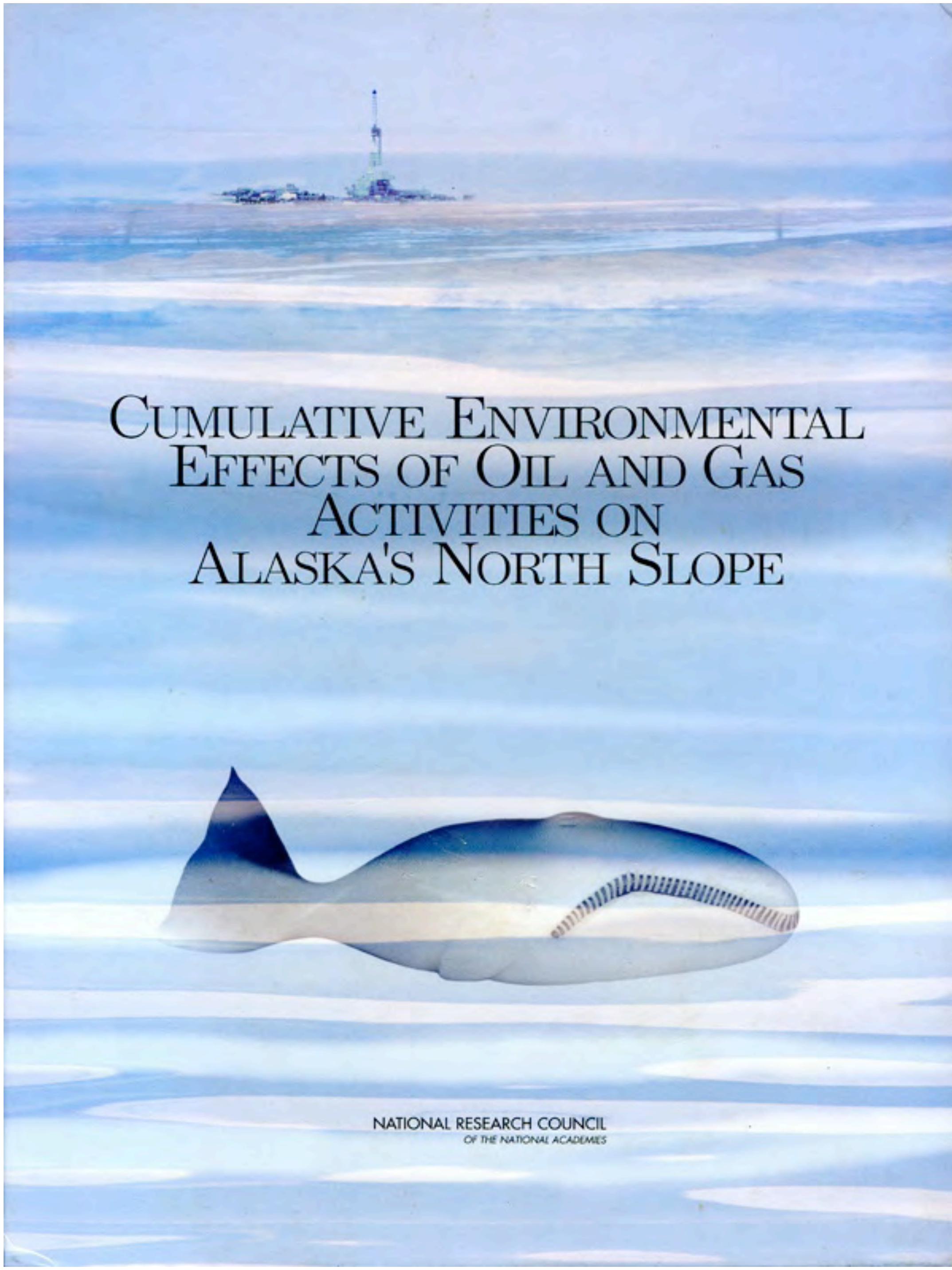

Anchorage Museum at Rasmuson Center. Library & Archives.

Construction of Trans-Alaska Pipeline

- 1974-1977.
- Buried under rivers and areas with non-ice rich permafrost

First required construction of Dalton Highway.

- 667 km from Livengood to Prudhoe Bay.
- Constructed in one year! 1974.



Main resource for Alaska cumulative effects

NRC, 2003, Cumulative environmental effects of oil and gas activities on Alaska's North Slope: Washington, DC, The National Academic Press, p. 304.

Main resource for Yamal cumulative effects

Forbes, B.C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A., and Kaarlejärvi, E., 2009, High resilience in the Yamal-Nenets social-ecological system, west Siberian Arctic, Russia: Proceedings of the National Academy of Sciences, v. 106, p. doi: 10.1073/iti5209106, 22041-22048.

And other papers resulting from the ENSINOR project

BOX 1-1 Statement of Task

The Committee on Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope was charged to review information about oil and gas activities (including exploration, development, and production) on Alaska's North Slope and assess the known and probable cumulative effects on the physical, biological, and human environments of Alaska's North Slope (including the adjacent marine environment) of oil and gas activities there from the early 1900s to the present, including cleanup efforts. The committee was asked to provide an assessment of potential future cumulative effects, based on its judgment of likely changes in technology and the environment, on a variety of scenarios of oil and gas production volumes, and in combination with other probable human activities, including tourism, fishing, and mining. As part of its report, the committee was charged to describe and document its methodology for assessing cumulative effects, identify gaps in knowledge, and make recommendations for future research needed to fill those gaps. Although cumulative effects of oil and gas activities occur beyond the North Slope (e.g., related to transportation and ultimate combustion), the committee was asked to confine its focus to the North Slope (i.e., north of the crest of the Brooks Range) and as far into the Arctic Ocean as there is evidence of environmental effects.

Statement of task for the NRC report

Definition of cumulative effects

Cumulative impacts are the result of incremental impacts of the actions that when added to other past, present, and reasonably foreseeable future actions result in individually minor but collectively significant actions taking place over a period of time.

Council on Environmental Quality 1978

Generally, the cumulative effects cannot be predicted by simply adding the effects of all known impacts.

Approach used here expands the definition to include the simultaneous and interactive effects of developing many gas and oil fields and other ongoing social and ecological factors such as population growth and climate change.

Some types of cumulative effects

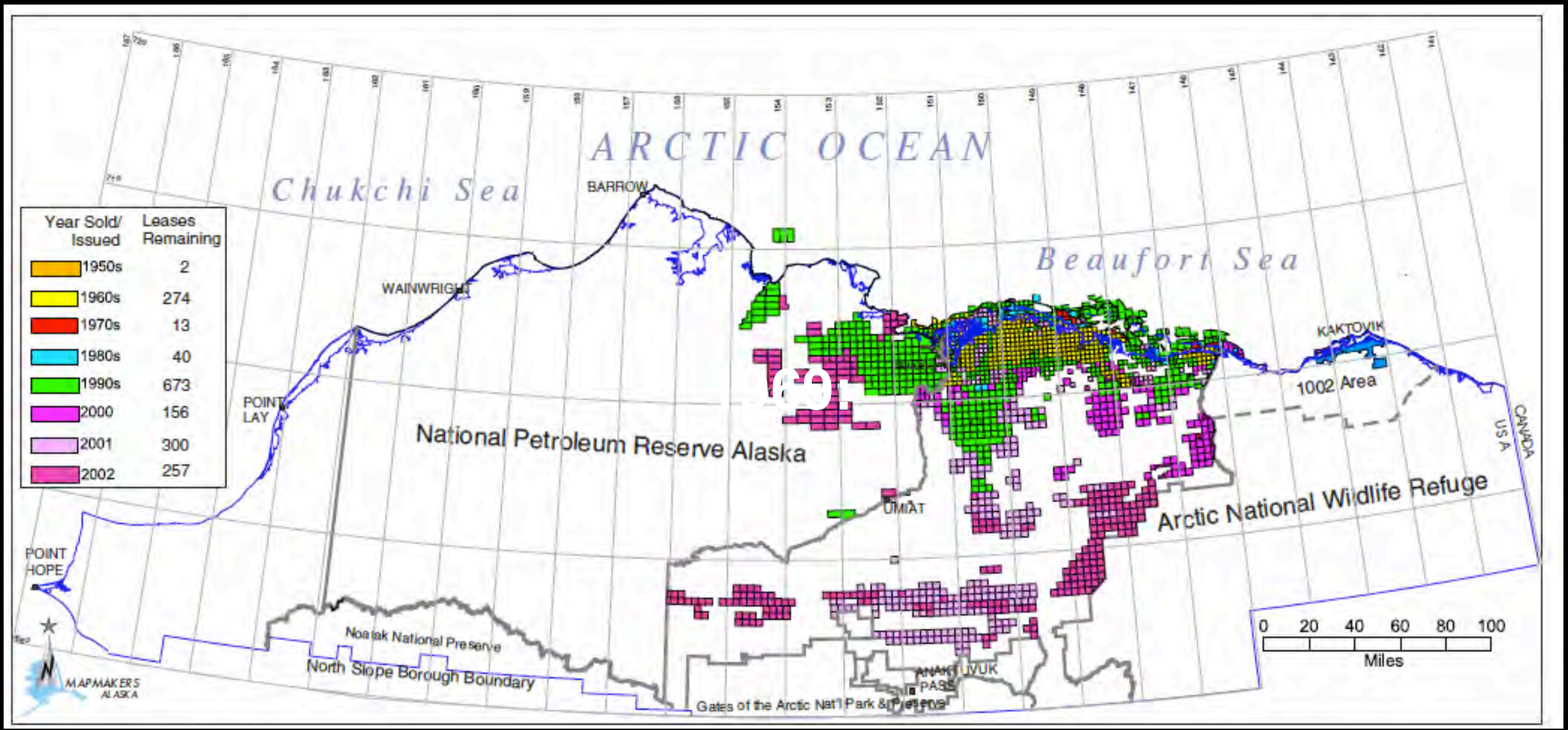
Space crowding—high density of effects on a single environmental medium, such as a concentration of drilling pads in a small region so that the areas affected by individual pads overlap.

Compounding effects—synergistic effects attributable to multiple sources or interaction of natural and anthropogenic effects, such as the Exxon Valdez oil spill and El Niño events.

Thresholds—effects that become qualitatively different once some threshold of disturbance is reached, such as when eutrophication exhausts the oxygen in a lake, converting it to a different type of lake.

Nibbling—progressive loss of habitat resulting from a sequence of activities, each of which has fairly innocuous consequences, but the consequences on the environment accumulate.

Documenting history of exploration



- 1968: Discovery of Prudhoe Bay field
- 1969: Discovery of Kuparuk, West Sak & Milne Point fields.
- 1970-80s: Exploration and expansion mainly in areas around Prudhoe Bay.
- 1990s: Expansion into NPR-A and south of the Prudhoe Bay.
- 2000s: Rapid expansion of leases in the Arctic Foothills, mainly gas exploration.

And potential future impacts: Strip mining of coal and/or development of coal-bed methane deposits.

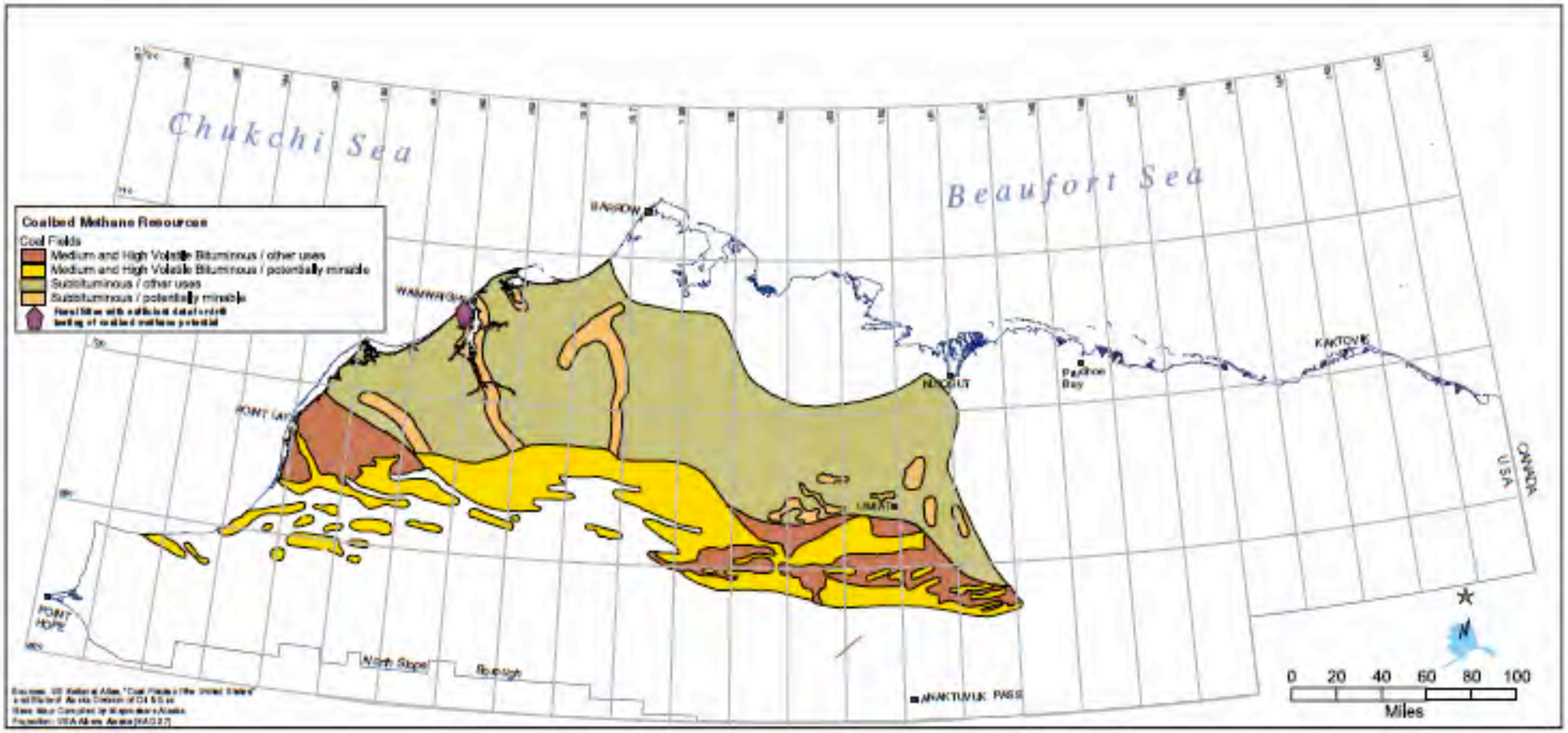


FIGURE 5-2 Coal and coalbed methane resources on the North Slope. Funded by the National Academies. Drawing by Mapmakers Alaska, 2002.

Schematic of oil field operations

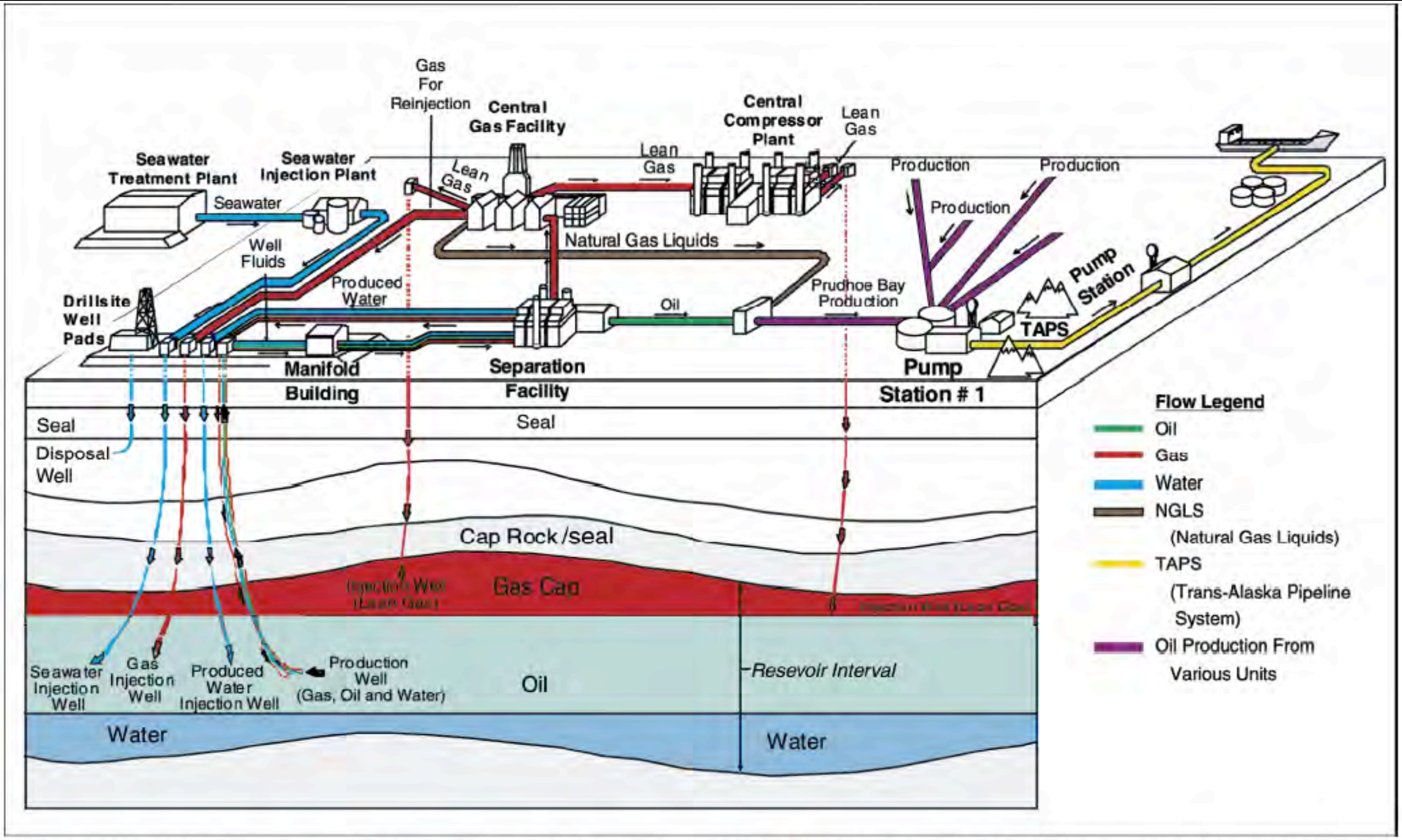
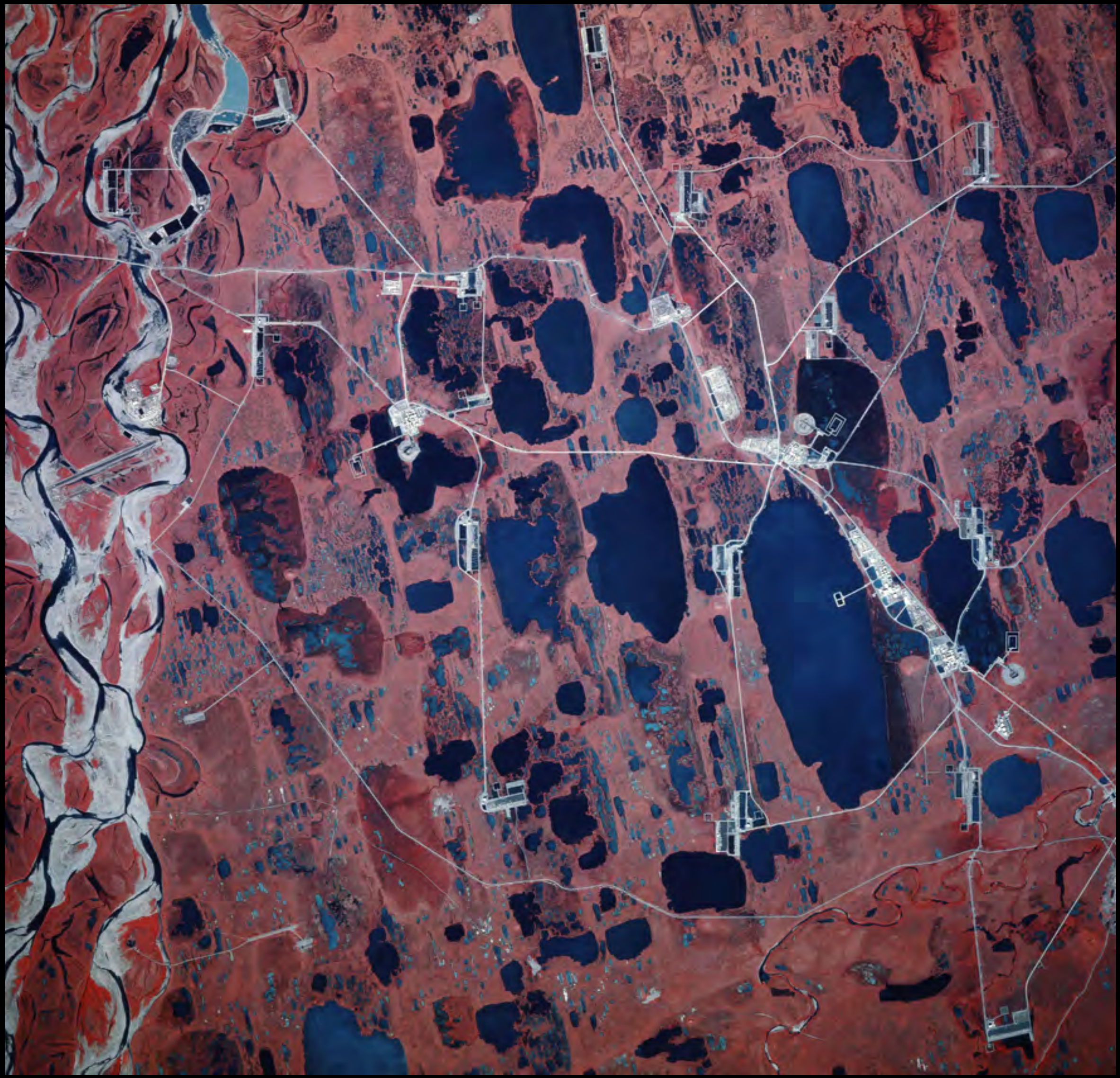


FIGURE 4-7 Schematic diagram of North Slope oil-field operations. SOURCE: Modified from Alaska Department of Natural Resources, Division of Oil and Gas, unpublished material, 1996.

Complex of roads, pipelines, production facilities, contractor service centers, but no permanent population

Total area affected is about 2,600 km^2 (about the size of Rhode Island or Luxumborg).

Complete aerial image history of development



NASA CIR aerial photo.

- The area presents a unique opportunity to examine the conversion from a remote wilderness in 1968 to an sprawling industrial complex in 2011.
- The entire history is contained in aerial photographs and remote sensing images spanning the period 1949 to the present.

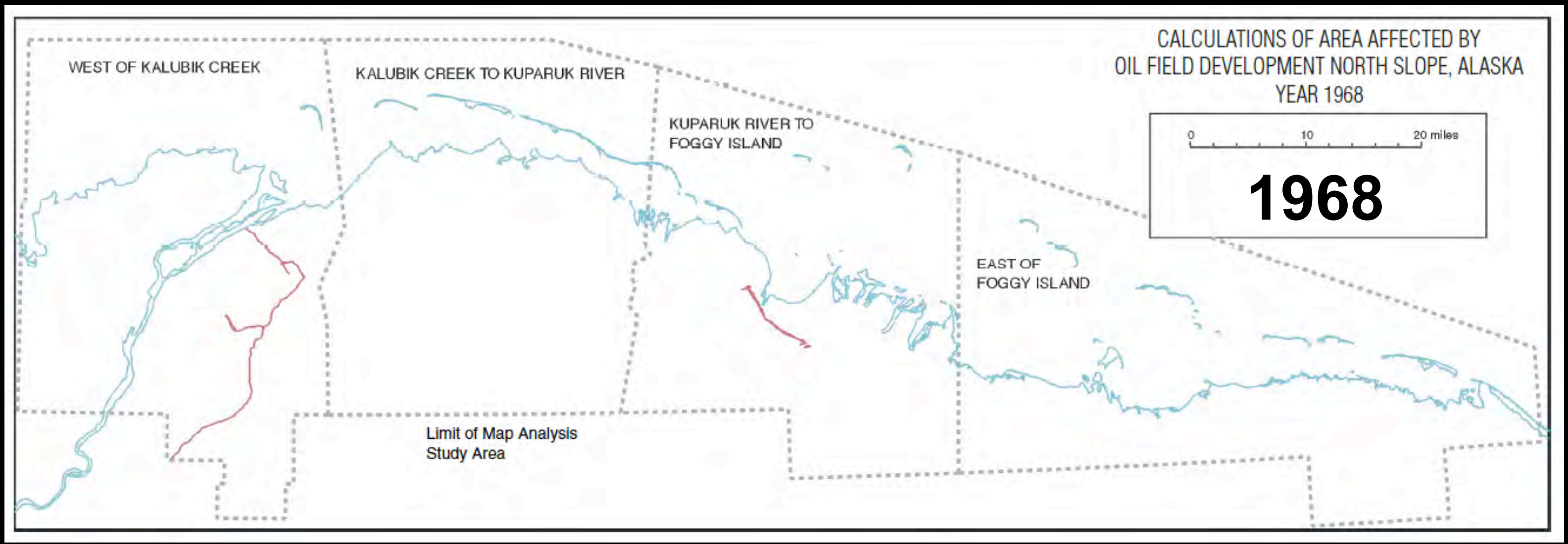
Aeromap Inc. GIS study: documenting changes in infrastructure area, length of roads and number of facilities

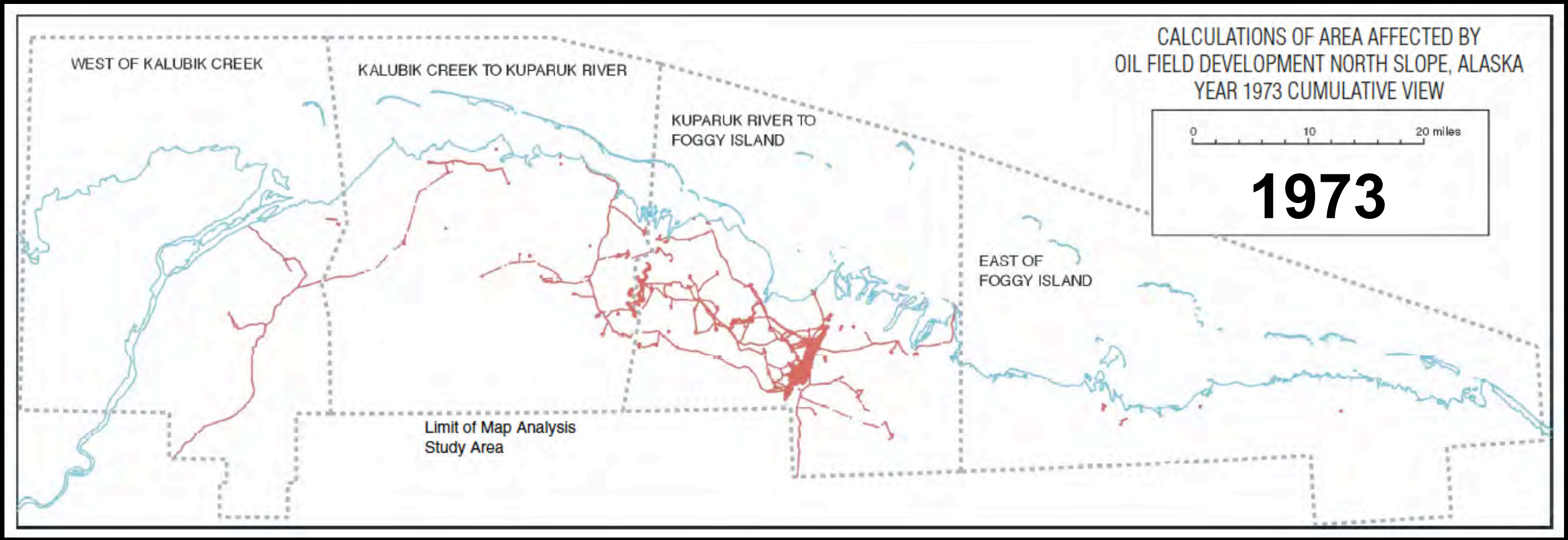
TABLE 4-4 Infrastructure Area (Acres) (Not Including Dalton Highway)

