Drought, Fire and Bark Beetles
A Short History of the Kenai Peninsula Since the Glaciers Left

14th International Circumpolar Remote Sensing Symposium

Ed Berg, PhD
US Fish & Wildlife Service (Retired)
Kenai National Wildlife Refuge
Kenai Peninsula College
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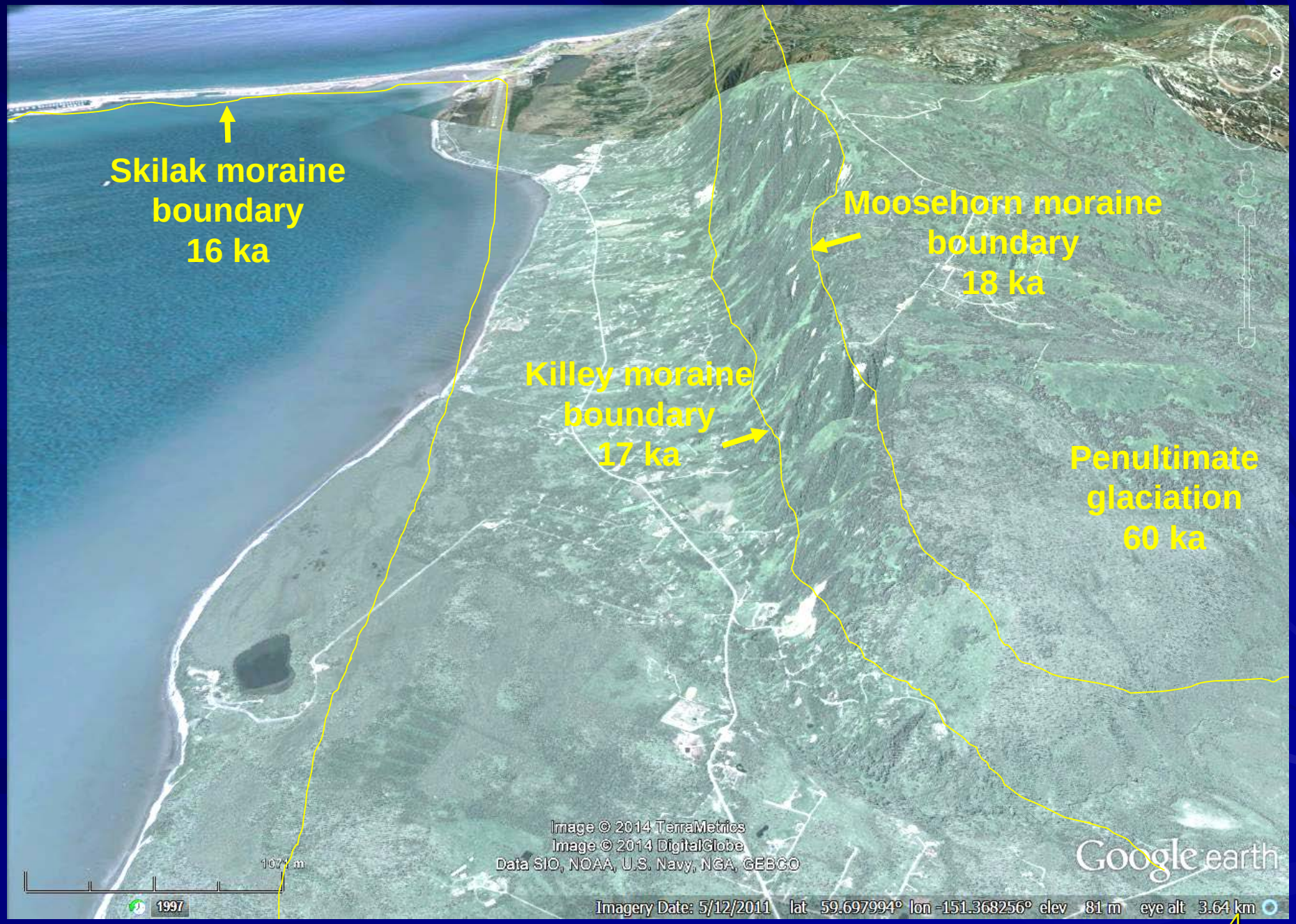
Topics to be Discussed