	1968	1973	1977	1983	1988	1994	2001
Gravel roads and causeways							
Roads	—	677	1,002	2,029	2,448	2,536	2,745
Causeways	—	0	48	82	235	229	227
Total gravel road and causeway area	—	677	1,050	2,110	2,683	2,765	2,971
Airstrips (gravel or paved)	6	136	252	287	313	313	287
Offshore gravel pads, islands							
Exploration islands	0	0	5	54	57	57	53
Production islands	0	0	0	0	76	92	101
Total offshore gravel pad, island area	0	0	5	54	133	149	155
Gravel pads							
Production pads, drill sites	0	276	647	2,199	2,917	3,019	3,126
Processing facility pads	0	74	390	692	874	890	917
Support pads (camps, power stations)	14	441	769	1,340	1,444	1,470	1,463
Exploration site	0	109	175	339	317	314	305
Total gravel pad area	14	901	1,981	4,570	5,552	5,692	5,817
Total gravel footprint	20	1,713	3,288	7,022	8,681	8,919	9,225
Other affected areas							
Exploration site-disturbed area around gravel pad	55	346	467	613	627	650	645
Exploration airstrip-thin gravel, tundra scar	0	68	68	68	68	68	67
Peat roads	143	547	546	546	520	517	517
Tractor trail, tundra scar	110	250	272	263	258	258	258
Exploration roads-thin gravel, tundra scar	0	177	179	177	178	178	177
Gravel pad removed, site in process of recovery	0	1	21	27	46	81	100
Gravel pad removed, site is recovered	—	—	—	—	—	—	95
Total other affected area	308	1,388	1,552	1,694	1,698	1,753	1,765
Gravel mines							
In rivers	25	4,732	4,996	5,011	5,063	5,061	5,082
In tundra	0	34	151	745	1,179	1,186	1,283
Total gravel mine area (acres)	25	4,766	5,146	5,756	6,241	6,246	6,364
Total impacted area (acres)	353	7,868	9,987	14,472	16,620	16,918	17,354

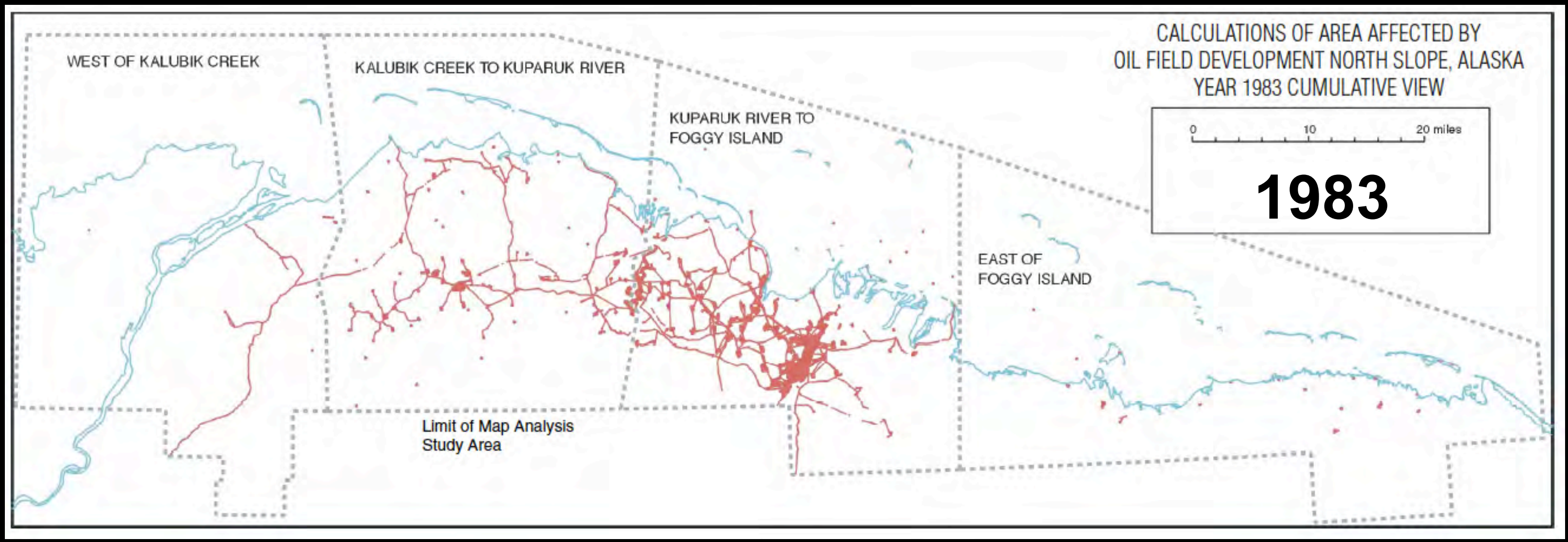
NRC 2003

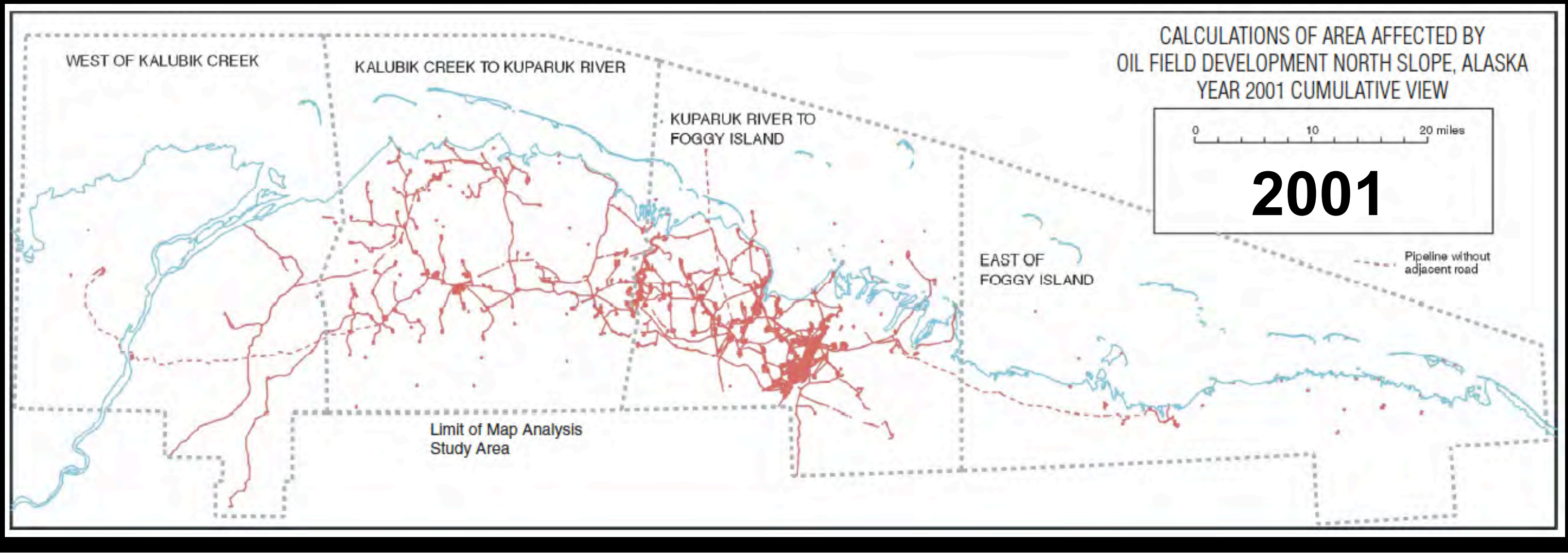
Growth of Prudhoe Bay infrastructure (1968-2001)





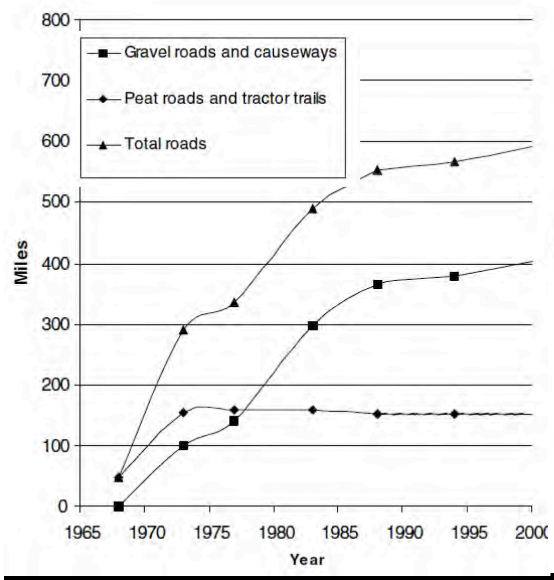
Growth of Prudhoe Bay infrastructure (1968-2001)



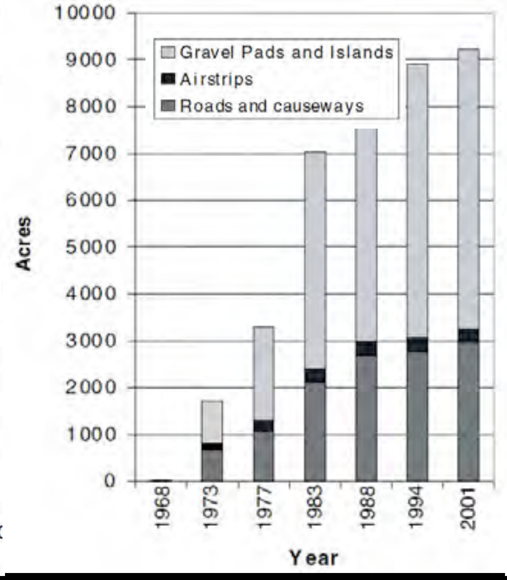


Growth of Prudhoe Bay infrastructure, 1968-2001

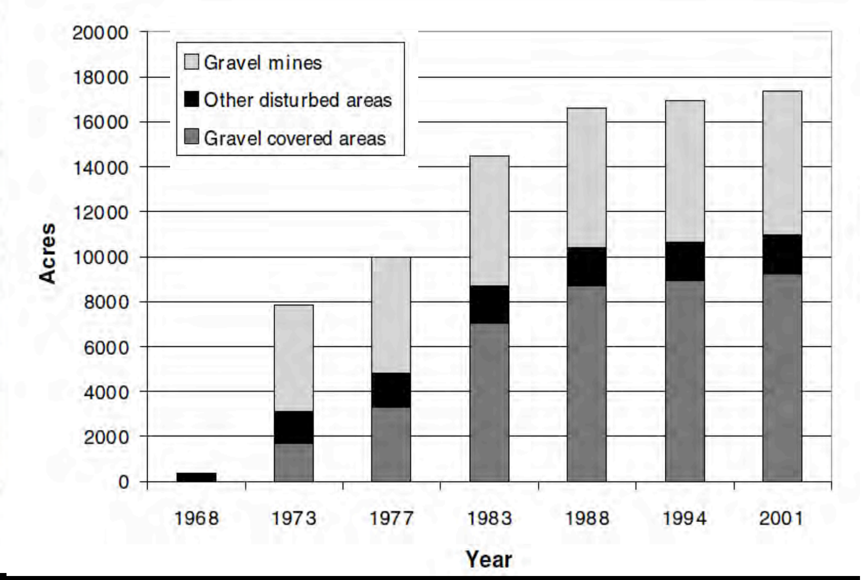
Length of Roads



Areas of gravel placement



Area of direct disturbances*



* Observable at 1:24,000 scale

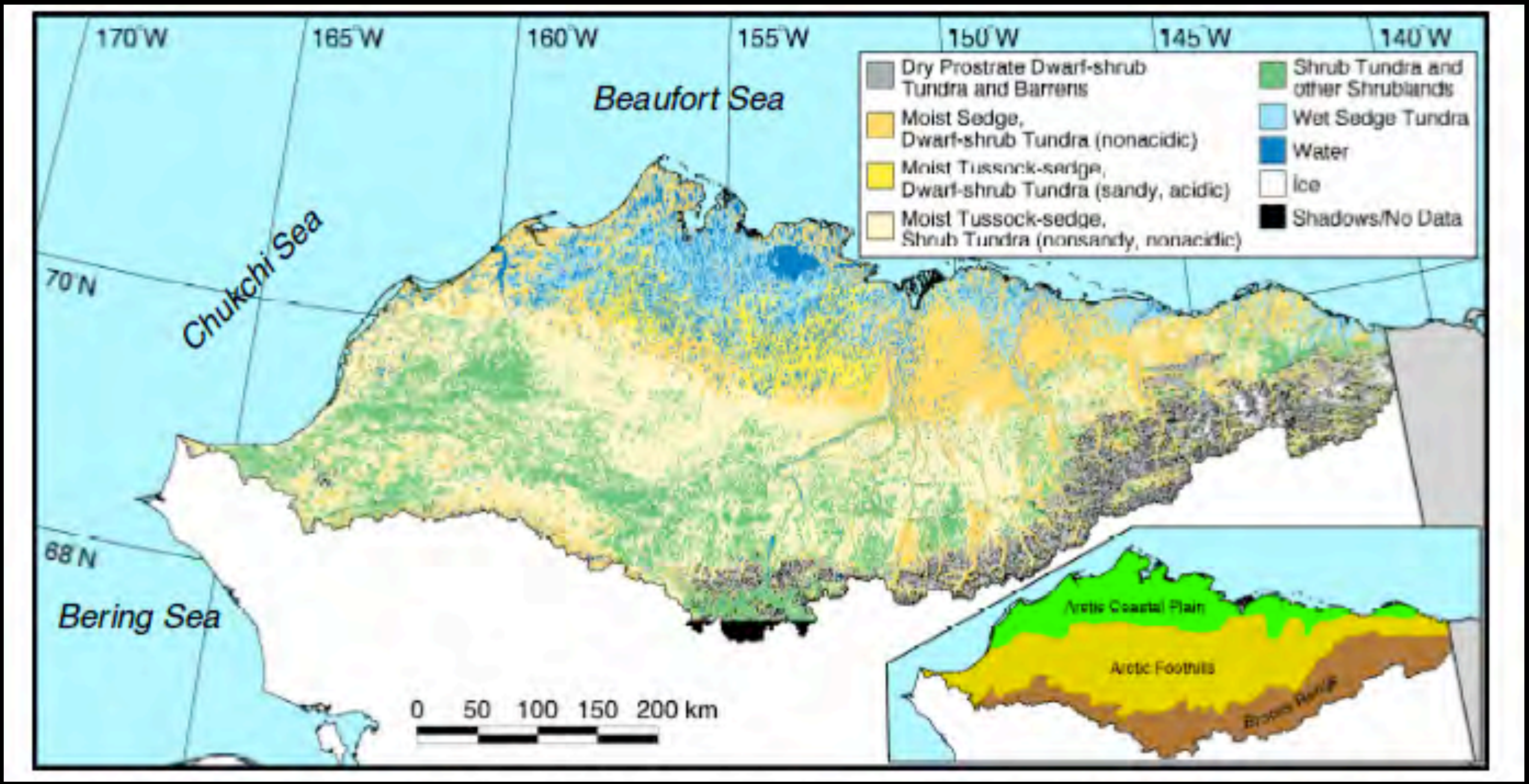
Direct impacts (infrastructure) of North Slope oil development in 2001

Gravel roads (km)	400
Pipelines (km)	450
Powerlines (km)	219
Production pads (count)	115
Airstrips (count)	4
Culverts (count)	1395
Bridges (count)	17

Gravel area (km^2)	37.5
Gravel mines	25.7
Off-shore gravel	0.6
Other impacted areas	7.1

Total directly impacted area: 70.2 km^2

Documenting changes to natural ecosystems



Ten largest oil spills on North Slope

TABLE F-4 Ten Largest Crude Oil Spills on the North Slope, 1977–2000

Number	Date	Volume (bbl)	Description
1	28 Jul 89	925	Oil reserve tank overflowed into reserve pit. Alarm system failed.
2	26 Sep 93	650	Pump failure caused tank overflow. Inlet valve was closed and outlet valve opened, allowing oil to spill into a containment dike. High winds carried some oil mist to snow outside containment dike.
3	30 Dec 93	375	Wind-induced vibration caused a flowline to crack. Crude oil sprayed from crack. High winds carried some oil away from the pad.
4	10 Jun 93	300	High-level alarm failed on drum.
5	24 Dec 93	180	Level monitor, high-level alarm, and automatic shutoff devices froze on a tank, allowing oil to flow out of the overflow line. Crude oil flowed into the lined area surrounding the tank.
6	8 Nov 89	180	Break in temporary flowline caused by internal erosion. Crude oil was released onto gravel pad.
7	10 Dec 90	176	Explosion and fire caused by fluid leaking from a vacuum truck. Oil was released onto pad.
8	15 Nov 85	175	Faulty valve allowed crude oil to be released into a holding pit.
9	5 Nov 84	125	Bleeder valve was stuck in open position. Oil?
10	25 Mar 87	120	Information pending.

SOURCE: Modified from Maxim and Niebo 2001b.

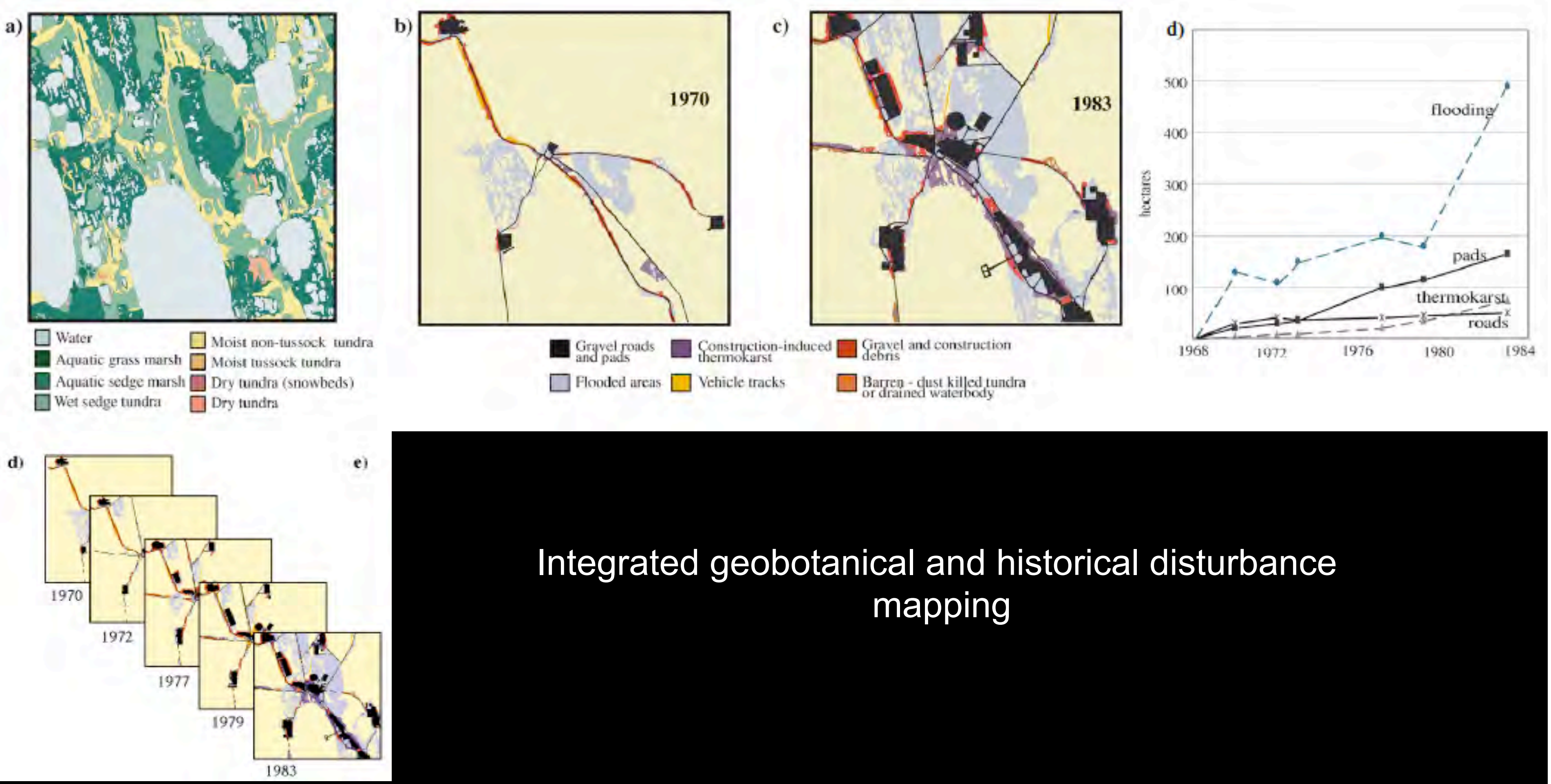
TABLE F-8 Five Largest Crude Oil or Mixed Crude Oil/ Water Spills That Affected Tundra Vegetation on the North Slope, 1977–1999

Year	Oil Field	Containment Area (m)	Tundra Affected (m)
1989	Kuparuk	5,800	1,700
1994	Kuparuk	930	465
1972	Prudhoe	560	220
1993	Kuparuk	400	200
1985	Prudhoe	350	125

SOURCE: McKendrick 2000b.

Public perception is that this is a big problem, but study documented relatively few spills, none covering large areas.

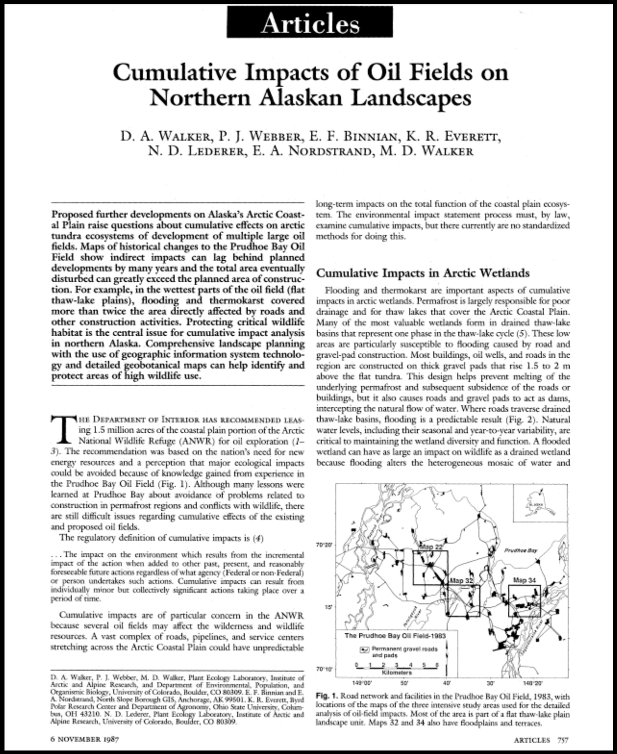
Indirect landscape impacts
(i.e., those that were not planned)



Integrated geobotanical and historical disturbance mapping

Key papers describing the approach and results of the cumulative impacts analysis at Prudhoe Bay

Use of Geobotanical Maps and Automated Mapping Techniques to Examine Cumulative Impacts in the Prudhoe Bay Oilfield, Alaska



Articles

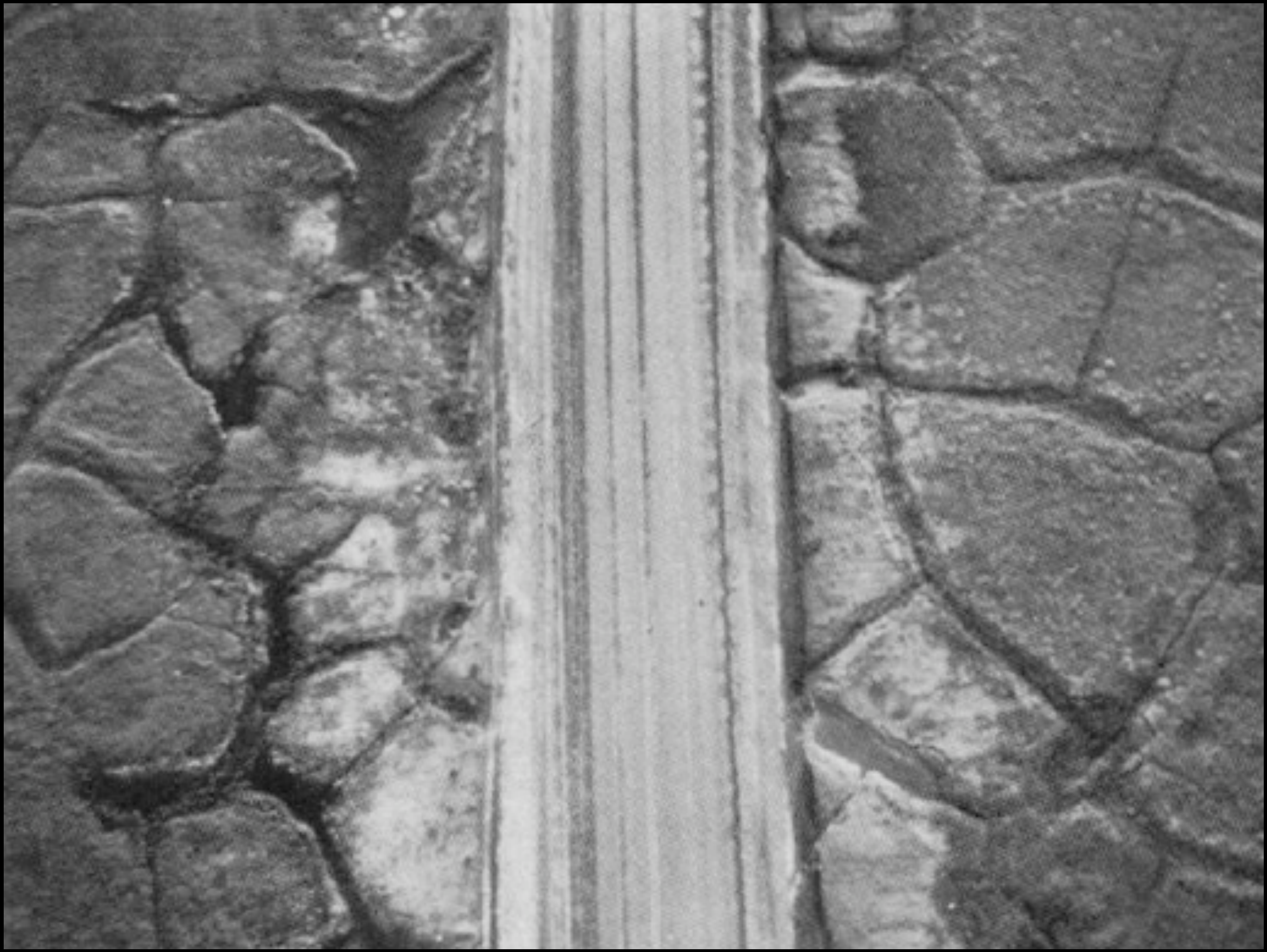
Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes

D. A. Walker, P. J. Webber, E. F. Binnian, K. R. Everett, N. D. Lederer, E. A. Nordstrand, M. D. Walker

Walker, D.A., Webber, P.J., Walker, M.D., Lederer, N.D., Meehan, R.H., and Nordstrand, E.A., 1986, Use of geobotanical maps and automated mapping techniques to examine cumulative impacts in the Prudhoe Bay Oilfield, Alaska: Environmental Conservation, v. 13, p. 149-160.

Walker, D.A., Webber, P.J., Binnian, E.F., Everett, K.R., Lederer, N.D., Nordstrand, E.A., and Walker, M.D., 1987, Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes: Science, v. 238, p. 757-761.

Road-related impacts

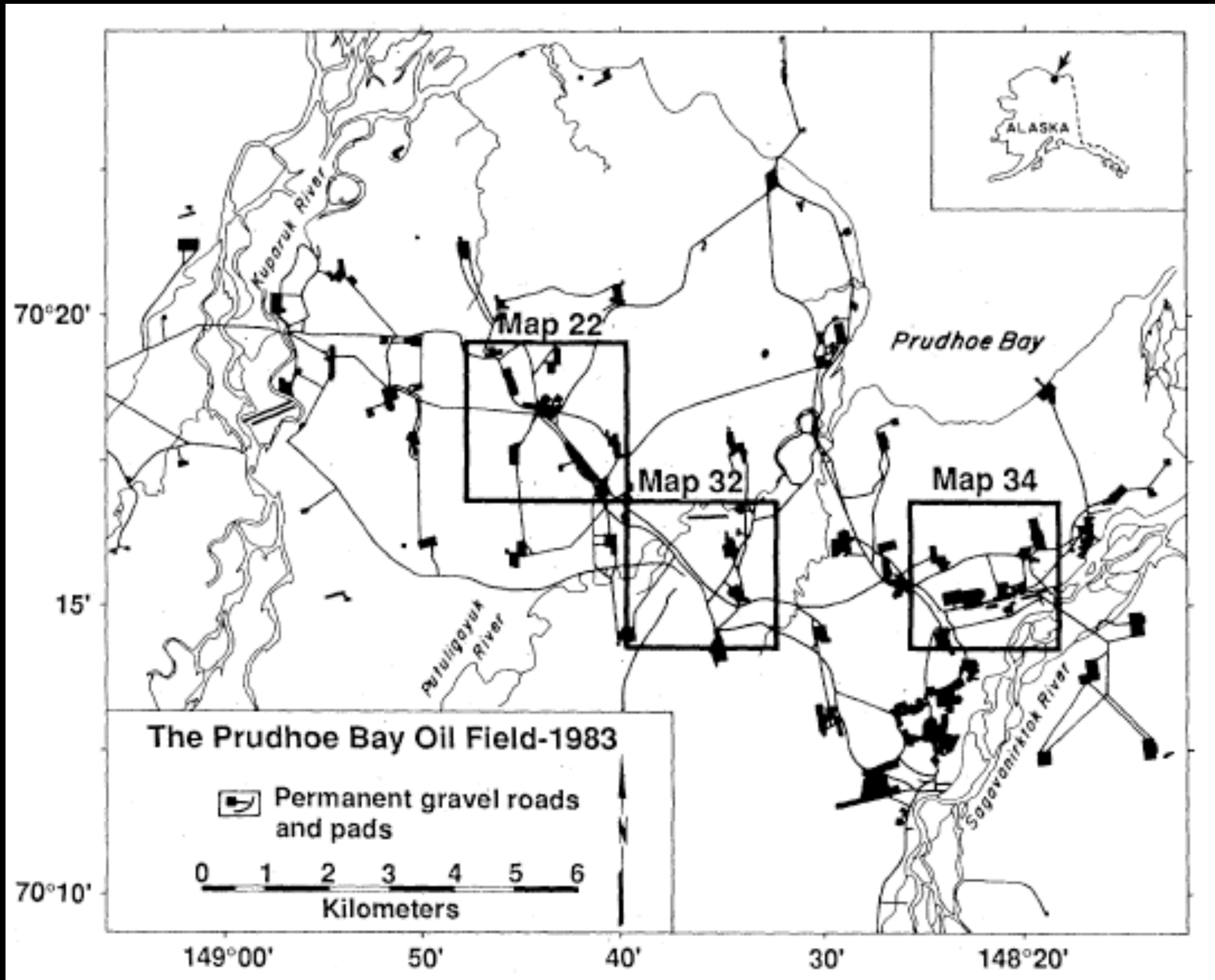


- Thermokarst
- Gravel spray from road.
- Road dust.

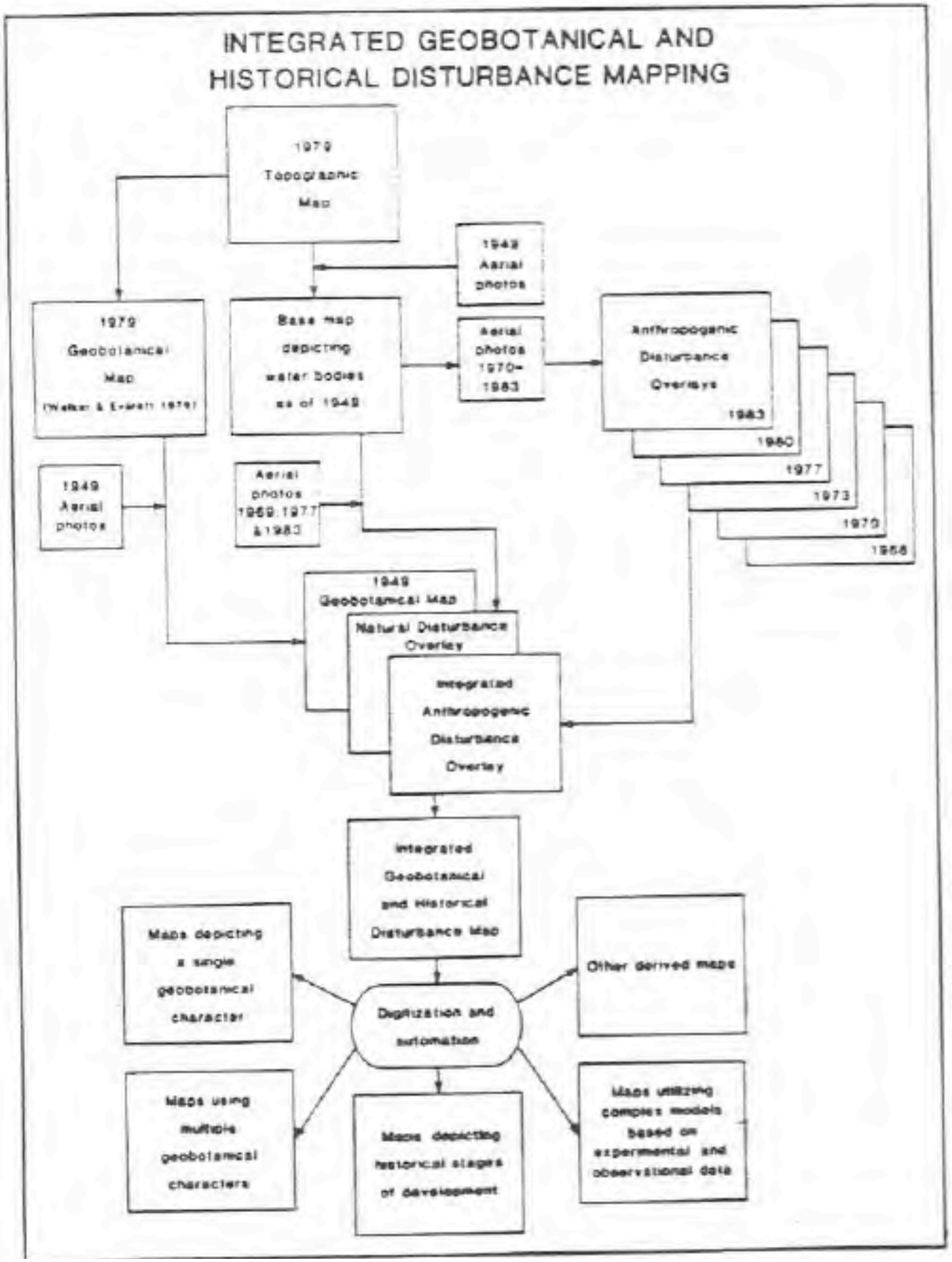
Road-related impacts

- Roadside flooding, mainly in drained thaw-lake basins related to lack of culvert problems.

Areas of detailed mapping at Prudhoe Bay



Flow chart of IGHDM methods



Geobotanical codes

TABLE II

Geobotanical Codes Used in the Prudhoe Bay Region, Alaska.
(Codes are modified from Walker *et al.* [1980, 1983].)

Code	Description
VEGETATION	
1	Water
2	Aquatic grass tundra
3	Aquatic sedge tundra
5	Wet sedge tundra
6	Wet graminoid tundra (saline areas)
9	Moist sedge, dwarf-shrub tundra
10	Moist tussock-sedge, dwarf-shrub tundra
13	Moist or dry dwarf-shrub, fructicose-lichen tundra (snow beds)
16	Moist shrubland (riparian areas)
19	Dry dwarf-shrub, crustose-lichen tundra
21	Dry dwarf-shrub, forb, grass tundra
22	Dry low-shrub, forb, grass tundra
24	Dry forb tundra
26	Dry grassland (dunes)
PERCENTAGE OPEN WATER	
1	0–5%
2	6–30%
3	31–60%
4	61–90%
5	91–100%
LANDFORM	
1	Distinct drained thaw-lake basin, or developing basins in residual surfaces of the coastal plain
2	Basin associated with hilly terrain often with thermokarst features
3	Residual surface (gently rolling thaw-lake plains)
4	Inter-thaw-lake area (gently rolling and flat thaw-lake plains; may include some very old, indistinct thaw-lake basins)
11	Pingo
12	Active braided floodplain
13	Stabilized braided floodplain
14	Meander floodplain
15	Stream drainage
16	Sand dunes
17	Beach
18	Spit
25	Island
51	Lake or pond
52	River or stream
53	Ocean
54	Artificial impoundment

Code	Description
SURFACE FORM	
1	High-centred polygons*, centre-trough relief greater than 0.5 m
2	High-centred polygons*, centre-trough relief less than 0.5 m
3	Low-centred polygons*, centre-rim relief greater than 0.5 m
4	Low-centred polygons, centre-rim relief less than 0.5 m
5	Mixed high- and low-centred polygons*
6	Frost scars
7	Strangmoor** and/or discontinuous low-centred polygon rims (generally well-defined features visible on 1:6,000-scale photographs)
8	Hummocky terrain associated with steep slopes
9	Pingo, with undefined or varied surface forms
10	Non-patterned ground or with pattern occupying less than 20% (includes some areas with aligned hummocks that are not visible on photographs)
11	Reticulate pattern
12	Active sand-dune
13	Active floodplain alluvium
14	Thermokarst pits (density greater than 4 pits per 1 cm circle on 1:6,000-scale photograph)
21	Water
SOIL**	
1	Pergelic Cryoborolls
2	Pergelic Cryaquolls or Cryosaprists
3	Complex of: *a)* Pergelic Cryohemists or Cryofibrists**; *b)* Histic Pergelic Cryaquepts; *c)* Pergelic Cryaquepts
4	Association of: *a)* Pergelic Cryohemists or Cryofibrists or Histic Pergelic Cryaquepts; *b)* Pergelic Cryosaprists or Cryaquolls
5	Association of: *a)* Pergelic Cryaquolls or Cryosaprists; *b)* Pergelic Cryaquepts
6	Pergelic Cryorthents
7	Pergelic Cryopsamments
8	Pergelic Cryaquepts
9	Soil covered by a thin layer of wind-blown sand
10	No soil

* Ice-wedge polygons have two basic forms: high-centred and low-centred polygons. High-centred forms consist of an elevated 'centre', usually about 5–10 m wide surrounded by a 'trough' which delineates the locations of the ice wedges and separates one polygon from the adjacent ones. Low-centered forms consist of a central 'basin' surrounded by an elevated 'rim' and a 'trough'.

** United States Soil Survey nomenclature (7th approximation, Soil Survey Staff, 1975).

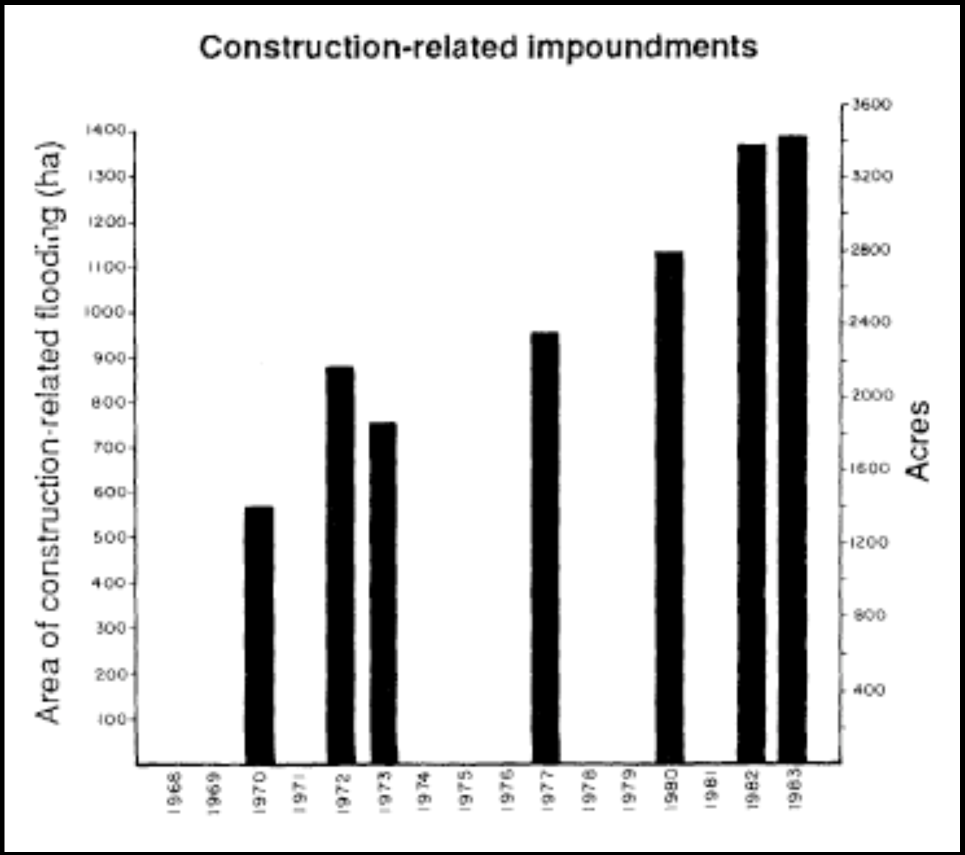
Disturbance codes

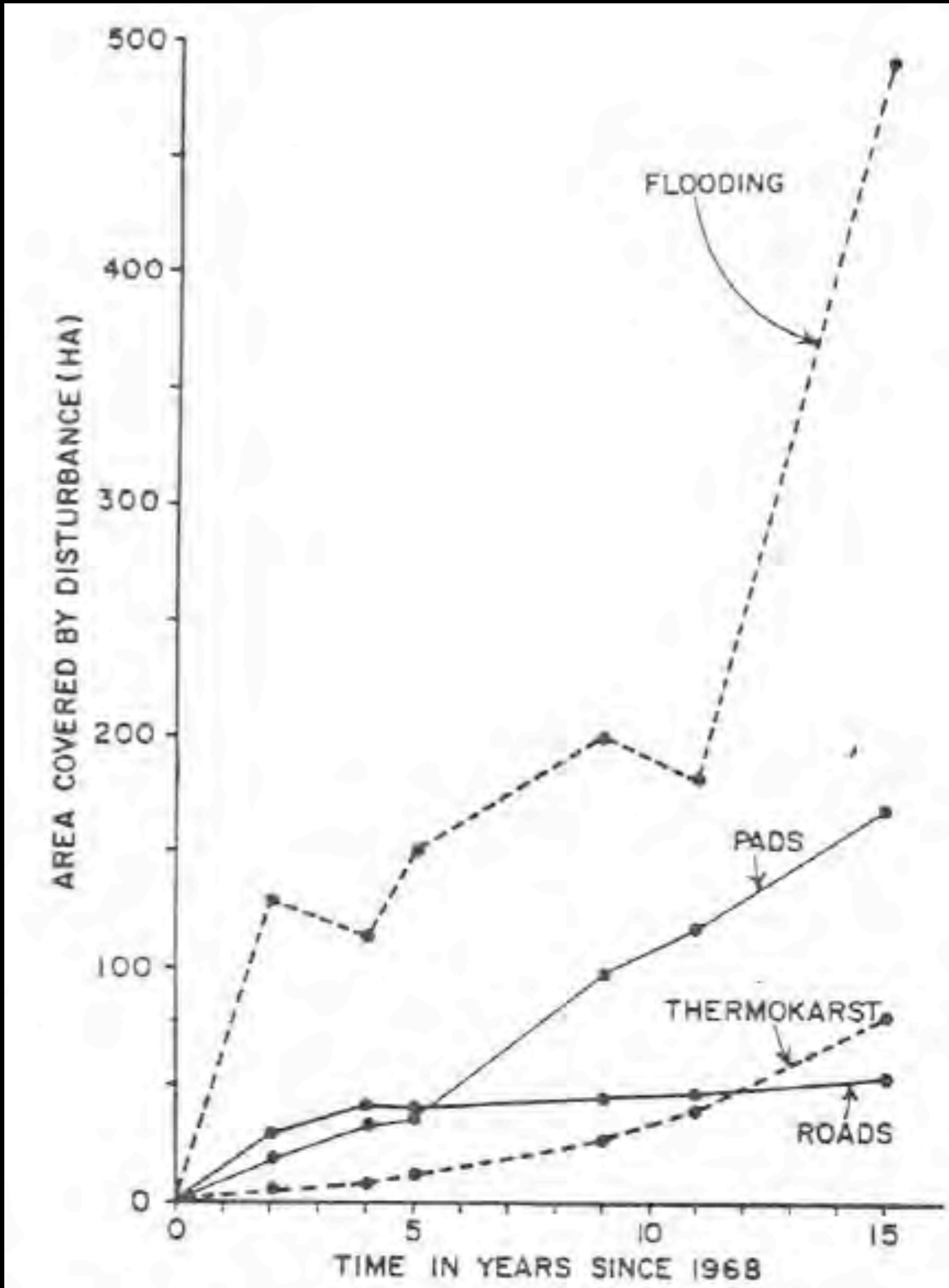
TABLE III

Disturbance Codes for the Anthropogenic Disturbance Overlay

Code	Disturbance Type
1	Gravel roads and pipeline construction roads
2	Peat roads
3	Gravel pads
4	Continuous flooding, more than 75% open water
5	Discontinuous flooding, less than 75% open water
6	Construction-induced thermokarst
7	Vehicle tracks—deeply rutted and or with thermokarst
8	Vehicle tracks—not deeply rutted
9	Winter road
10	Gravel and construction debris (more than 75% cover)
11	Gravel and construction debris (less than 75% cover)
12	Heavy dust or dust-killed tundra
13	Excavations of river gravels or other gravel sources, road-cuts or construction excavations
14	Barren tundra caused by oil-spills, burns, blading, etc.
15	Barren tundra caused by previous flooding

Historical changes to impoundment

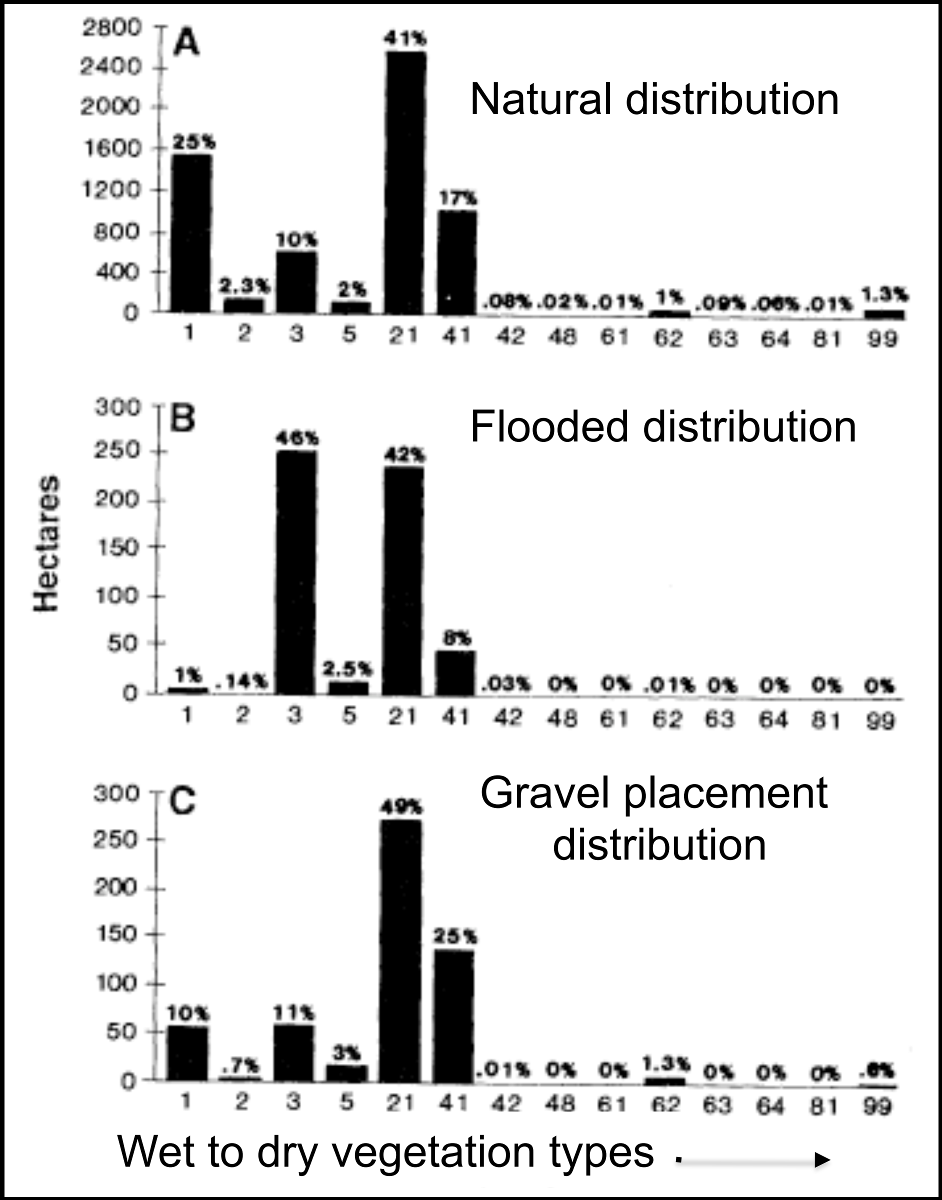




Comparison of direct and indirect impacts within Map 22

Solid lines: Direct impacts
Dashed lines: Indirect impacts.

Hectares of impacted tundra in each vegetation type compared to natural vegetation distribution



- Flooding focuses in aquatic sedge marsh (Type 3), often eliminating microhabitats used by shorebirds and waterfowl for nest sites.
- Gravel placement selects for moist sedge, dwarf-shrub, moss tundra (Type 41), a preferred habitat for for some species of shorebirds and relatively uncommon.

Quickbird image of Prudhoe Bay development.

New tool for assessing cumulative effects: High-resolution satellite imagery

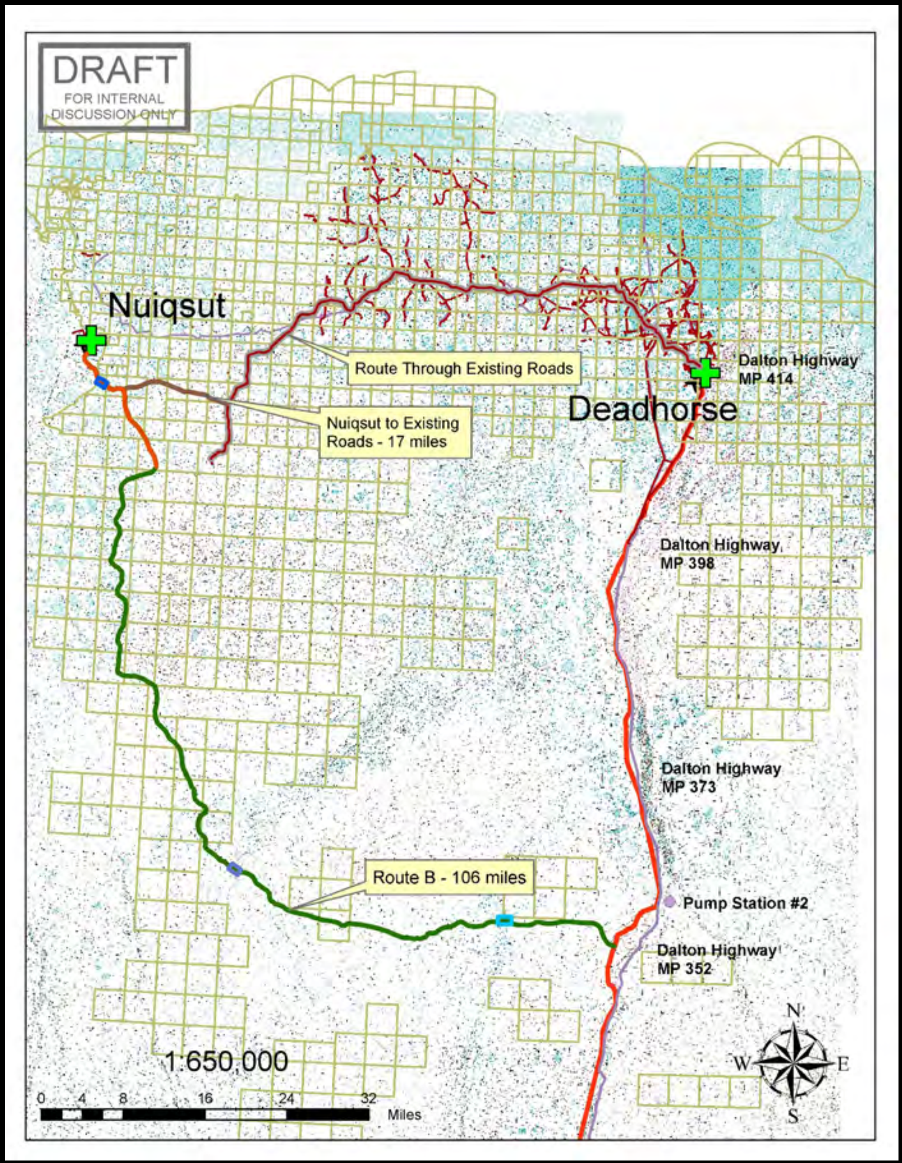
Thermokarst in Nuiqsut village.

New planned road to access Nuiqsut and NPR-A / Foothills Oil & Gas

The State of Alaska is working with the oil industry and NSB to define a staged construction road project that would accelerate:

- Oil and gas exploration and production in NPR-A
- Open exploration on foothills leases now largely inaccessible.
- A new NPR-A staging area near Nuiqsut

– The project would also provide Nuiqsut access to Dalton Highway for fuel and freight transport.



Winter seismic operations

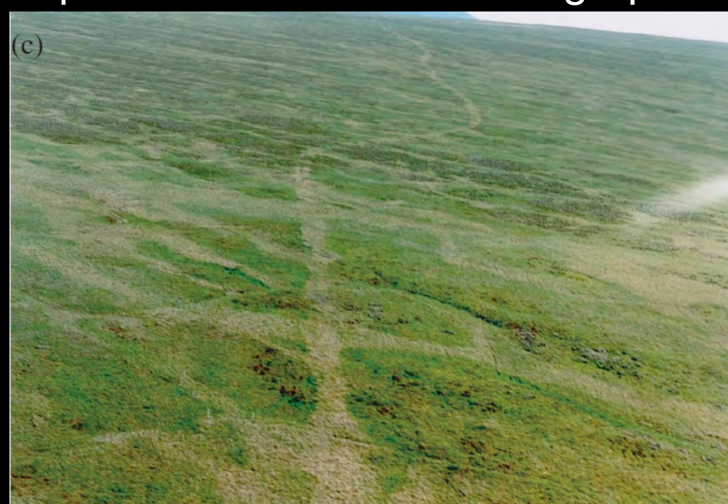
- Methods of seismic exploration changed dramatically in the 1990s when 2-dimensional seismic (linear lines of data) was replaced by 3-D seismic (volumetric pictures of the stratigraphy).
- 3-D seismic requires much denser networks of seismic lines spaced a few hundred meters apart.