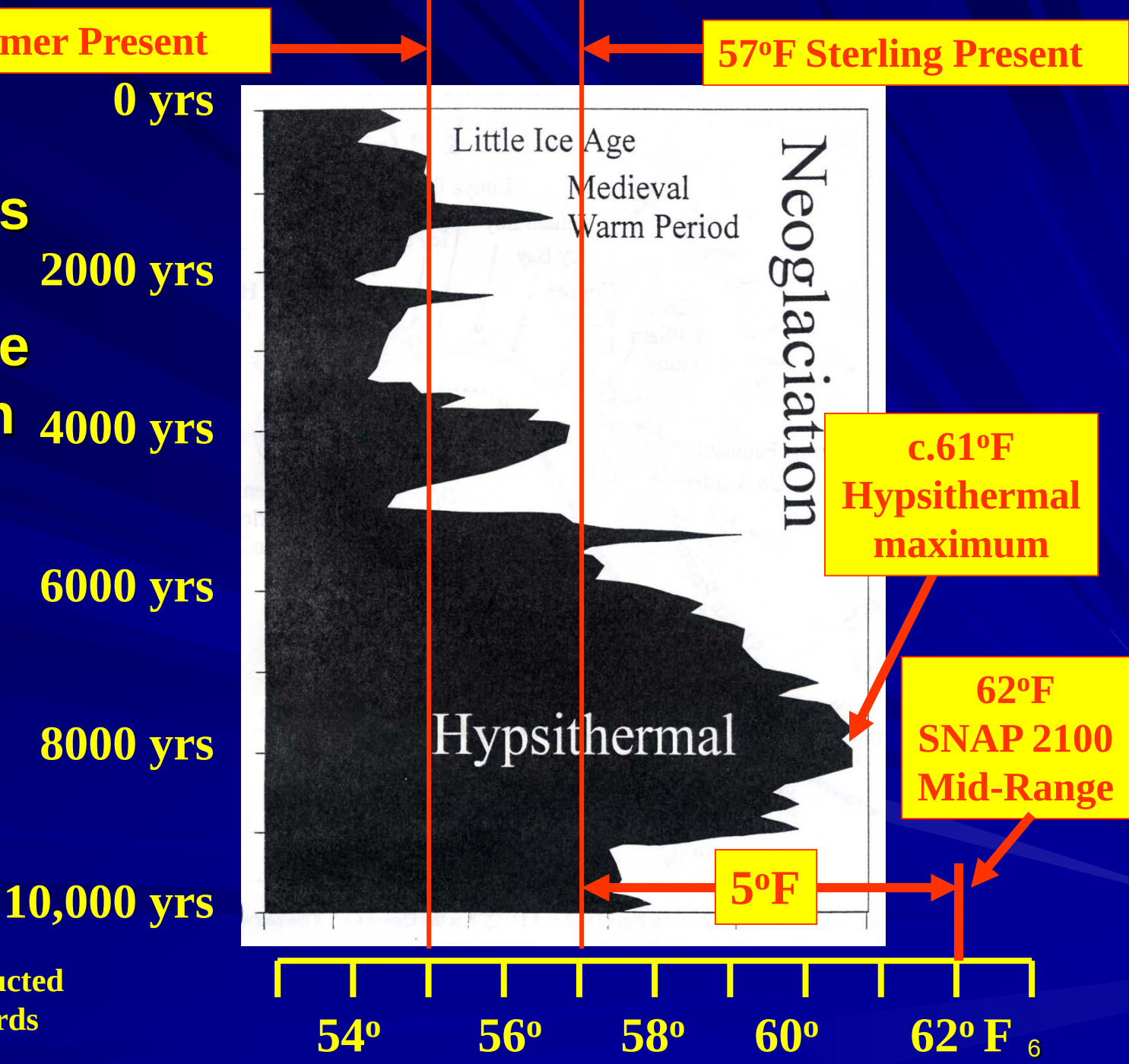
- Vegetation since the Last Glacial Maximum (LGM)
- Massive drought after the LGM
- Fire history
- Spruce bark beetle outbreaks
- Return of the drought
- 2099 and beyond