Courtesy of Janet Jorgenson

Aerial views of seismic trails

2-D Seismic trails winter 2001: Photographed summer 2001.

Camp move trails 1985: Photographed 1995.



15% of trails made in 1984 were still visible in 1995.

Courtesy of Janet Jorgenson

Ground views of seismic disturbance categories

0 – None

No effect to slight scuffing of higher microsites.

Trail goes through photo from foreground to background, passing between the two wooden stakes in the distance. Note slight color difference in tussocks on trail (light brown color rather than gray), due to scuffing of tops of tussocks.

1 – Low

Less than 25% decrease in vegetation or shrub cover; less than 5% soil exposed. Comparison of standing litter and slight scuffing in wet graminoid and moist sedge-shrub tundra. Tussocks or hummocks scuffed. Trail evident only with tracks on *Dryas* terrace sites.

All of the foreground and much of the background of this photo show tussocks disturbed by dispersed vehicle traffic. Note the flattened, brown-topped tussocks compared to the tussocks with level 0 disturbance pictured above.

2 – Moderate

Vegetation or shrub cover decrease 25-50%, exposed soil 5-15%. Compression of mosses and standing litter in wet graminoid and moist sedge-shrub tundra; may have increase in aquatic sedges. Tussocks or hummocks crushed but show regrowth. Portions of trail may appear wetter than surrounding area. Some disruption of vegetative mat within tracks of riparian shrublands and *Dryas* terrace. May be some change in vegetative composition.

Note the two vehicle tracks going from foreground to background. Tussocks in the tracks are crushed.

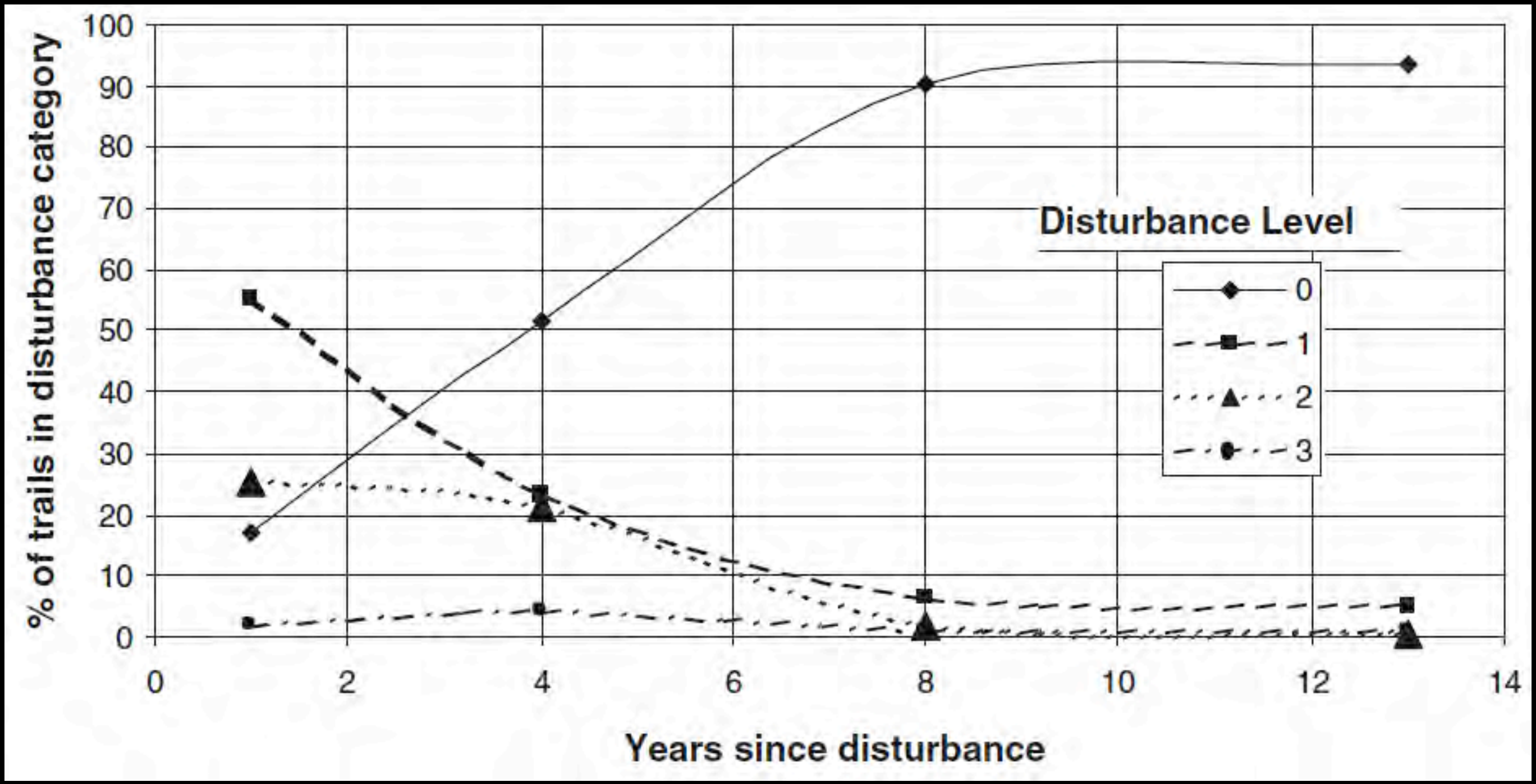
3 – High

Over 50% decrease in vegetation cover or shrub cover; over 15% soil exposed. Obvious track depression in wet graminoid and moist-shrub tundra; standing water is apparent on trail that is not present in adjacent areas in wet years; moist sedge-shrub tundra changing to wet graminoid. Crushed tussock or hummocks nearly continuous; general depression of the trail is evident; change in vegetation composition. In riparian shrub and *Dryas* terrace vegetative mat and ground cover substantially disrupted.

Note the exposed soil and crushed tussocks on the trail.

Courtesy of Janet Jorgenson

Percent of trails in disturbance categories vs. years since disturbance



SOURCES: Data from Felix et al. 1992; Emers et al. 1995; FWS, unpublished, 2002.

Hypothetical cumulative line miles of seismic trails in the 4 disturbance levels 1990-2001

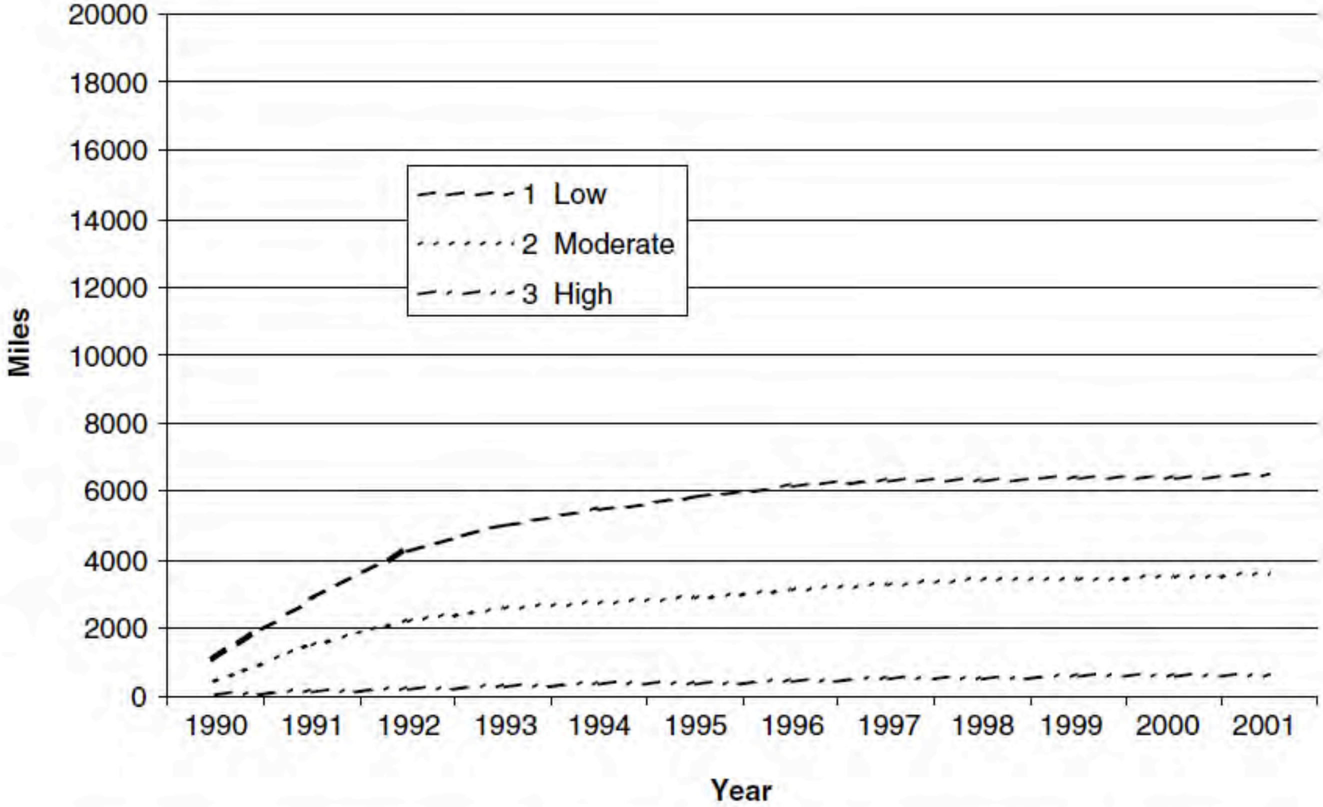


FIGURE 7-9 Hypothetical cumulative line miles of trails during 12 years and totals in the four disturbance levels based on the following: (1) Total seismic line miles equivalent to that during 1990–2001. (2) The ratios of line miles in each disturbance category is the same as that resulting from the 1984–1985 seismic surveys in the Arctic National Wildlife Refuge (Emers et al. 1995). (3) The recovery rate in each disturbance category is the same as that in the Arctic National Wildlife Refuge studies. SOURCE: Alaska Geobotany Center, University of Alaska Fairbanks, 2002.

Opening and closing dates for seismic operations, North Slope

FIGURE 7-8 Opening and closing dates of North Slope off-road traffic. SOURCE: ADNR

Regulations require the tundra to be sufficiently froze to support heavy seismic equipment and to be sufficiently snow covered to avoid damage.

Season for seimic exploration has become progressively shorter.

Possibly due to a combination of changing climate and/or changes in monitoring methods.

Documenting effects on wildlife

Post-calving caribou, Arctic Coastal Plain. Photo: Ken Whitten

North Slope caribou herds

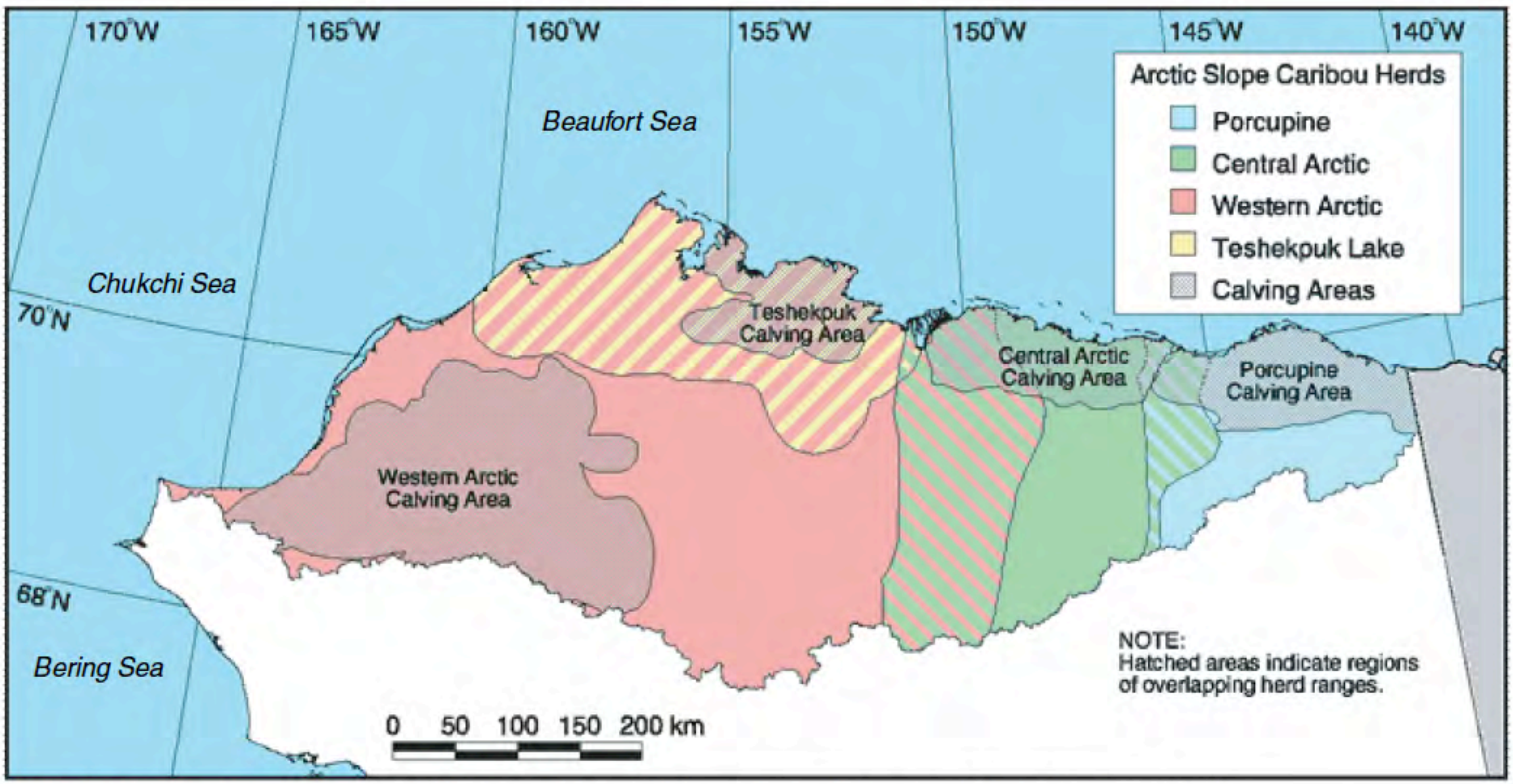


FIGURE 8-2 Arctic caribou herds. SOURCE: Alaska Geobotany Center, University of Alaska Fairbanks, 2002.

Relative post-calving herd sizes PCH, WAH, CAH and TLH (1976-2001)

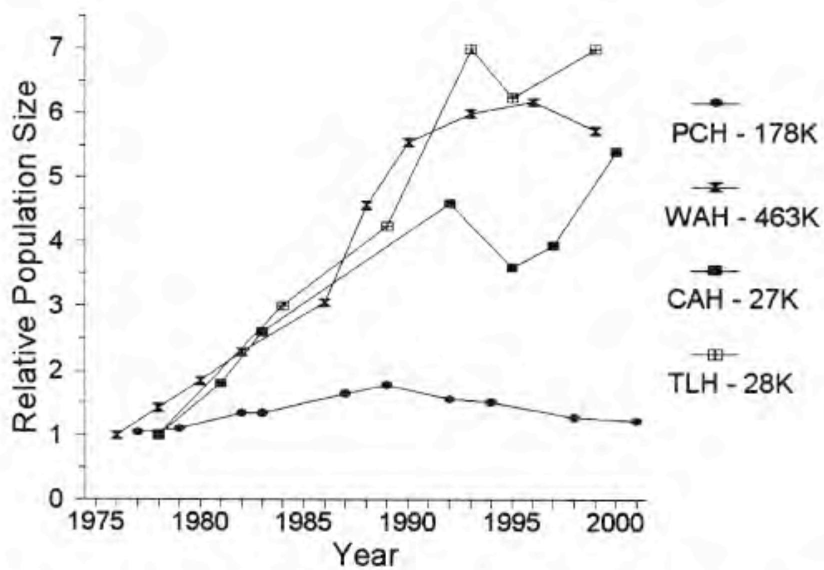


FIGURE 8-3 Relative post-calving herd sizes (minimum observed =1.0) of the four Alaska barren-ground caribou herds (PCH, Porcupine Caribou Herd; WAH, Western Arctic Herd; CAH, Central Arctic Herd; TLH, Teshekpuk Lake Herd), 1976–2001. Maximum observed population size for each herd is noted in the legend. SOURCE: Griffith et al. 2002.

- Most North Slope caribou herds (except for the Porcupine herd) grew during the period of Prudhoe Bay development.

Roads and pipelines in the Prudhoe Bay region

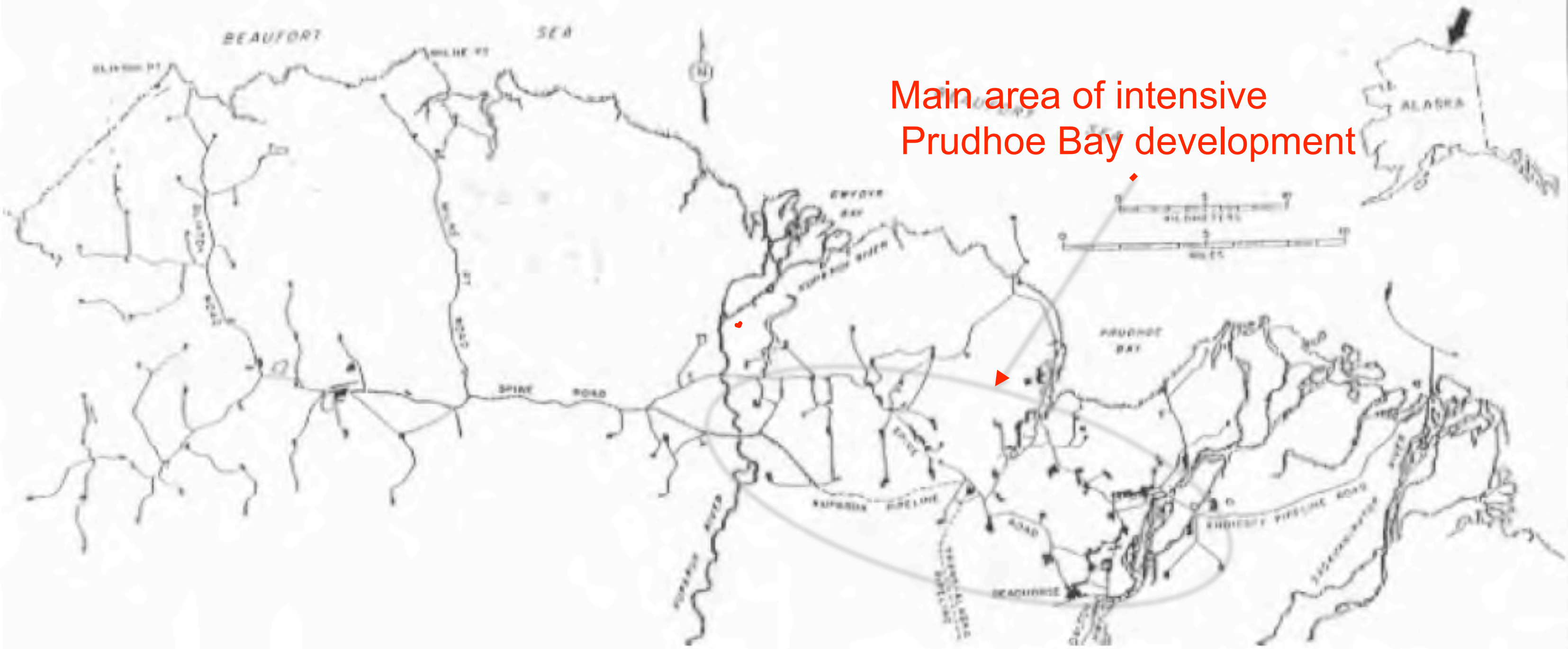


FIGURE 8-4 Roads and pipelines in the Prudhoe Bay region, Alaska, circa 1990. Note: One or more pipelines (stippled) are adjacent to most roads. SOURCE: Cameron et al. 1995. Reprinted with permission, copyright 1995, Rangifer.

Locations of radio collared caribou during the study

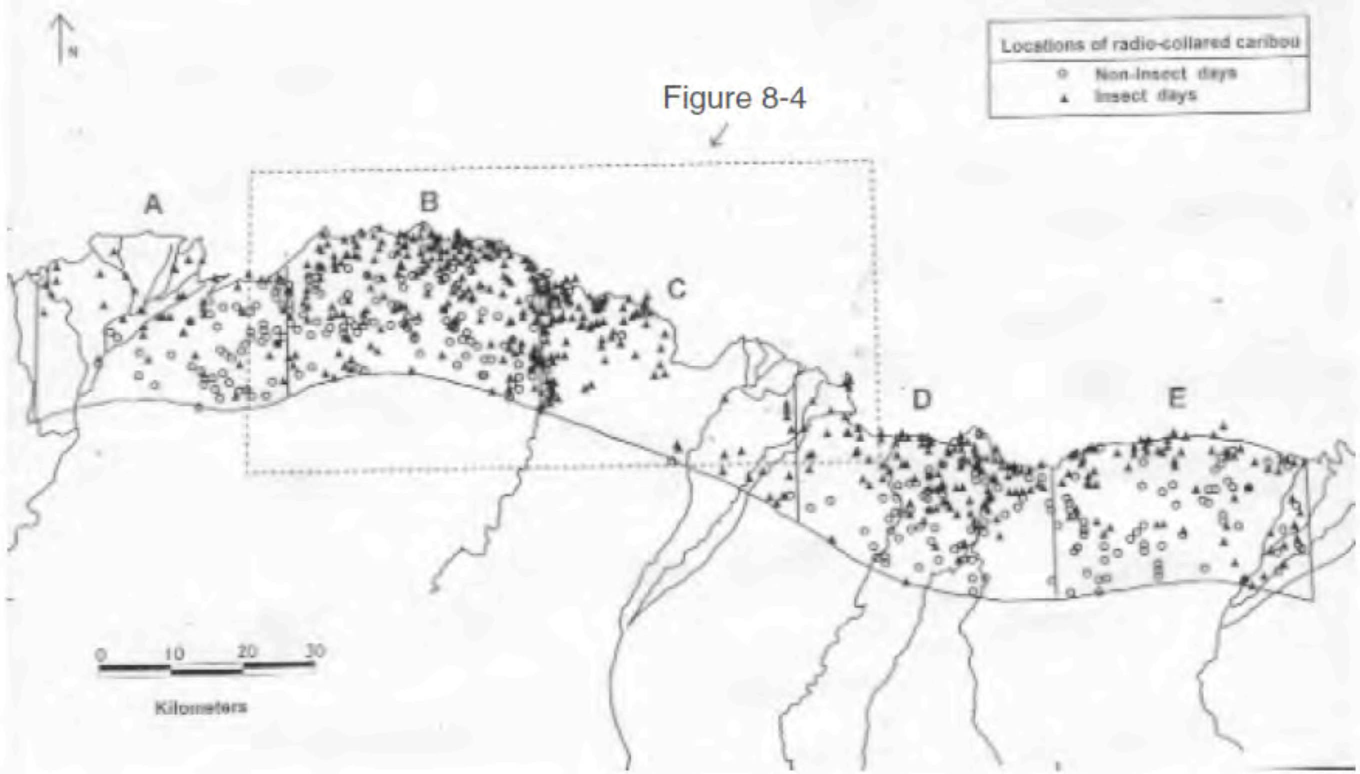


FIGURE 8-5 Locations of radio-collared female caribou within 850-km² coastal quadrants in relation to insect activity. Central Arctic Herd, Alaska, summer 1980–1993. Note: Some points represent >1 female in a single group. SOURCE: Cameron et al. 1995. Reprinted with permission, copyright 1995, Rangifer.

Collar data show few caribou utilizing the Prudhoe Bay area after 1980.

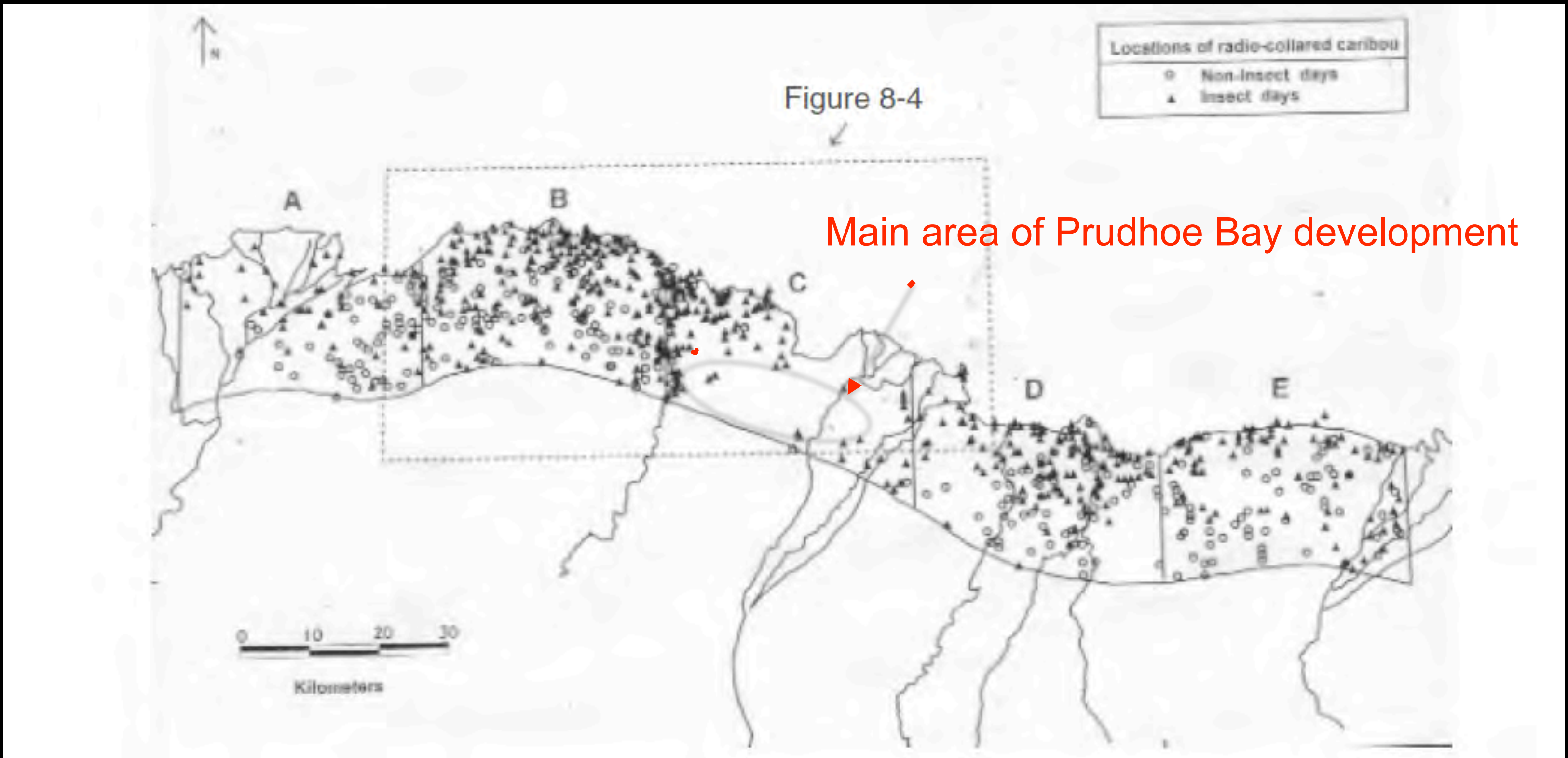


FIGURE 8-5 Locations of radio-collared female caribou within 850-km² coastal quadrants in relation to insect activity. Central Arctic Herd, Alaska, summer 1980–1993. Note: Some points represent >1 female in a single group. SOURCE: Cameron et al. 1995. Reprinted with permission, copyright 1995, Rangifer.

- By 1978, caribou use of the main Prudhoe Bay area had declined by 78% and lateral movements had declined by 90%.

Birthing rates of CAH caribou related to insect activity

- East area is outside the oilfield.
- West area is within the oil field.
- Effect of the oilfield on parturition rates is greatest in years of high insect activity. oil-field development, by delaying or deflecting.

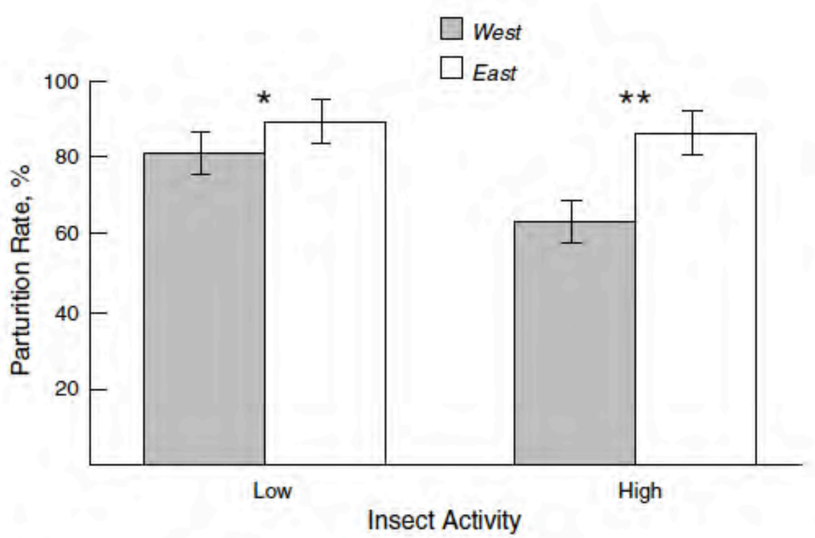


FIGURE 8-7 Parturition rates of 72 radio-collared female caribou of the Central Arctic Herd in Alaska west and east of the Sagavanirktok River, 1988–2001, following years of low and high insect activity, determined, respectively, as the number of insect days below and above the median of 20.5 days (range, 15–27) for 1987–2000 (see Figure 8-6 legend). *$P = 0.043$, paired t-test. **$P = 0.004$, paired t-test. SOURCES: Data from ADF&G files, Lenart 2001.

Major conclusions from the caribou portion of the NRC report

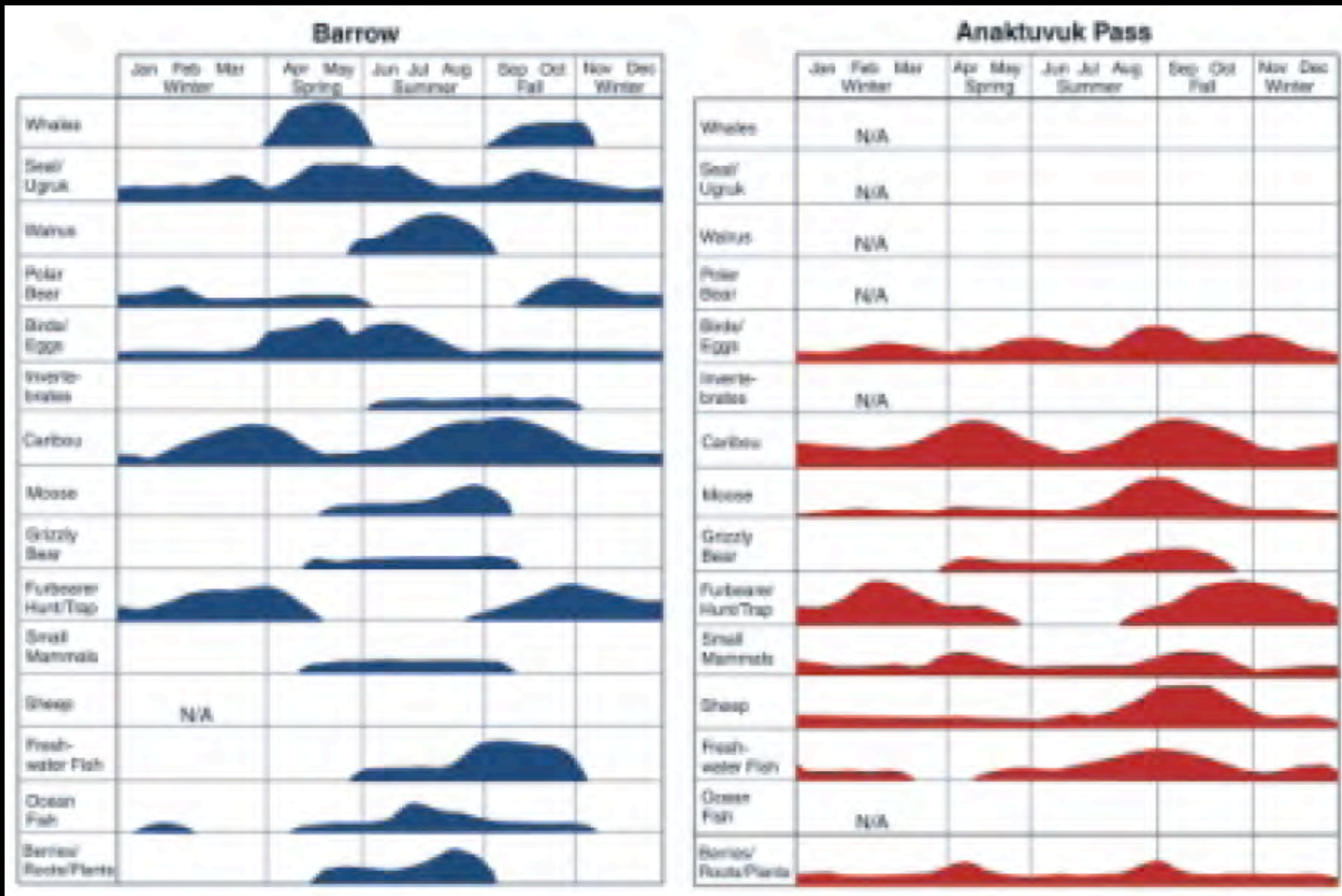
- Current technology will probably continue to evolve, as discussed elsewhere in this report, but adverse effects on caribou are likely to increase with both the density of infrastructure development and the area over which it is spread.
- Radio-collared female caribou west of the Sagavanirktok River shifted their calving concentration area from developed areas nearer the coast to undeveloped areas inland. No such shift has occurred for caribou calving east of the Sagavanirktok River where there is no development.
- Unless future requirements for infrastructure can be greatly reduced, exploitation of oil and gas reserves within the calving and summer ranges of the CAH, TLH, and PCH will likely have similar consequences.

Documenting social effects of oil development:

Shift in lifestyles from exclusively subsistence hunting to providing services and government

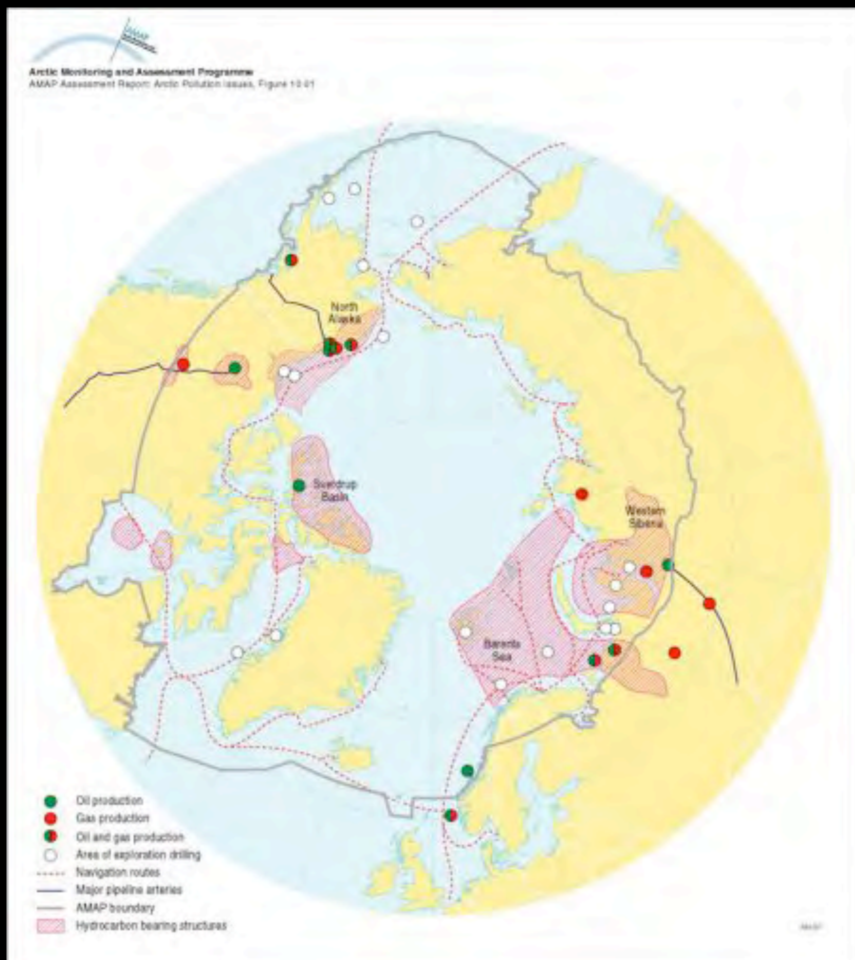
Photos (from left): David Policansky, Ken Stenek, Larry Moulton.

Seasonal subsistence cycle at Barrow and Anaktuvuk Pass

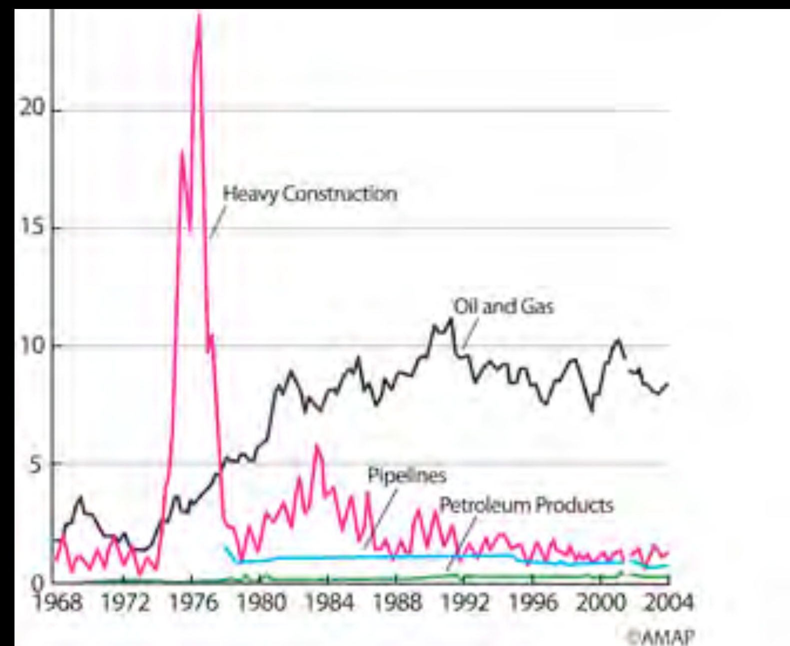


Effects of development on employment

Major oil and gas resources in the Arctic



Employments in thousands



Effects of oil on North Slope Borough, Alaska per capita income

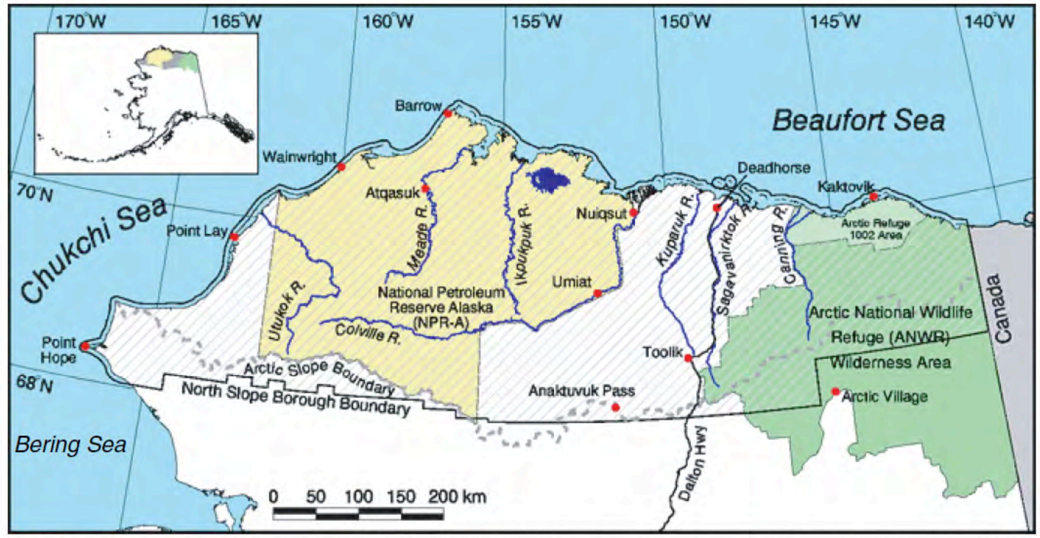


FIGURE 1-1 The Alaska North Slope region. The dashed line is the southern boundary of the drainage basin. The Trans-Alaska Pipeline is close to the Dalton Highway. SOURCE: Data from Alaska Geobotany Center, University of Alaska Fairbanks, 2002.

TABLE 2-2 Per Capita Income for 1999 Compared

Area or Place	Income
Anaktuvuk Pass	$15,283
Atqasuk	$14,732
Barrow	$22,902
Kaktovik	$22,031
Nuiqsut	$14,876
Point Hope	$16,641
Point Lay	$18,003
Wainwright	$16,710
North Slope Total	$20,540
Alaska	$22,660
United States	$21,587

SOURCE: Data from U.S. Bureau of the Census 2000.

Per capita income 1999:
NSB (average): $20,540.

Arctic Village (outside NSB): $10,761.

Growth of North Slope population (1939-1998)

TABLE 2-1 North Slope Population

	Anaktuvuk Pass[a]	Atqasuk[b]	Barrow	Kaktovik	Nuiqsut[b]	Point Hope	Point Lay	Wainwright	Total
1939		78	363	13	89	257	117	341	1,258
1950	66	49	951	46		264	75	227	1,678
1973	134		2,167	144	128	376	31	353	3,333
1980	203	107	2,267	165	208	464	68	405	3,887
1988	264	219	3,335	227	314	591	132	514	5,596
1990	259	216	3,469	224	354	639	139	492	5,792
1993	270	237	3,908	230	418	699	192	584	6,538
1998	314	224	4,641	256	420	805	246	649	7,555

[a]Anaktuvuk Pass was settled in the late 1940s.
[b]Atqasuk and Nuiqsut were abandoned, and then resettled in the 1970s, mainly by former residents of Barrow.
SOURCE: NSB 1999.

- North Slope population increased 6x between 1939 and 1998.
- Barrow increased nearly 13x, probably due to Naval Research Lab in the 1950-1973
- It about doubled during the period 1973-1998.

North Slope Borough employment by sector

TABLE 9-5 North Slope Borough Residents' Employment by Sector and Ethnicity,[a] 1998

Employer	Inupiat	White	Other Minority	Total
NSB government	509	217	151	877
NSB school district	134	108	47	289
Village corporation	225	33	17	275
ASRC or subsidiary	90	26	16	132
NSB capital improvement	82	23	7	112
Service	28	36	19	83
Ilisagvik College	21	36	12	69
Private construction	44	14	8	66
City government	43	8	6	57
Transportation	14	17	12	43
Federal government	17	11	11	39
State government	9	19	7	35
Trade	14	9	12	35
Oil industry	10	4	2	16
Communications		4	1	5
Finance and insurance		1		1
Other	171	68	45	284
Total	1,411	634	373	2,418

[a] Includes only the 74% of the borough who responded to a survey (NSB 1999).

Growth in total aggregate personal income, 1970-1999

EFFECTS ON THE HUMAN ENVIRONMENT

TABLE 9-1 Total Aggregate Personal Income for the Alaskan North Slope, 1970–1999

	Year	Total Personal Income (millions $)
Barrow-North Slope Division	1970	12.4
	1975	42.4
North Slope Borough	1980	82.1
	1985	133.6
	1990	145.6
	1995	200.6
	1999	205.8

SOURCE: BEA 2002.

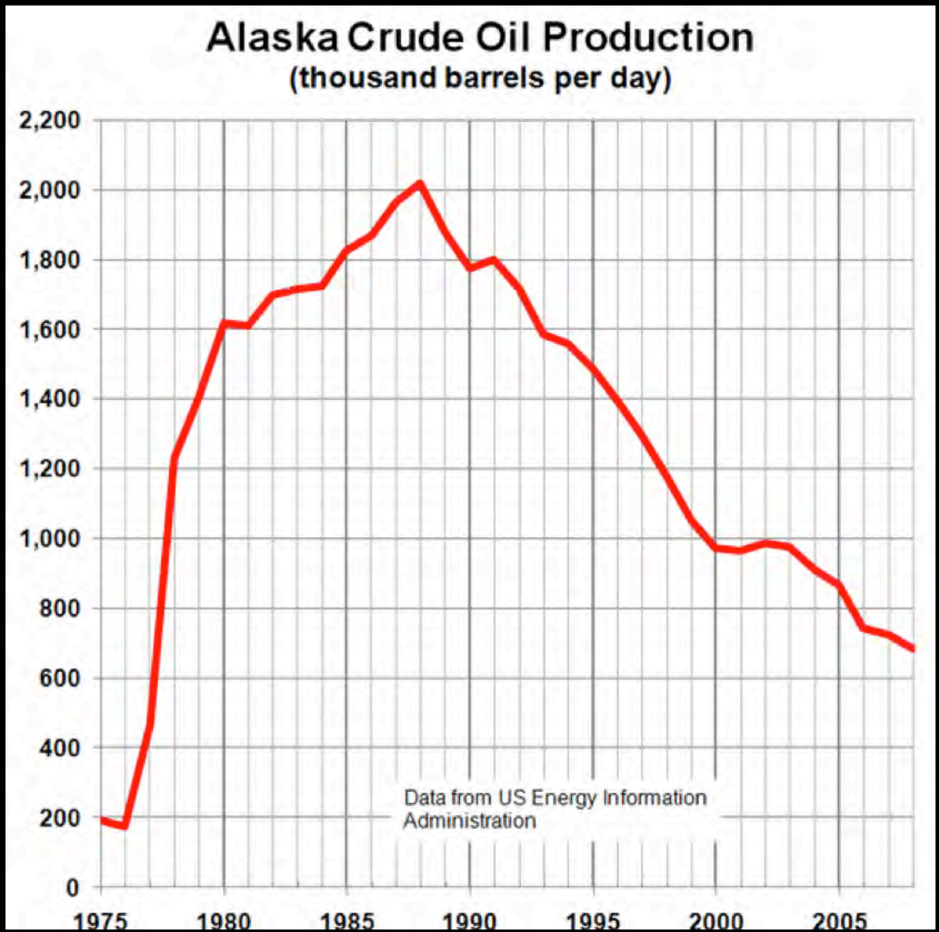
- About a 17x increase in aggregate personal income.

Per capitata income (1999)

Area or Place	Income
Anaktuvuk Pass	$15,283
Atqasuk	$14,732
Barrow	$22,902
Kaktovik	$22,031
Nuiqsut	$14,876
Point Hope	$16,641
Point Lay	$18,003
Wainwright	$16,710
North Slope Total	$20,540
Alaska	$22,660
United States	$21,587

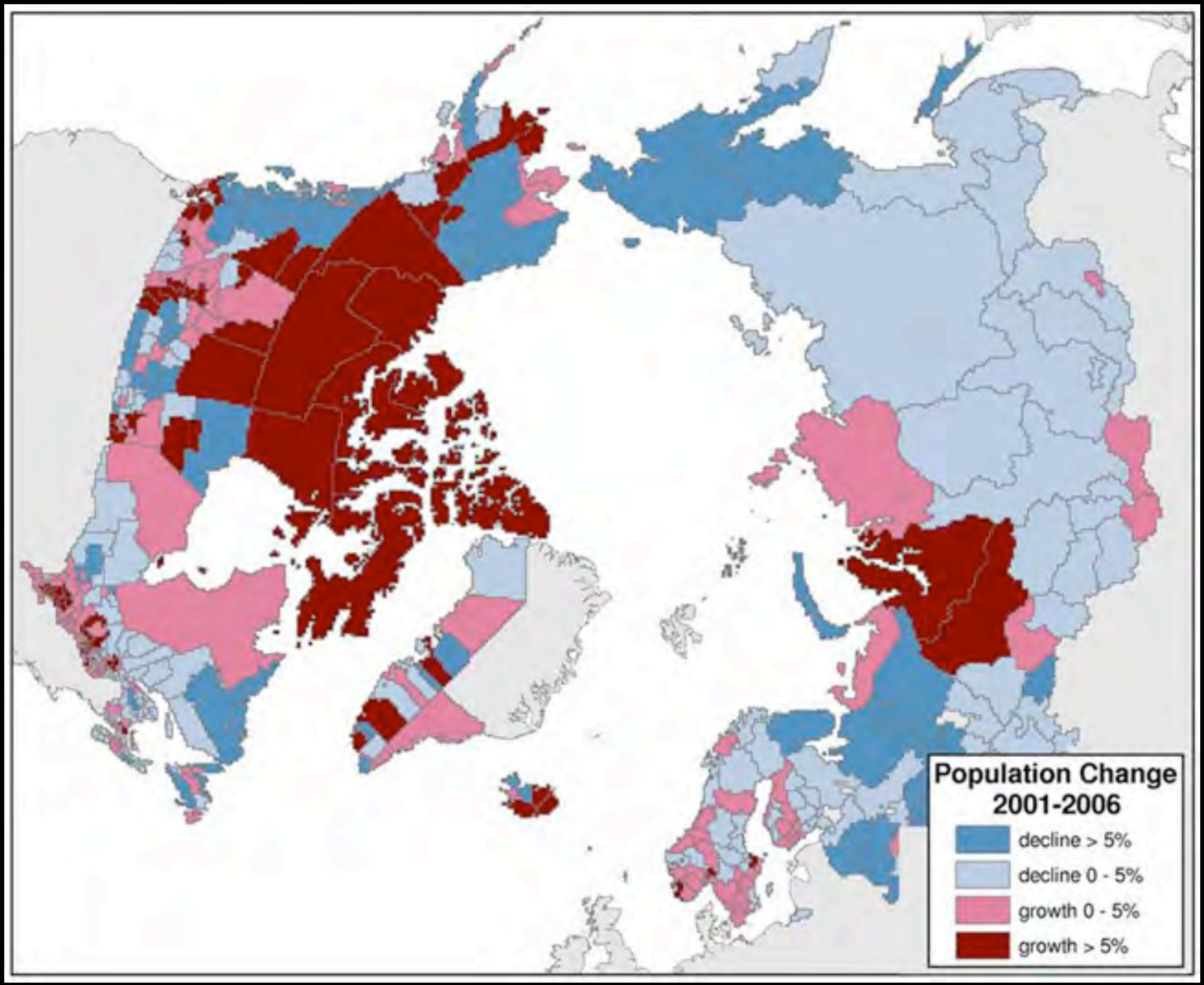
SOURCE: Data from U.S. Bureau of the Census 2000.

Trend in Alaska oil production, 1975-2009



- Peak oil was in 1988.
- Current production is similar to that in the early phases of the Prudhoe Bay field despite greatly expanded infrastructure.

Arctic Demographics



From Hamilton 2009, http://carseyinstitute.unh.edu/alaska-indicators-northern.html

- Boom in the Arctic has shifted from Alaska to Canada and West Siberia, Russia.

Size of Permanent Fund Dividends

- All Alaska residents, including children, receive an annual dividend from the Alaska State government.

TABLE 9-4 Permanent Fund Dividends, 1982–2001

Year	Amount
2001	$1,850.28
2000	$1,963.86
1998	$1,540.88
1996	$1,130.68
1994	$983.90
1992	$915.84
1990	$952.63
1988	$826.93
1986	$556.26
1984	$331.29
1983	$386.15
1982	$1,000.00

SOURCE: Alaska Permanent Fund 2001.

Size of Permanent Fund Dividends

- The size of the dividend is dependent on revenues on state taxes of the oil!

TABLE 9-4 Permanent Fund Dividends, 1982–2001

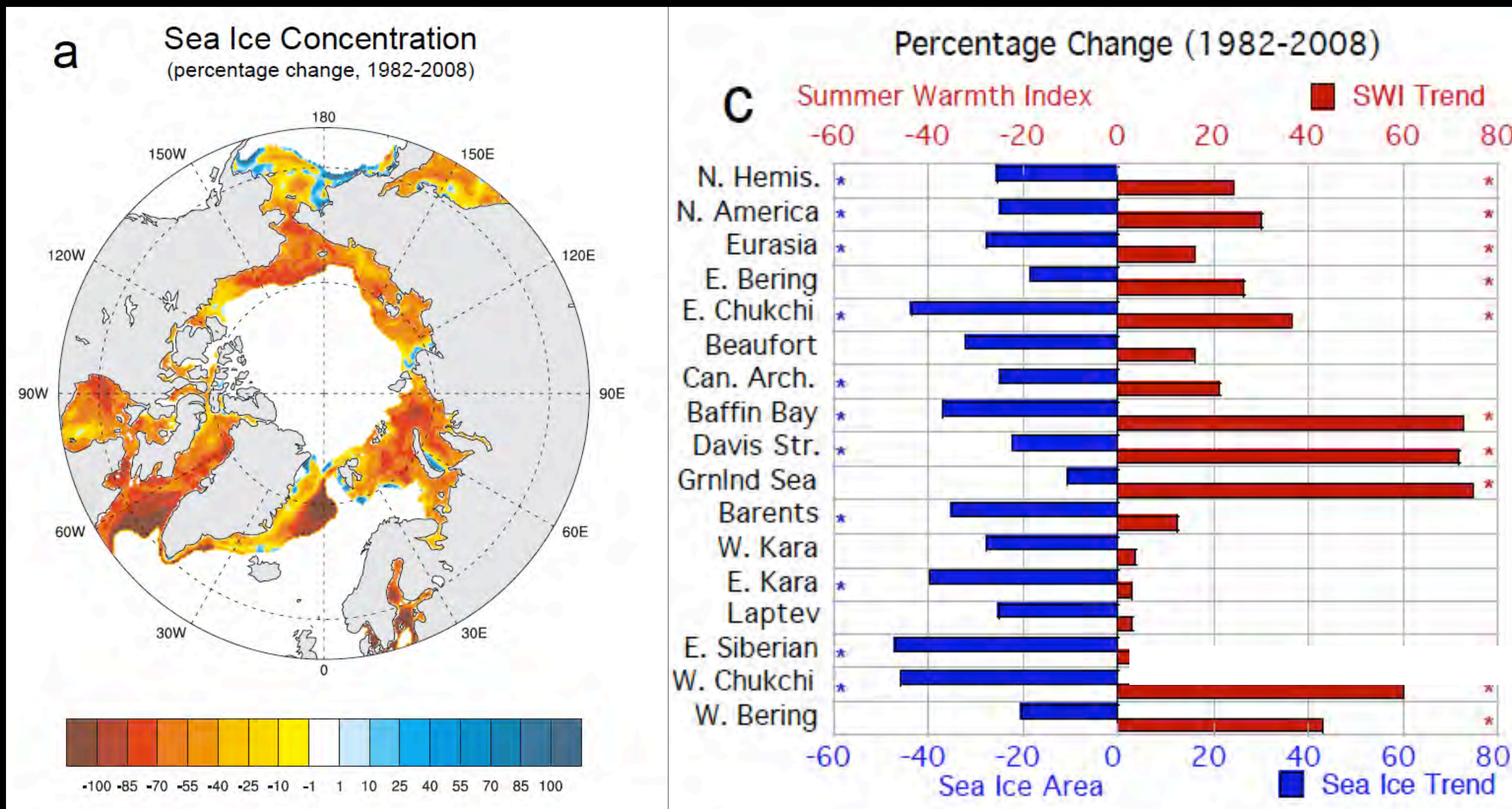
Year	Amount
2001	$1,850.28
2000	$1,963.86
1998	$1,540.88
1996	$1,130.68
1994	$983.90
1992	$915.84
1990	$952.63
1988	$826.93
1986	$556.26
1984	$331.29
1983	$386.15
1982	$1,000.00

SOURCE: Alaska Permanent Fund 2001.