Our view from above Homer from Skyline Drive was like this view 23,000 years ago

Harding Icefield


Skilak moraine boundary 16 ka
Moosehorn moraine boundary 18 ka
Killey moraine boundary 17 ka
Penultimate glaciation 60 ka
Image © 2014 TerraMetrics
Image © 2014 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
1071 m
1997
Imagery Date: 5/12/2011 lat 59.697994° lon -151.368256° elev 81 m eye alt 3.64 km

The Last 10,000 Years of July Temperature in Southern Alaska



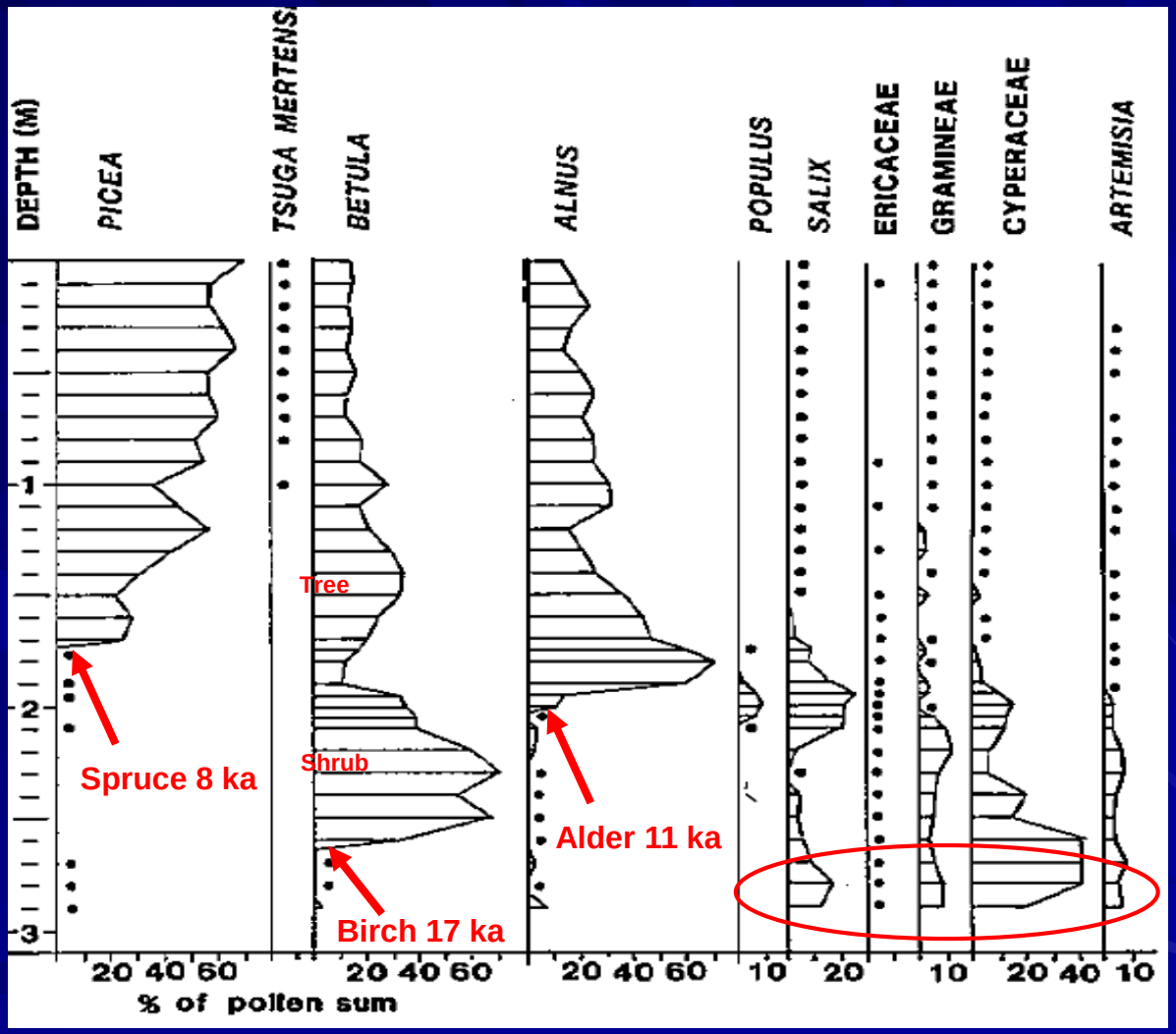
Temperature reconstructed from plant pollen records
Mann et al (1998)

Hidden Lake

Pollen in lake sediments

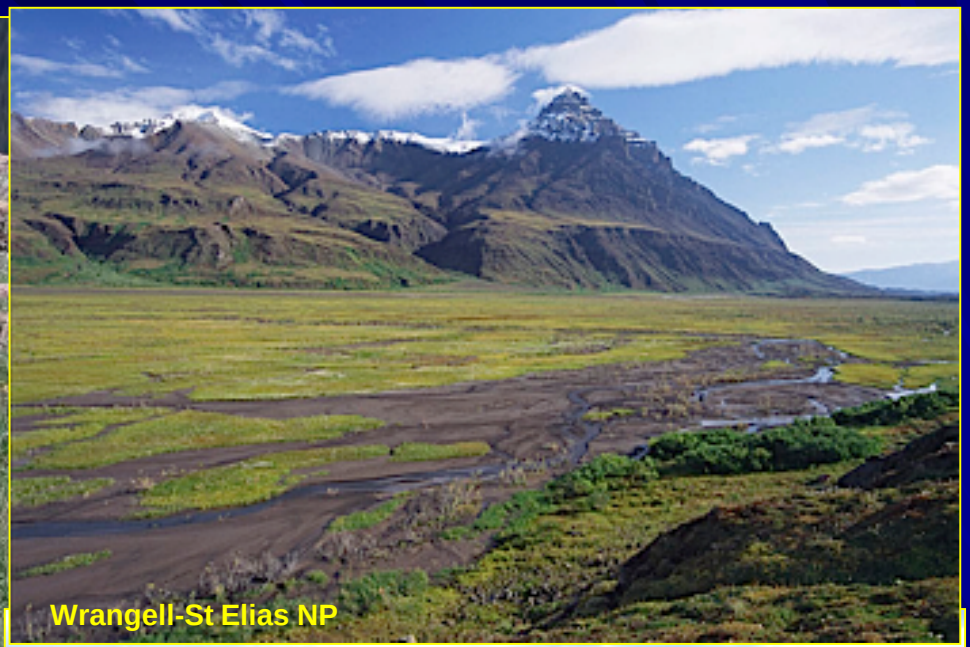
One of the oldest pollen records on Kenai (18 ka)