Major conclusions regarding social dimension on the North Slope

- Major changes occurred to North Slope life style and incomes as a result of oil development.
- The current standard of living for North Slope residents will be impossible to maintain unless significant external sources of local revenue are found.

Effects of Climate Change:
Impacts of changes in sea ice: Percentage changes in coastal sea ice and land temperatures (1982-2008)

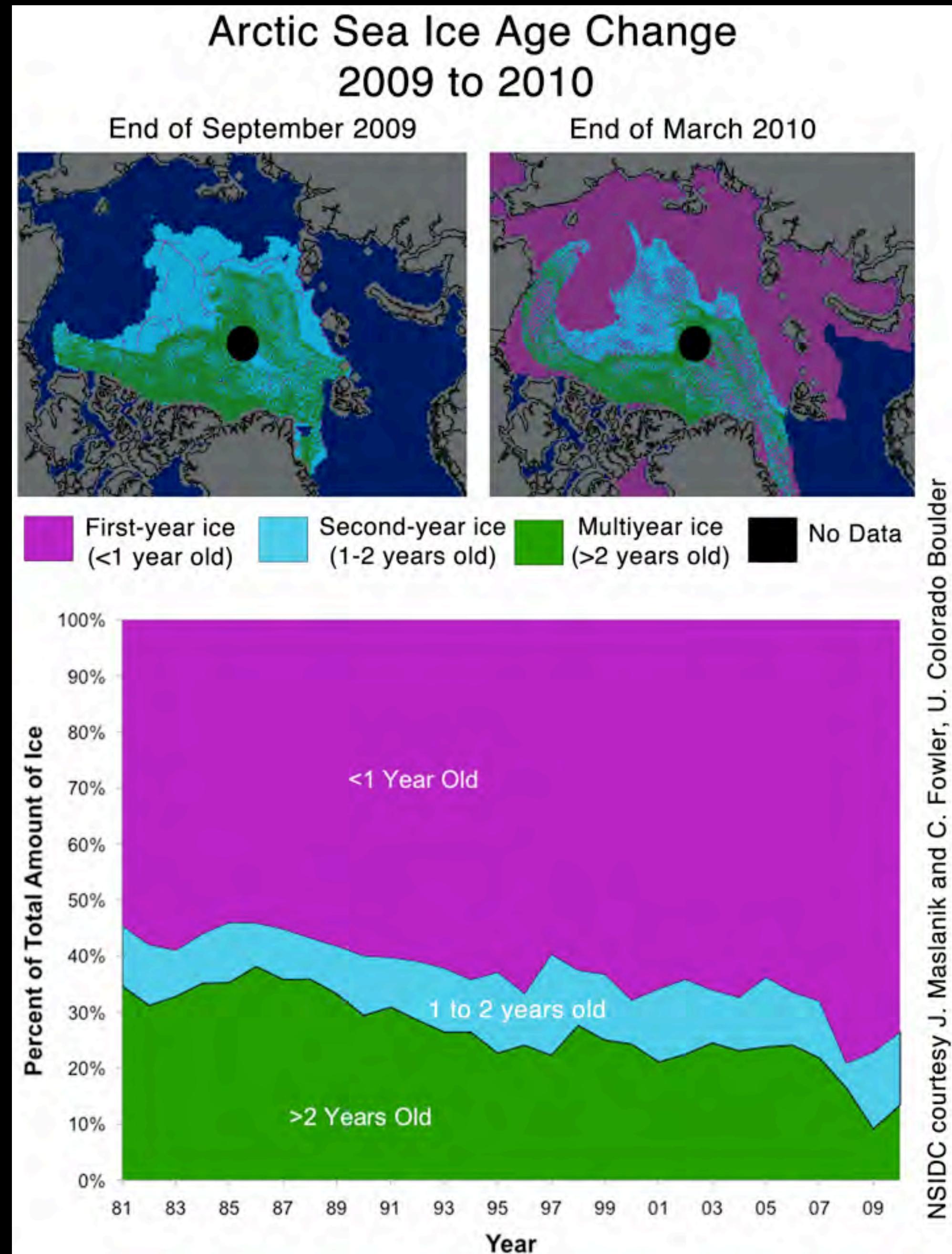


Sea ice within 50-km of coast: -25% for Arctic as a whole: <-44% in E. Siberia to Chukchi seas; some increases in Bering region and other scattered areas.

Summer land temperatures (SWI): +24% Arctic as a whole; +30% in North America, +16% Eurasia. Largest increases in Canadian High Arctic and Greenland (>70%).

Importance of multi-year ice

- Much of indigenous use of Arctic Ocean resources is dependent on thick multi-year sea ice.
- This has been declining steadily over the period of the record.

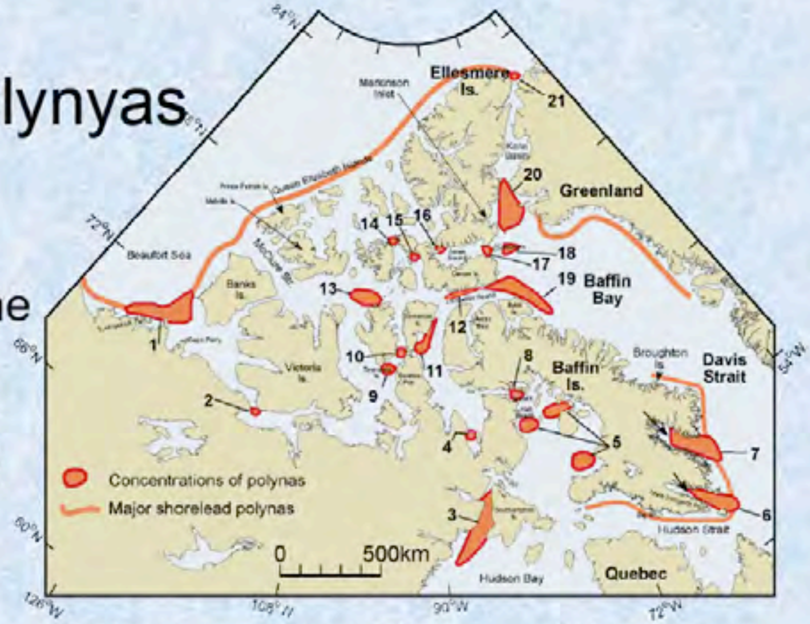


March 2010 sea-ice extent

Polynyas: Winter-long areas of open water with high subsistence value.

Known Polynyas

An area of ice free water in the midst of ice covered water (some or most of the time)



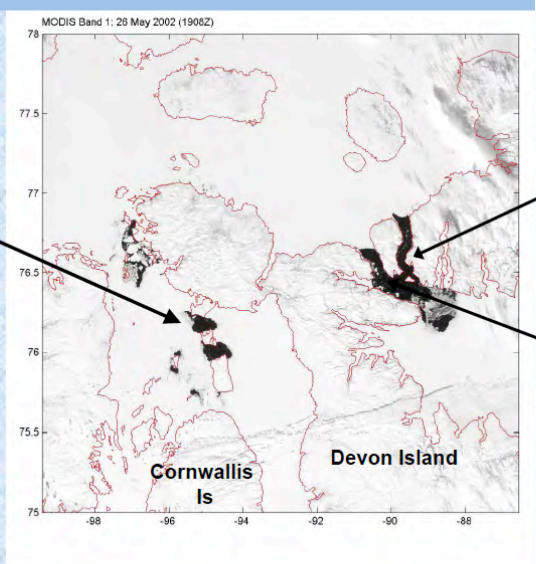
1 Cape Bathurst
2 Lambert Channel
3 Roes Welcome Sound
4 Committee Bay
5 Foxe Basin
6 Frobisher Bay
7 Cumberland Sound
8 Fury and Hecla Strait
9 Franklin Strait
10 Bellot Strait
11 Prince Regent Inlet
12 Lancaster Sound
13 Viscount Melville Sound
14 Queens Channel and Penny Strait
15 Dundas Island
16 Hell Gate - Cardigan Strait
17 Lady Ann Strait
18 Coburg Island
19 Bylot Island
20 NOW (Northwater)
21 Lincoln Sea

Barber and Massom 2007

Polynyas near Devon and Cornwallis islands (26 May 2002):

White is ice, snow and clouds.

Black is open water.



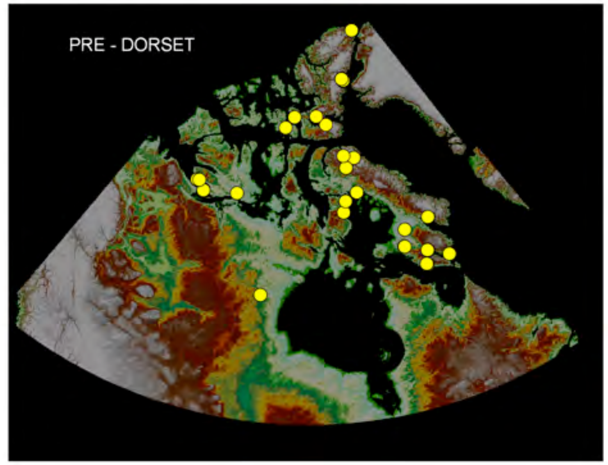
- In Arctic Canada: Sea-ice provides access polynyas.
- Many traditional village sites are located near polynyas.

From: Murray and Hannah 2010. Tidal Mixing, Polynyas, and Human Settlement in the Canadian Arctic Archipelago. State of the Arctic Conference, Miami, Fl.

Ecological hot spots:

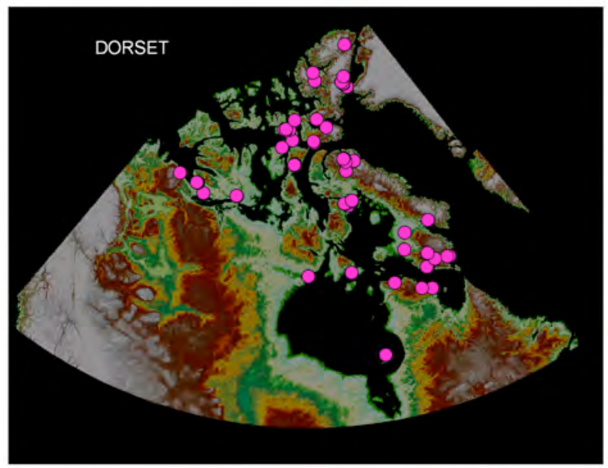
Prehistoric settlements in Northern Canada in relationship to polynyas

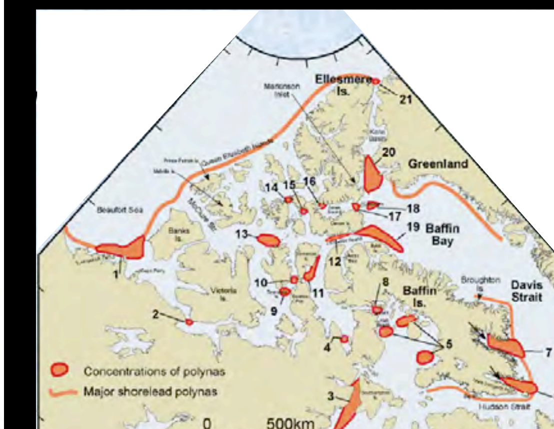
Pre-Dorset (Paleoeskimo), ca.4500-2300 BP



Ilulissat, Greenland, 2009

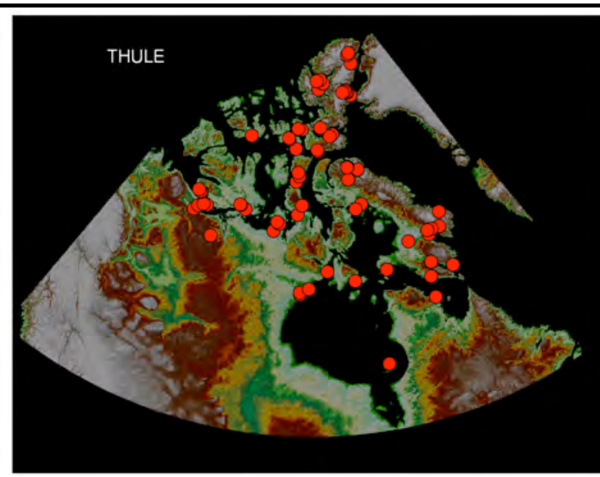
Dorset (Paleoeskimo), ca. 2300-1000 BP





Polynyas in Canadian Archipelago.

Thule (Ancestral Inuit), ca. 800-200 BP



From: Murray and Hannah 2010. Tidal Mixing, Polynyas, and Human Settlement in the Canadian Arctic Archipelago. State of the Arctic Conference, Miami, Fl.

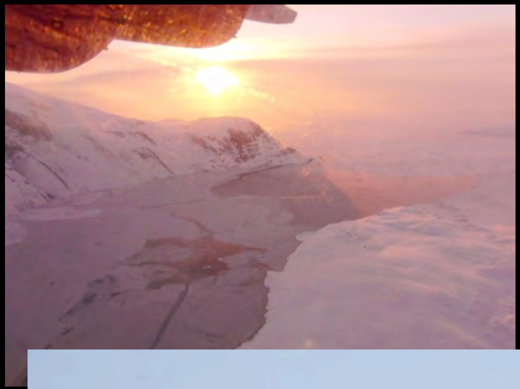
Siku-Inuit-Hila (Sea Ice-People-Weather) Project

Started by: Canadian scientist Shari Gearheard

Funding: US National Science Foundation.

Objective: To document the changing relationship of Inuit to the sea ice. Do it by setting up monitoring stations manned by locals and allowing Inuit hunters to travel to each others communities and see how ice was changing across the Arctic first-hand.

Recruited hunters in three northern communities: Clyde River, Canada; Barrow, Alaska; and Qaanaaq, Greenland. In total, 21 hunters and scientists were involved in the project.



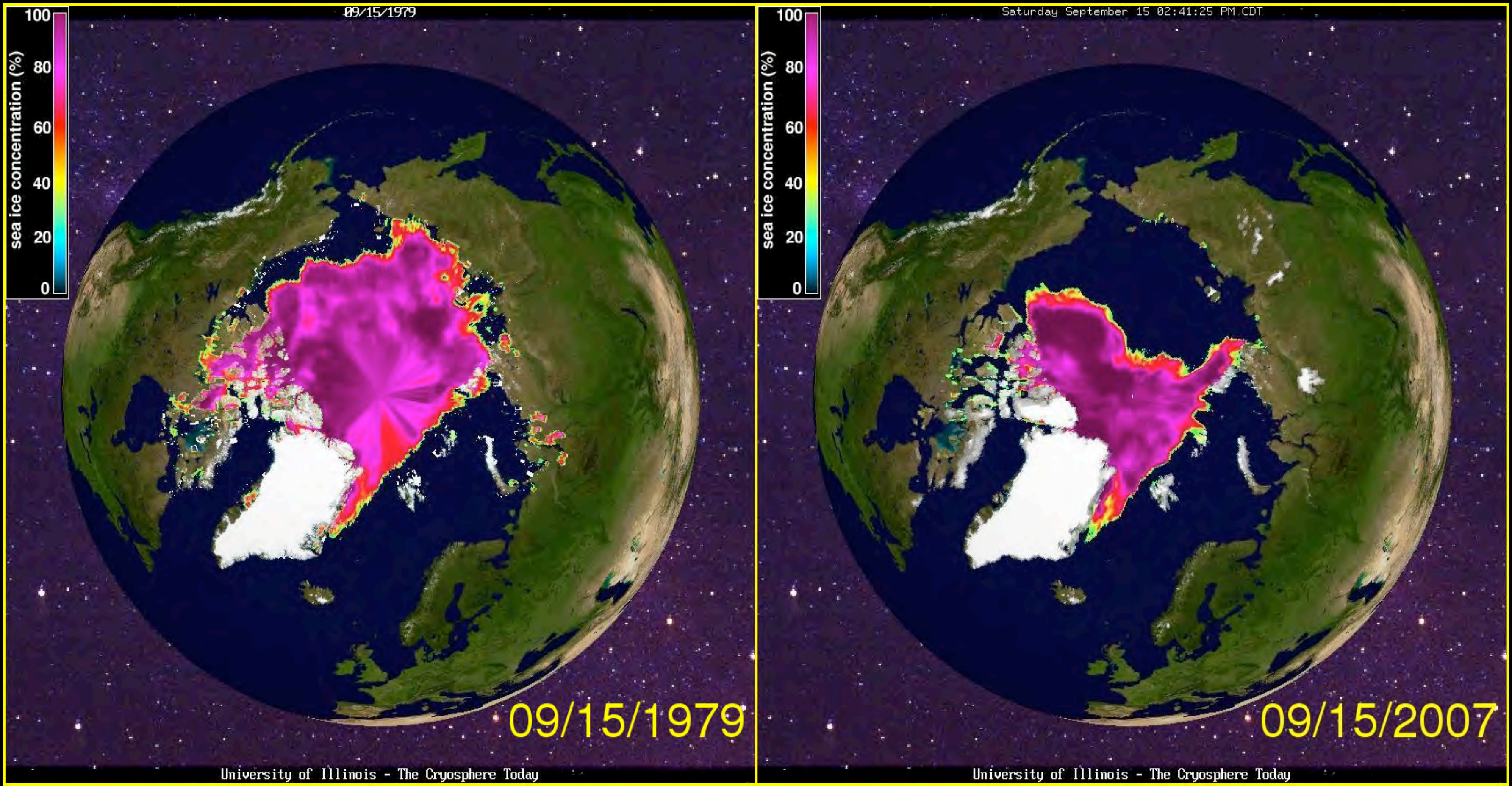
Melting ice like this has forced hunters in Qaanaaq, Greenland to change centuries-old hunting routes. Photo Lene Kielsen Holm, courtesy ICC-Greenland

Barrow whaling crew return to the sea ice edge in the their umiaq (seal skin boat).

Siku - Inuit - Hila hunters Joe Leavitt and Joelie Sanguya talk on sea ice edge near Barrow, Alaska.

Photos: courtesy Shari Gearheard

Effects of the 2007 sea-ice minimum



Immediate and cumulative effects of 2007 sea-ice minimum on coastal communities in Alaska

Butchering seals on the ice at Shishmaref, Alaska. Photo: K. Stenek

Feedbacks from changing environmental conditions and global processes:

- Greater distance traveled
- Higher cost of fuel
- Lower success of harvest
- Higher cost of purchased goods
- Needs for wage labour
- Out migration to cities
- Impacts on health

Courtesy of Maribeth Murray

Cumulative effects of resource development, reindeer herding, and climate change on the Yamal Peninsula, Russia

The Yamal: Typical of the sorts of changes that are likely to become much more common in tundra areas of Russia and the circumpolar region within the next decade.

- Currently, large undeveloped areas with no roads, but…
- large-scale gas and oil potential,
- extraordinarily sensitive permafrost environment
- traditional pasturelands for the nomadic Yamal Nenets people,
- rapid changes in climate.

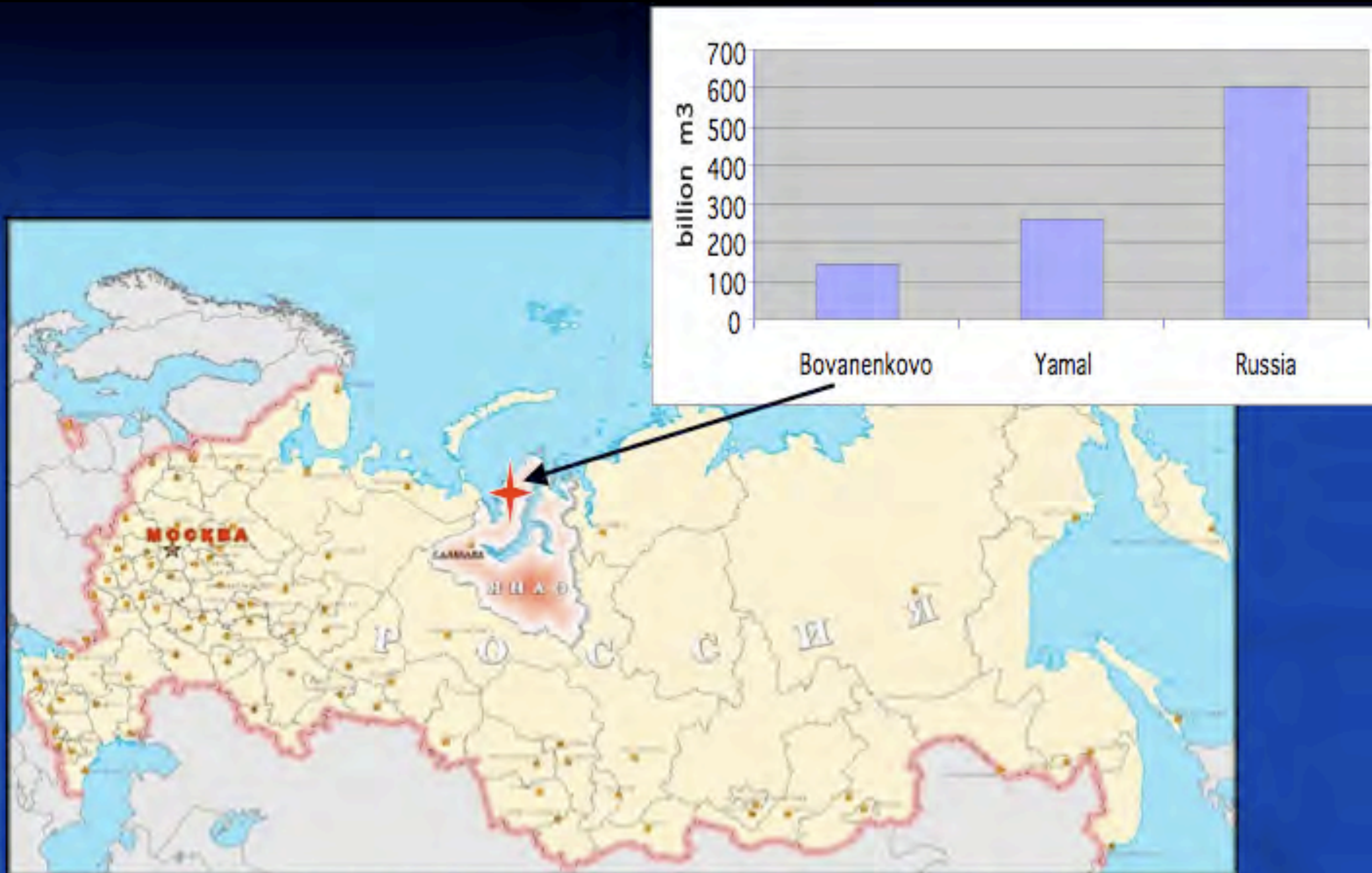
Goal: Develop tools using detailed ground observations, remote sensing and modeling to better predict the cumulative effects of resource development, climate change, reindeer herding, and the role of terrain factors in affecting changes in tundra regions.

Finnish ENSINOR project

- Environmental and Social Impacts of Industrialization in Northern Russia (ENSINOR).
- Funded by Finnish Government because Finland is almost totally dependent on Russia for gas.
- Case study in three intensive research areas.
  Oil in NAO and gas in YNAO.
- Studied changes in social-ecological systems, including herding.
- 20-30+ time slice.
- Local and scientific knowledge (geography, anthropology, biology).
- Partners included herders, Russian scientists, indigenous organizations, industry representative, and museums.


PNAS
High resilience in the Yamal-Nenets social–ecological system, West Siberian Arctic, Russia

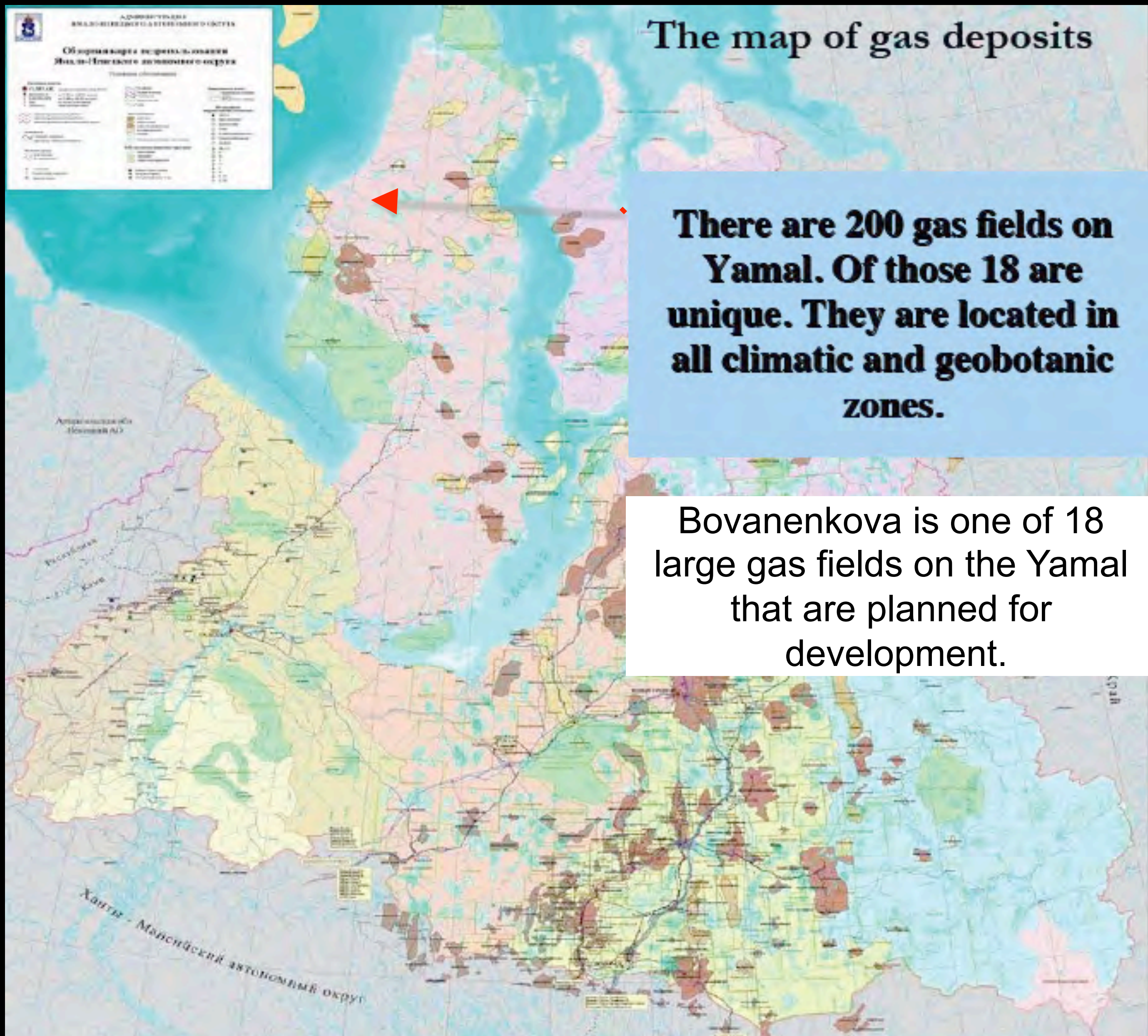
Yamal: Center of future gas production in Russia



- Contemporary Russia's gas production is more than 600 billions m^3 of gas which makes up 20% of the world consumption.
- In 2030 gas production on Yamal will be as high as 250 – 260 billions m^3/yr.

Courtesy of A. Gubarkov

Gas deposits in Yamalo-Nenets Autonomous Okrug



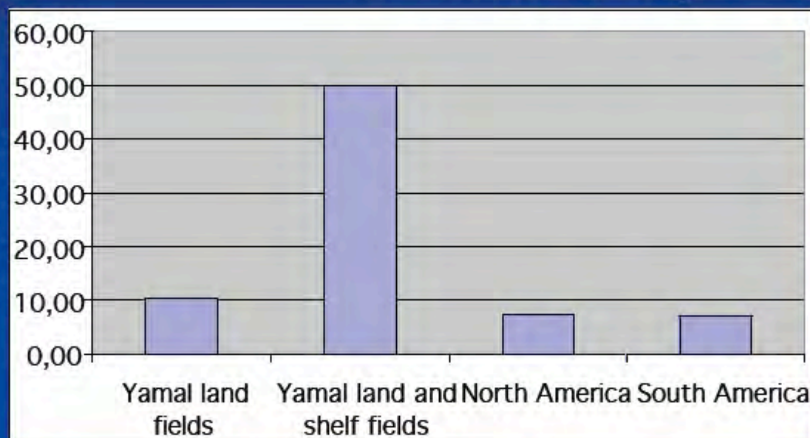
There are 200 gas fields on Yamal. Of those 18 are unique. They are located in all climatic and geobotanic zones.

Bovanenkova is one of 18 large gas fields on the Yamal that are planned for development.

Courtesy of A. Gubarkov

Huge potential gas reserves

Gas deposits of Yamal compared to Americas (in trillion m^3)

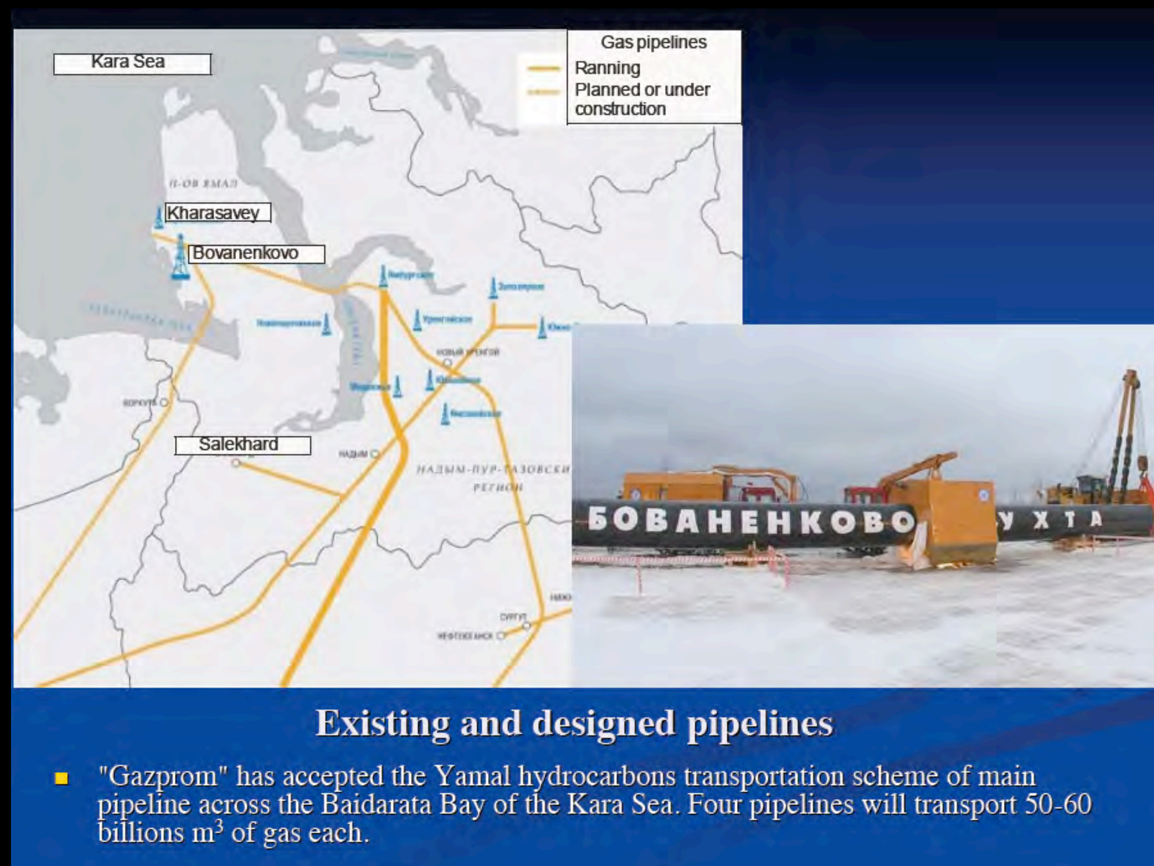


- Yamal gas deposits contain 13.5 trillion m^3 of proven gas reserves inland, reaching 50 trillion m^3 with additional deposits of the Kara sea shelf. The largest deposits of Yamal: Bovanenkovo, Kharasavey and Novy Port contain 5.8 trillions m^3 of gas, 100.2 million tons of gas condensate, and 227 million tons of oil. Proven Yamal reserves are close to that of North American (7.5 trillion m^3), and South American (7.1 trillion m^3) reserves taken together.

Courtesy of A. Gubarkov

Yamal is currently at the stage of development that Prudhoe Bay was in 1974 before construction of the Dalton Highway.

- Development has been delayed since the 1980s by several factors including settlement of Nenets land claims.
- Currently no road or train access.
- Both should be in place in summer 2011.



Existing and proposed gas lines and transportation corridors

Existing gas fields and pipelines in the Yamalo-Nenets Autonomous Okrug

Proposed pipeline and transportation corridors on Yamal Peninsula

Courtesy of A. Gubarkov

Yambourg Gas Field, Tazovsky Peninsula

- Discovered in 1981 and rapidly developed with winter road access.

Terrain factors that make the Yamal region so sensitive to disturbance

Sandy nutrient poor soils:

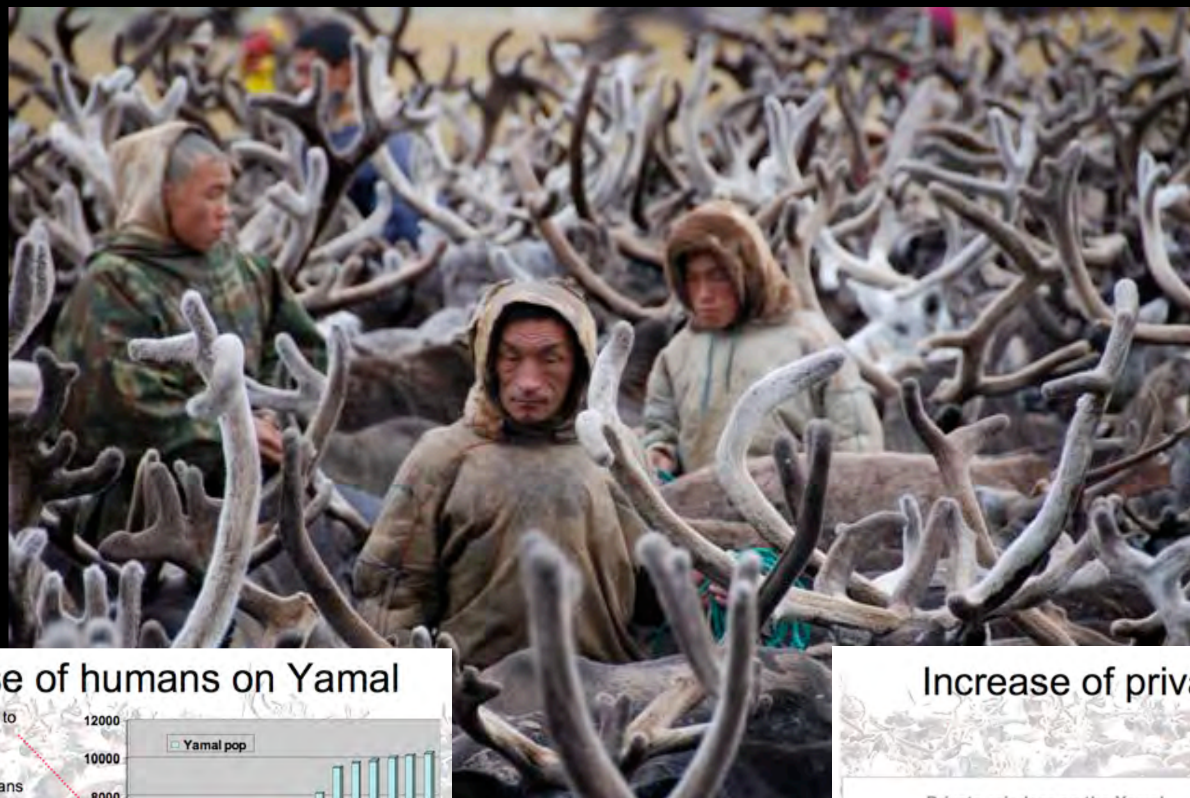
– Highly susceptible to wind erosion.
– Poor plant production, low plant diversity, slow recovery.

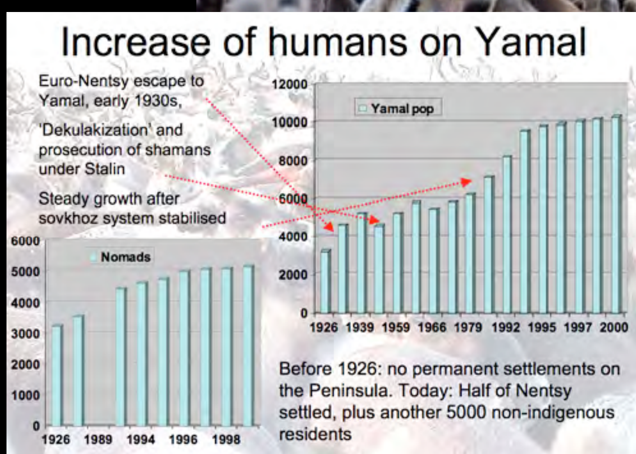
Extreme ground-ice conditions:

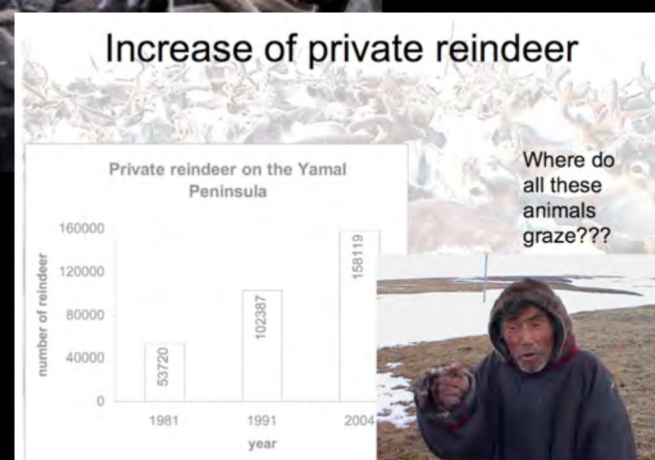
– Extreme ice-rich permafrost makes the region very susceptible to thermal erosion and landslides.

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

The Nenets people and their reindeer

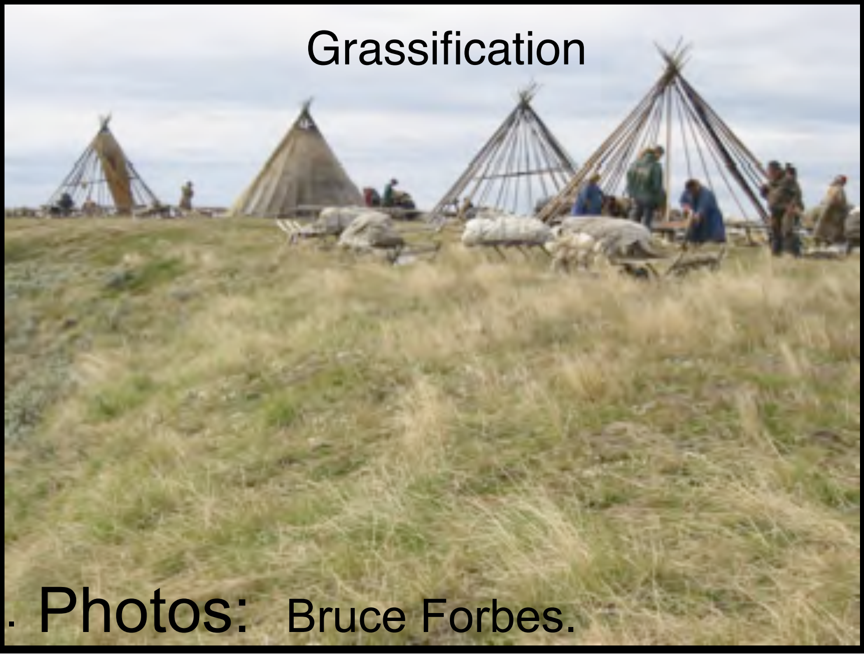






Florian Stammler: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008; Central photo: D.A. Walker.

Effects of reindeer herding

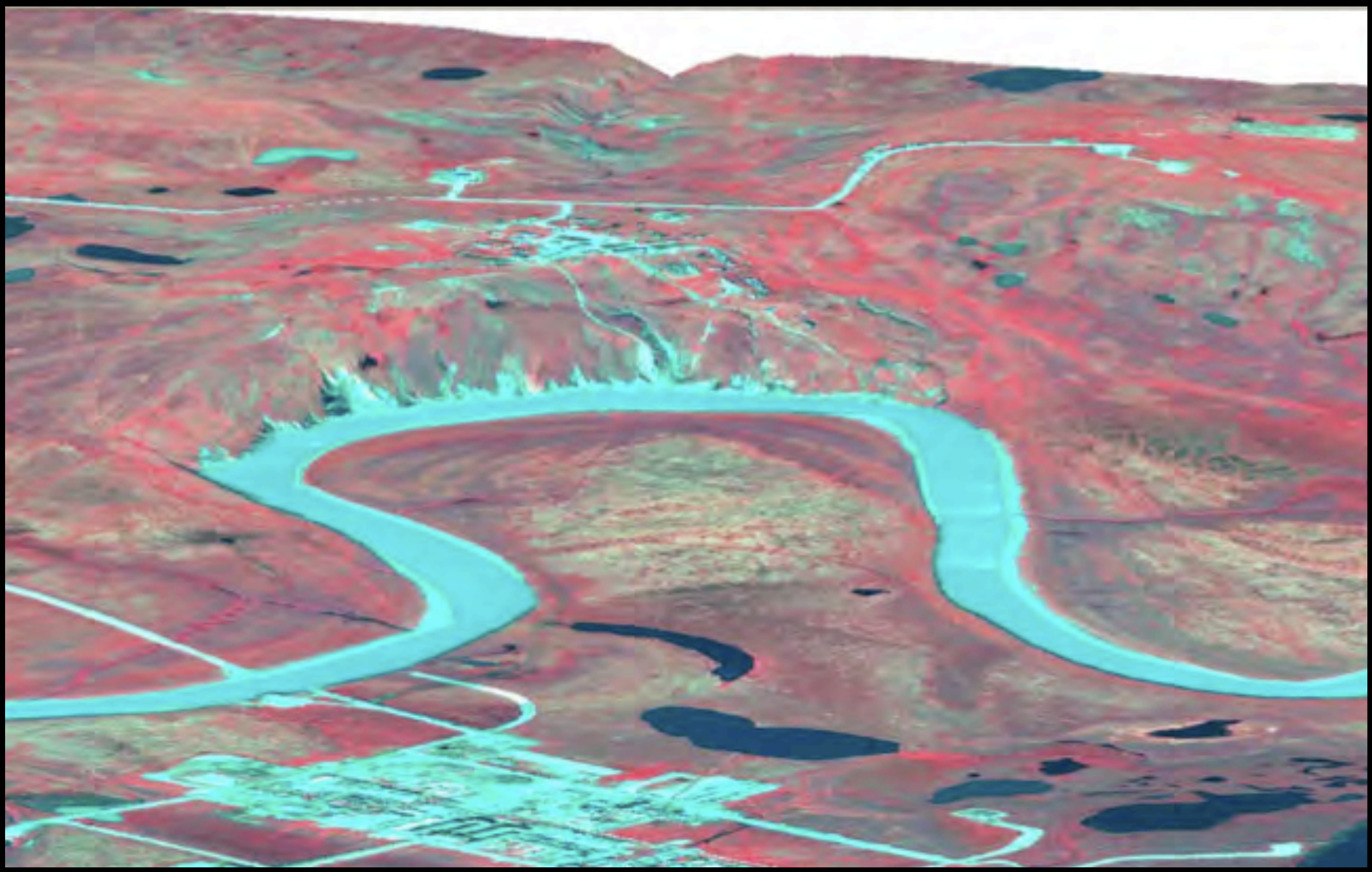


Working with sociologists:
Combining remote sensing and traditional knowledge

Florian Stammler interviewing members of Nenets brigade using remote sensing products to learn about their land-use patterns.

Photo: Bruce Forbes

Effects of resource extraction: Use of remote sensing and GIS to inventory direct and indirect effects of the Bovanenkovo Gas Field.



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

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.

Impact / Detectivity	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

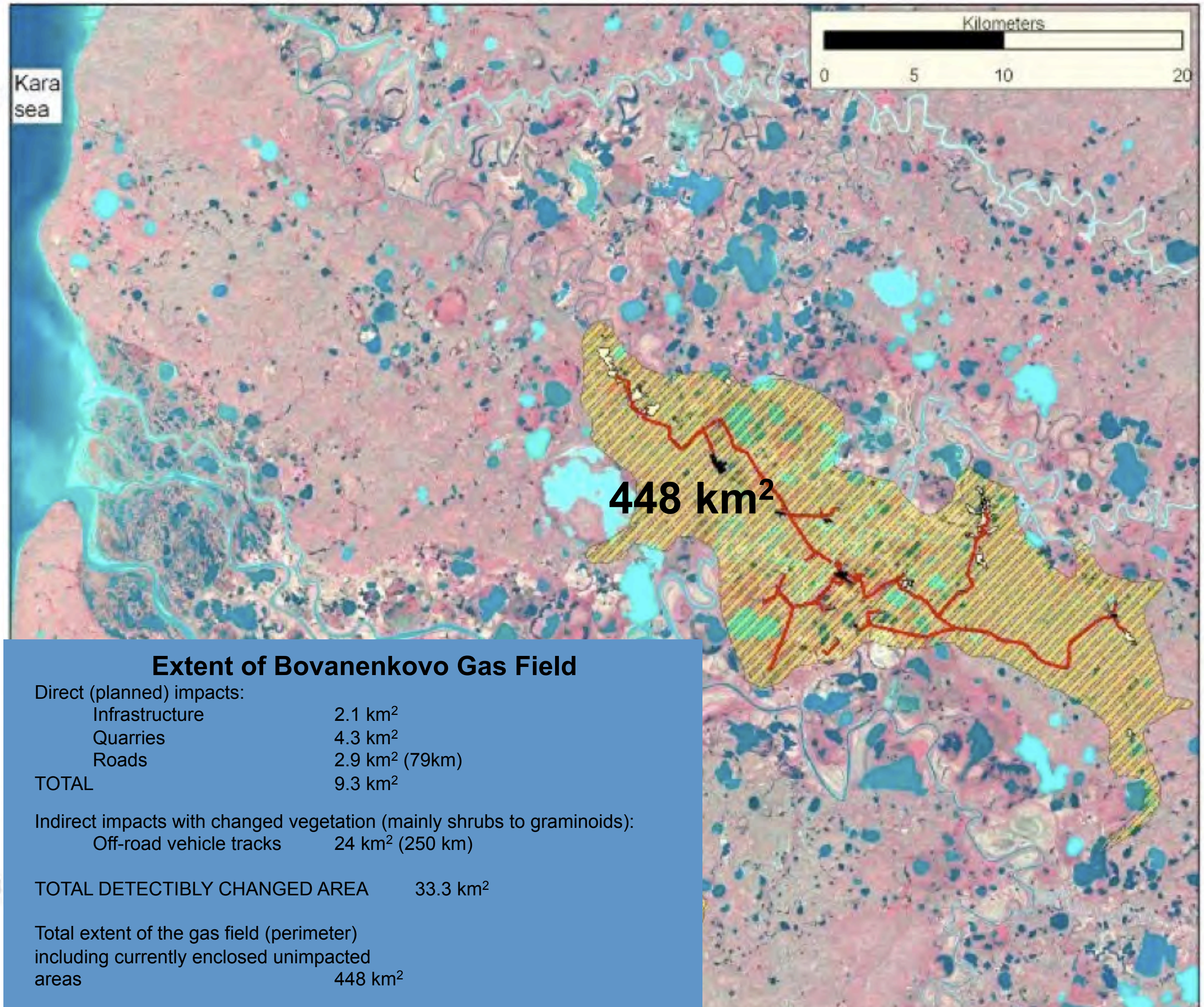
T. Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

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)

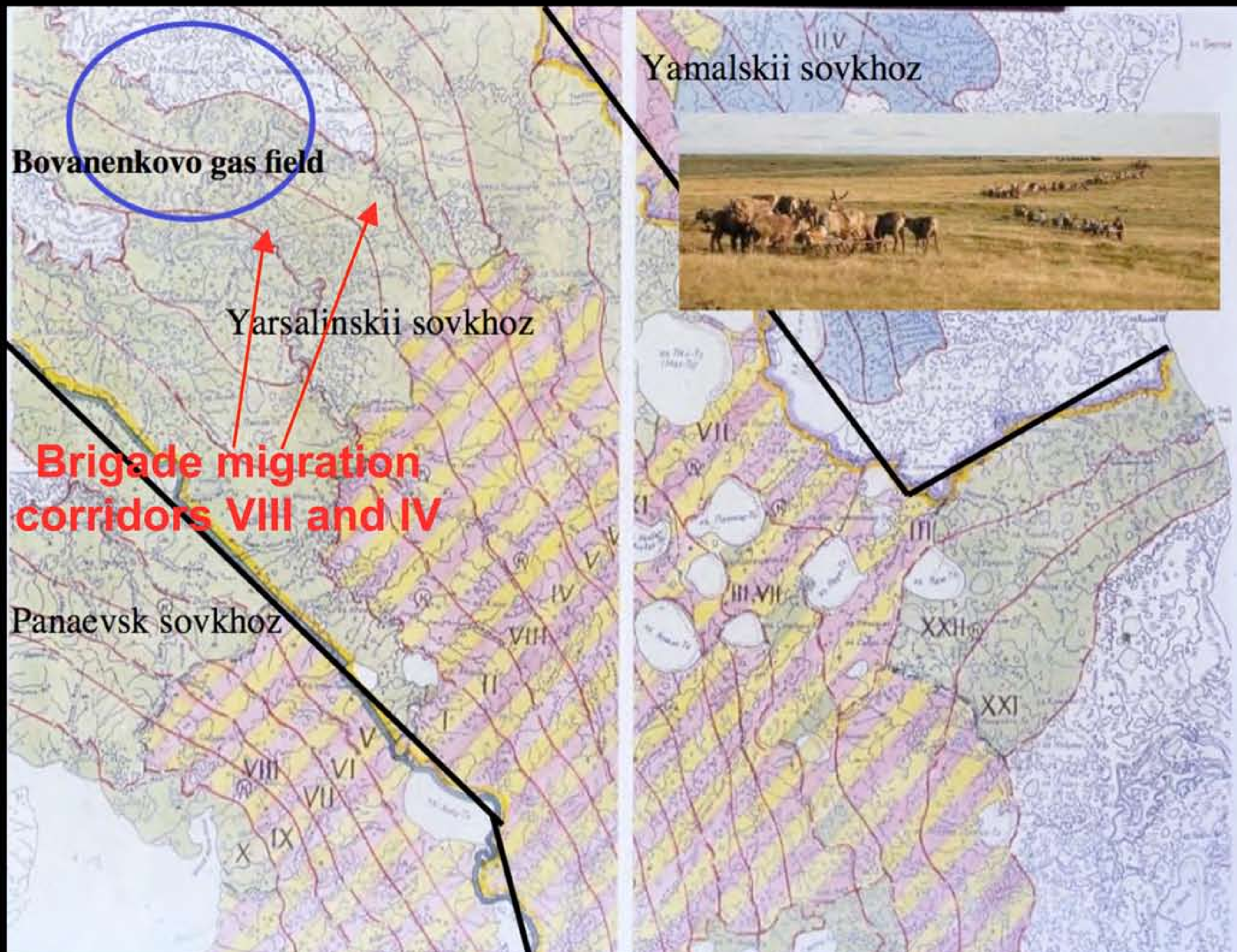
Background image:
Landsat TM 07.08.1988

Extent of Bovanenkovo Gas Field

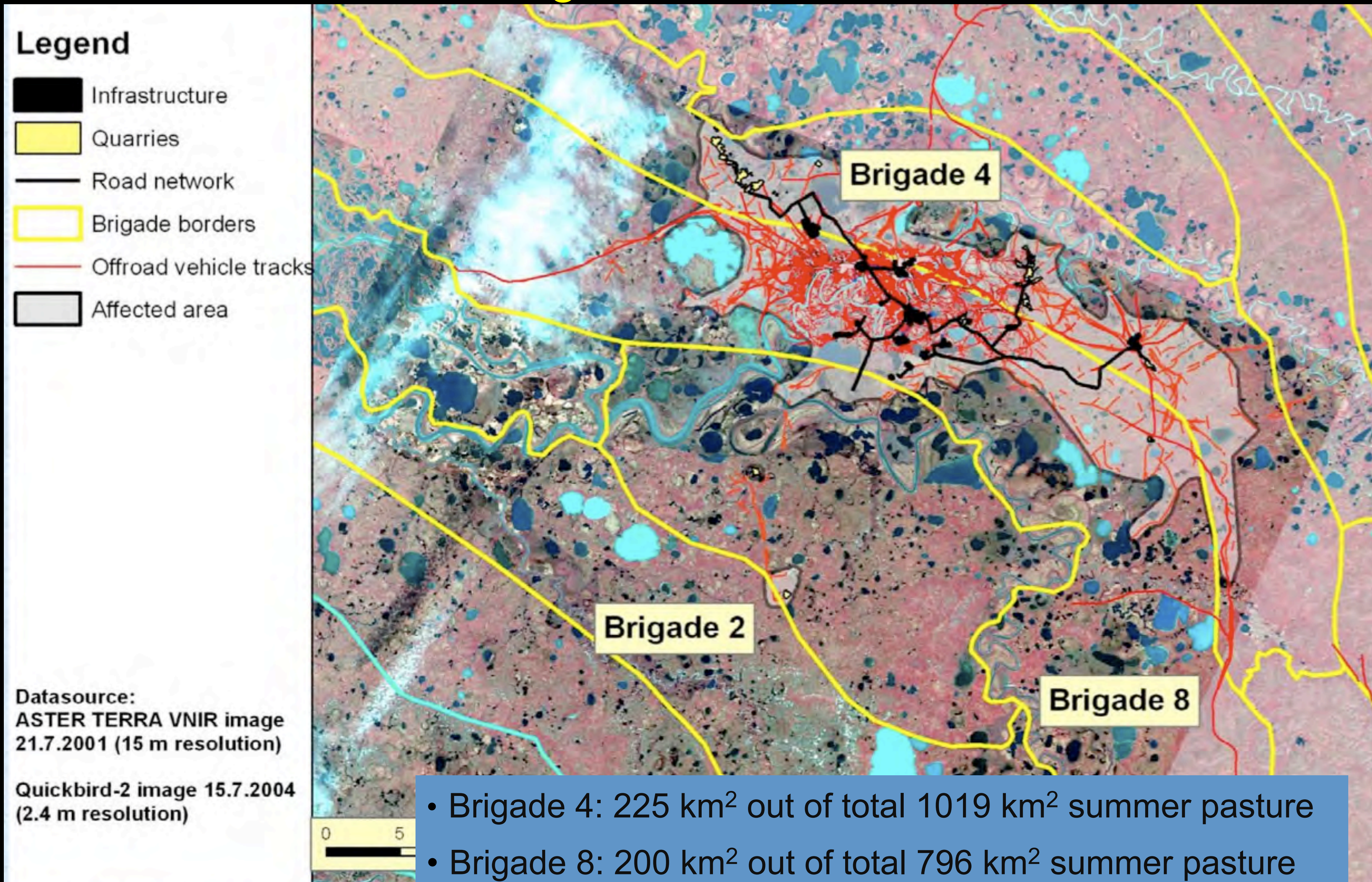
Direct (planned) impacts:	
Infrastructure	2.1 km^2
Quarries	4.3 km^2
Roads	2.9 km^2 (79km)
TOTAL	9.3 km^2
Indirect impacts with changed vegetation (mainly shrubs to graminoids):	
Off-road vehicle tracks	24 km^2 (250 km)
TOTAL DETECTIBLY CHANGED AREA	33.3 km^2
Total extent of the gas field (perimeter) including currently enclosed unimpacted areas	448 km^2

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

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

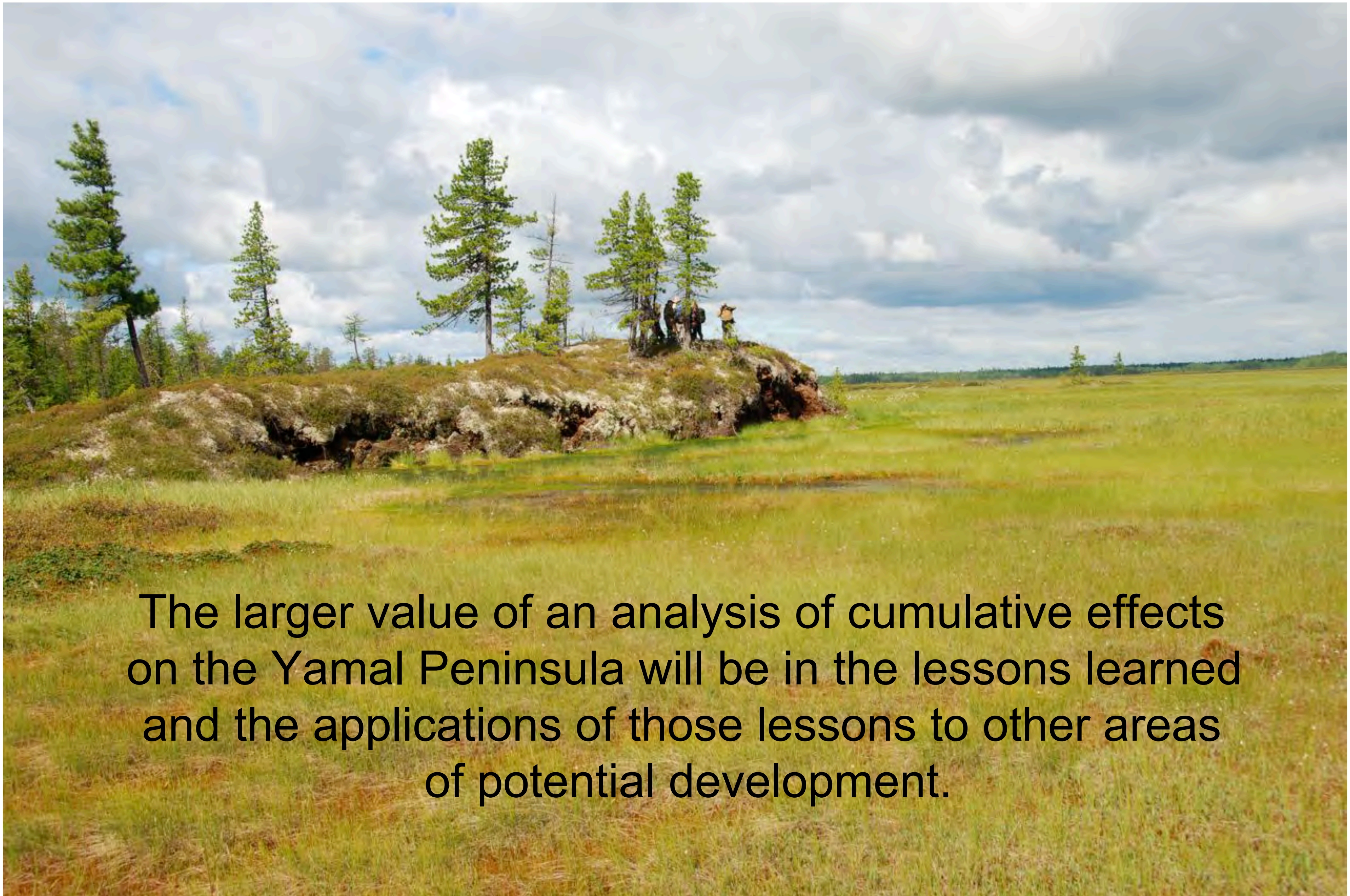
Comparison of Bovanenkova and North Slope development**

	Area (length), km^2 (km) Bovanenkova	North Slope
Direct impacts:		
Roads	2.9 (79)	12.0 (954)
Airstrips	0	1.1
Gravel pads	2.1	23.5
Quarries	4.3	25.8
Off-shore gravel placement	0	0.6
Total direct impacts:	9.3	62.4
Other affected area:	24	7.1
Total extent of field(s) perimeter including currently enclosed unimpacted areas.	448	2600

**Data: North Slope (NRC, 2003), Bovanenkova (Kumpula 2011)

General conclusions from the ENSINOR project

1. The patterns and processes of changes in sea ice, land use and land cover relevant to human dimensions are variable across the Arctic.
2. In North America, sea ice reduction has profound impacts on some aspects of human access to marine mammals, yet polynyas and ecological 'hot spots' remain remarkably consistent across millennia.
3. In the circumpolar North, sustained retreat of sea ice has profound implications for air temps and vegetation cover in tundra regions.
4. Increases in deciduous shrubs are pronounced for the western portion of the Russian Arctic and clearly linked to observed trend in NDVI.
5. The Yamal-Nenets social ecological system has successfully reorganized in response to recent shocks: Anthropogenic fragmentation of a large proportion of the environment, socioeconomic upheaval, and pronounced warming in summer and winter.
6. Institutional constraints and cultural factors and drivers were clearly as important as the documented ecological changes, so even the highest resolution satellite imagery only gets us so far in documenting change.
7. Particularly crucial to success is the unfettered movement of people and animals in space and time. Future institutional arrangements must specifically target mutual coexistence and make use of latest data.


The larger value of an analysis of cumulative effects on the Yamal Peninsula will be in the lessons learned and the applications of those lessons to other areas of potential development.

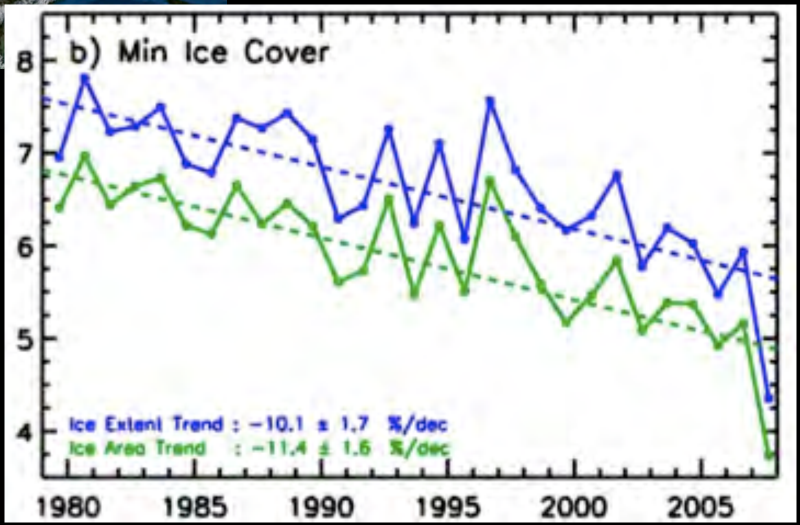
Analysis of sea-ice, land surface temperature and NDVI trends

Is the trend in sea-ice affecting Arctic vegetation ?

More about this in the next Lecture!

Since 1980, perennial sea ice extent in the Arctic has declined at the rate of 10.1% per decade.

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



2007-2010 Expedition to Yamal Peninsula Region, Russia

Data collected:

Soils

Plant Cover

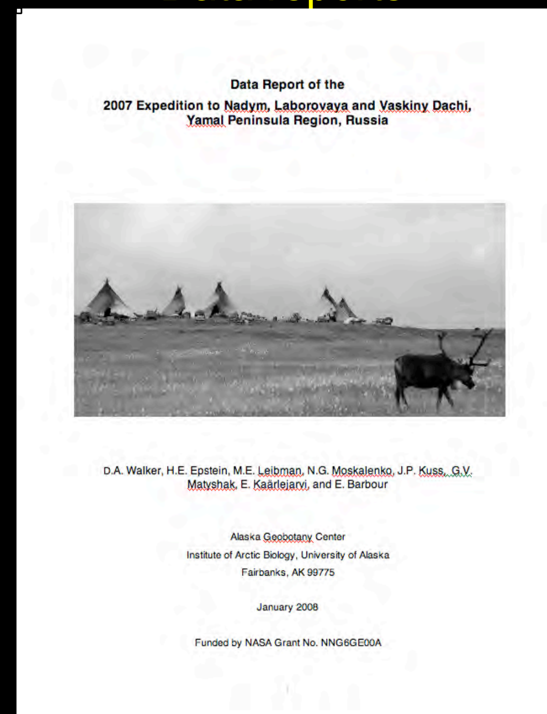
NDVI & LAI

Ground temperatures

Active layer

Plant Biomass

Data reports



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

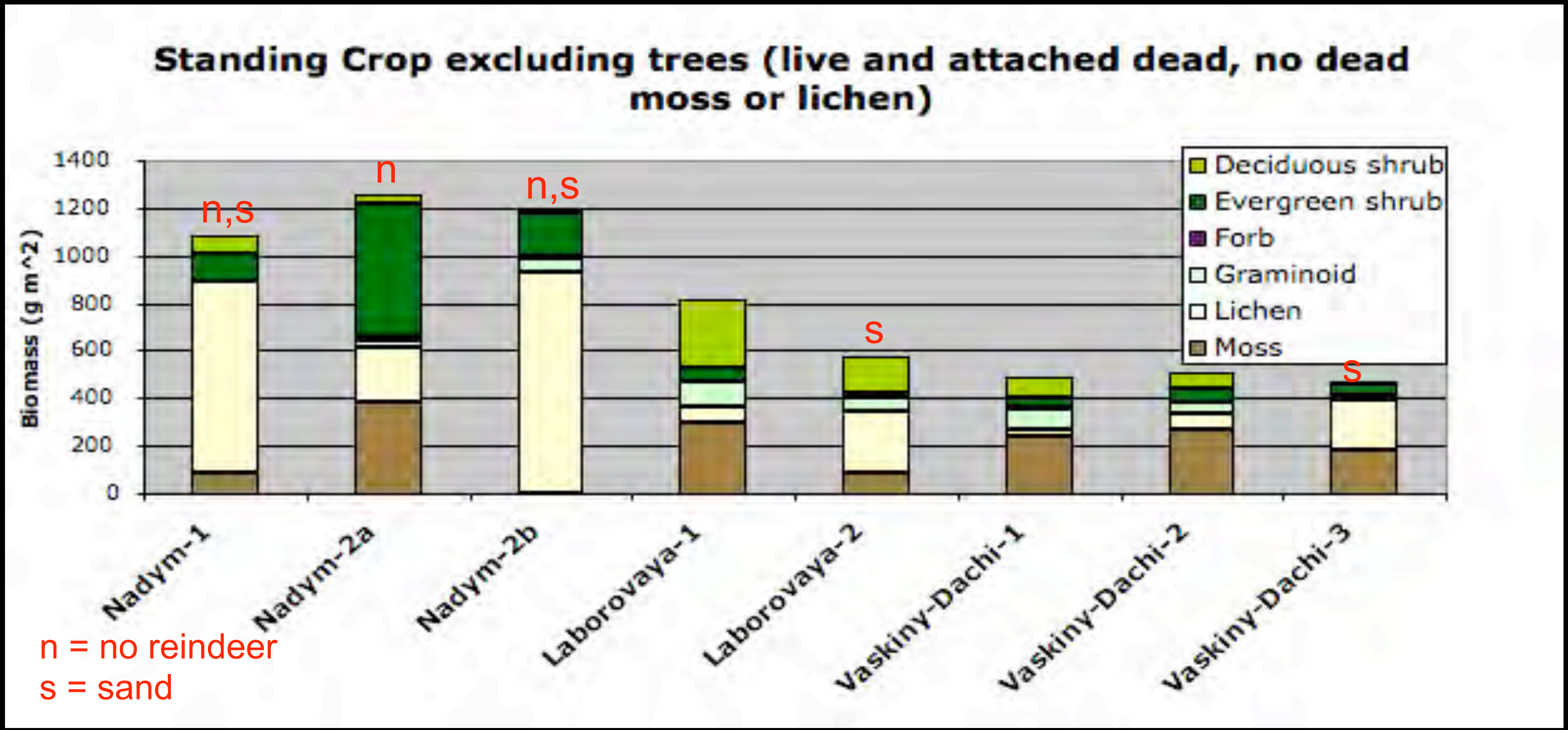
Alaska Geobotany Center
Institute of Arctic Biology, University of Alaska
Fairbanks, AK 99775

January 2008

Funded by NASA Grant No. NNG6GE00A

http://www.geobotany.uaf.edu/yamal/reports

Biomass along the Yamal transect



Epstein et al: NASA LCLUC meeting 2008.

Climate trend:

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

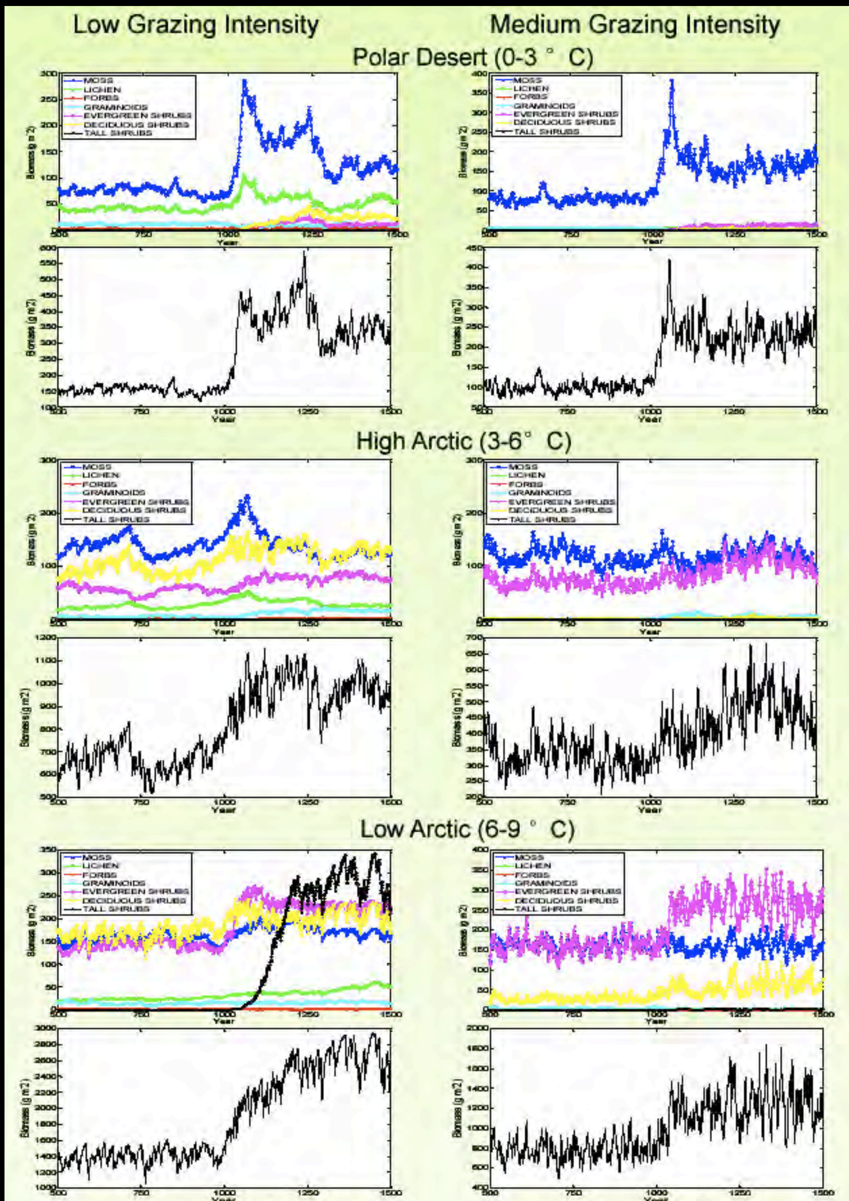
Effect of sandy soils:

- 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:

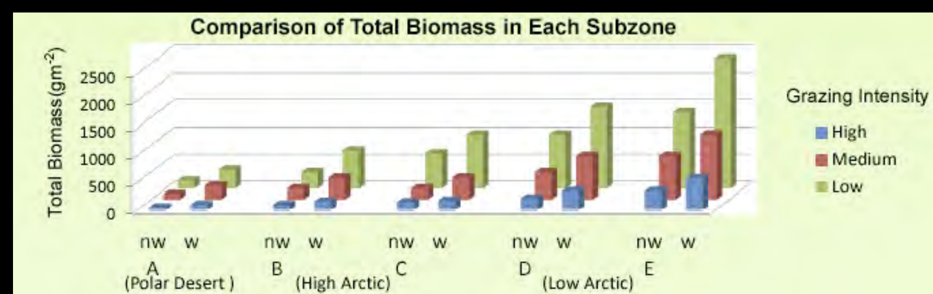
- Ungrazed sandy areas near Nadym – over 1000 g m-^{2}
- Less than 250 g m-^{2} in sandy areas where reindeer grazing has occurred annually.

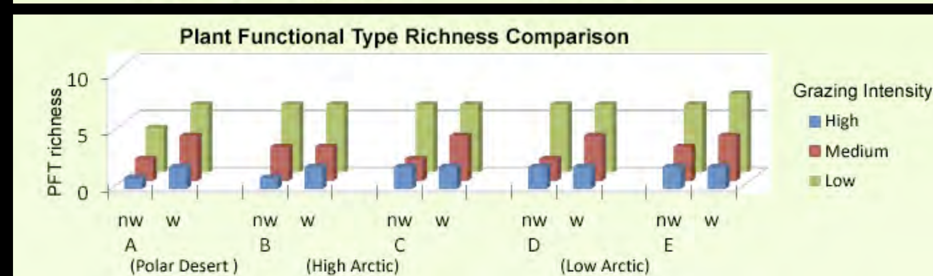
Modeled productivity of PFTs on the Yamal



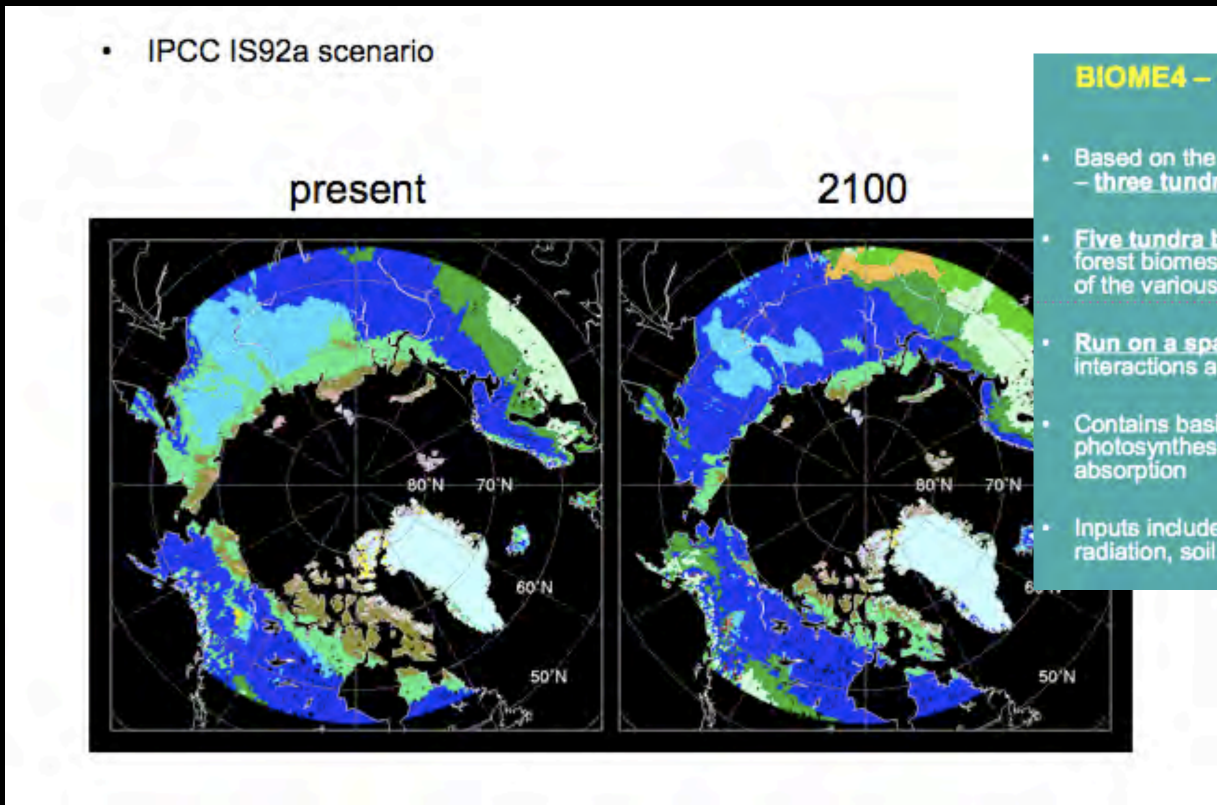
Yu and Epstein: 2008, NASA LCLUC conference.

- 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), relate to NDVI and develop regional extrapolations.





BIOME4/LPJ model



BIOME4 – Vegetation Type Biogeography Model

- Based on the plant functional type concept (rather than species) – **three tundra PFTs** in BIOME4
- **Five tundra biomes**, a cold parkland biome, and two boreal forest biomes are simulated, based on the resultant composition of the various PFTs.
- **Run on a spatial grid (0.5° x 0.5°),** but does not simulate interactions among grid cells
- Contains basic **ecophysiological equations** for photosynthesis, respiration, soil hydrology, and sunlight absorption
- Inputs include **monthly temperatures and precipitation**, solar radiation, soil texture and atmospheric CO2 concentrations

Kaplan, J.: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Cumulative effects in the Yamal

Resource development:
- Indirect (unplanned) impacts are greater than the direct (planned) impacts.
- Roads and pipelines: serious barriers to migration corridors.
- Effects will increase as new field are developed.

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

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.
- They generally view the gas development positively because of increased economic opportunities.

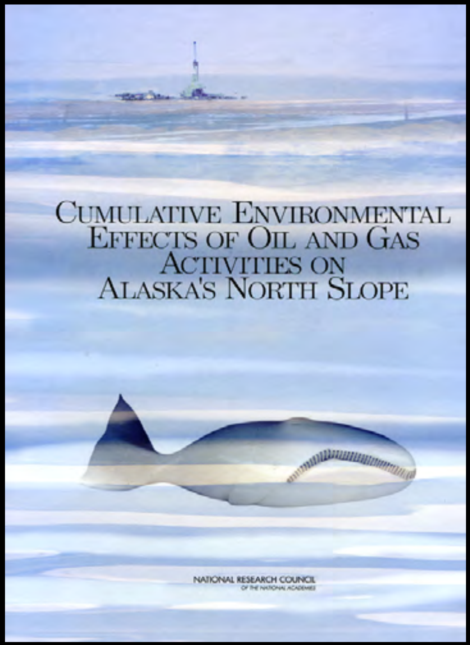
Climate change:
- Satellite data suggest that there has been only modest summer land-surface warming and only slight greening changes across the Yamal during the past 24 years. (Trend is much stronger in other parts of the Arctic, e.g. Beaufort Sea.)
- Kara-Yamal: negative sea ice, positive summer warmth and positive NDVI are correlated with positive phases of the North Atlantic Oscillation and Arctic Oscillation.

Recent publications

- Goetz, S.J., Epstein, H.E., Alcaraz, J.D., Beck, P.S.A., Bhatt, U.S., Bunn, A., Comiso, J.C., Jia, G.J., Kaplan, J.O., Lilschke, H., Lloyd, A., Walker, D.A., and Yu, Q., 2011, Recent changes in Arctic vegetation: Satellite observations and simulation model predictions, in Gutman, G., and Reissell, A., eds., Eurasian Arctic Land Cover and Land Use in a Changing Climate, Volume VI: New York, Springer, p. 9-36.

- Walker, D.A., Forbes, B.C., Leibman, M.O., Epstein, H.E., Bhatt, U.S., Comiso, J.C., Drozdov, D.S., Gubarkov, A.A., Jia, G.J., Karlejaärvi, E., Kaplan, J.O., Khumutov, V., Kofinas, G.P., Kumpula, T., Kuss, P., Moskalenko, N.G., Raynolds, M.K., Romanovsky, V.E., Stammler, F., and Yu, Q., 2011, Cumulative effects of rapid land-cover and land-use changes on the Yamal Peninsula, Russia in Gutman, G., and Reissel, A., eds., Eurasian Arctic Land Cover and Land Use in a Changing Climate, Volume VI: New York, Springer, p. 206-236.

- Walker, D.A., Leibman, M.O., Epstein, H.E., Forbes, B.C., Bhatt, U.S., Raynolds, M.K., Comiso, J., Gubarkov, A.A., Khomutov, A.V., Jia, G.J., Kaarlejaärvi, E., Kaplan, J.O., Kumpula, T., Kuss, H.P., Matyshak, G., Moskalenko, N.G., Orechov, P., Romanovsky, V.E., Ukraientseva, N.K., and Yu, Q., 2009, Spatial and temporal patterns of greenness on the Yamal Peninsula, Russia: interactions of ecological and social factors affecting the Arctic normalized difference vegetation index: Environmental Research Letters, v. 4, p. 16.



The Future

Synthesis of Yamal and North Slope cumulative effects studies.

Update the Prudhoe Bay studies to the present.

Develop predictive change models
- –Based on field data from both areas,
- –Apply to new areas of development.

Collaborators:

D.A. Walker, U.S. Bhatt, V.E. Romanovsky, G.P. Kofinas, M.K. Raynolds J.P. Kuss: *University of Alaska, Fairbanks, AK, USA.*

H.E. Epstein, Q. Yu, G.J. Jia, J.O. Kaplan, G.V. Frost: *Department of Environmental Sciences, University of Virginia, USA.*

B.C. Forbes, F. Stammler, T. Kumpula, E. Karlejäarvi: *Arctic Centre, Rovaneimi, Finland.*

M. Leibman, , N. Moskalenko, A. Gubarkov, A. Khomutov, G. Matyshak D. Drozdov: Earth, *Cryosphere Institute, and Moscow State University, Moscow, Russia.*

J.C. Comiso, J. Pinzon, J.C. Tucker: *NASA Goddard, USA.*

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