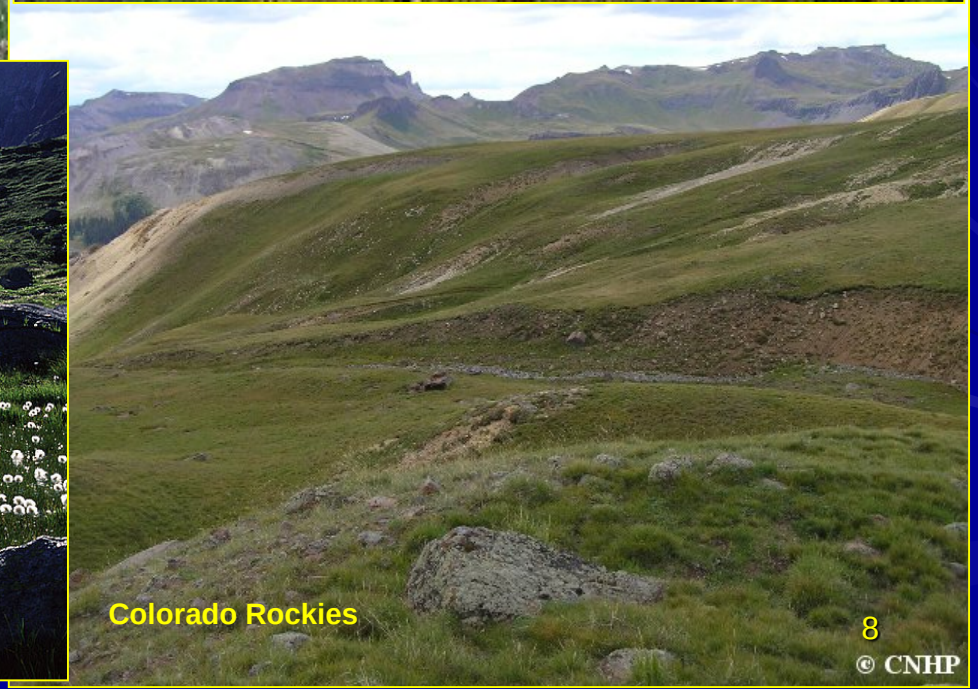
Basal zone is Graminoid-*Artemisia*-herb tundra with some willows



Ager 1983

Herb Tundra 19-17 ka

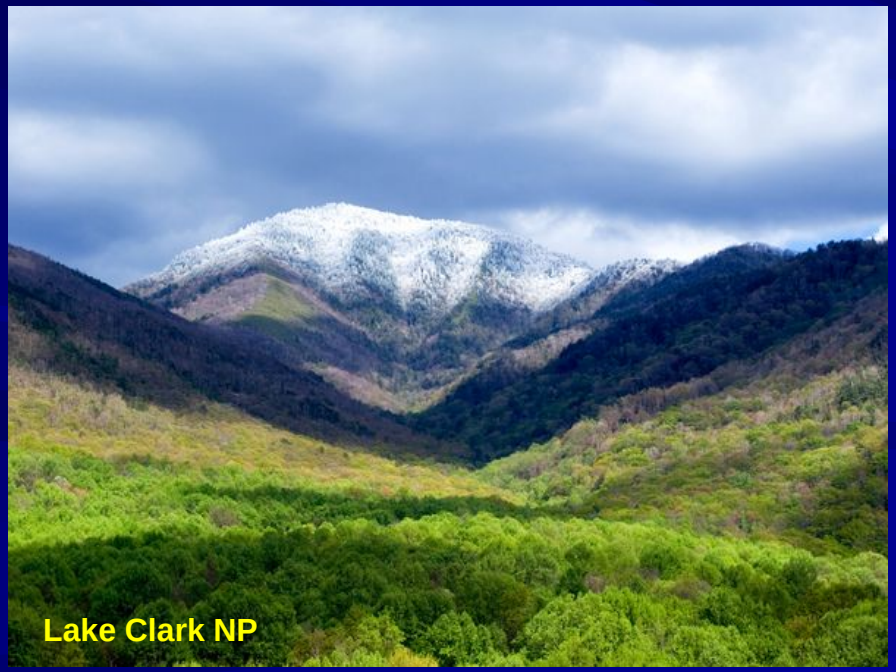


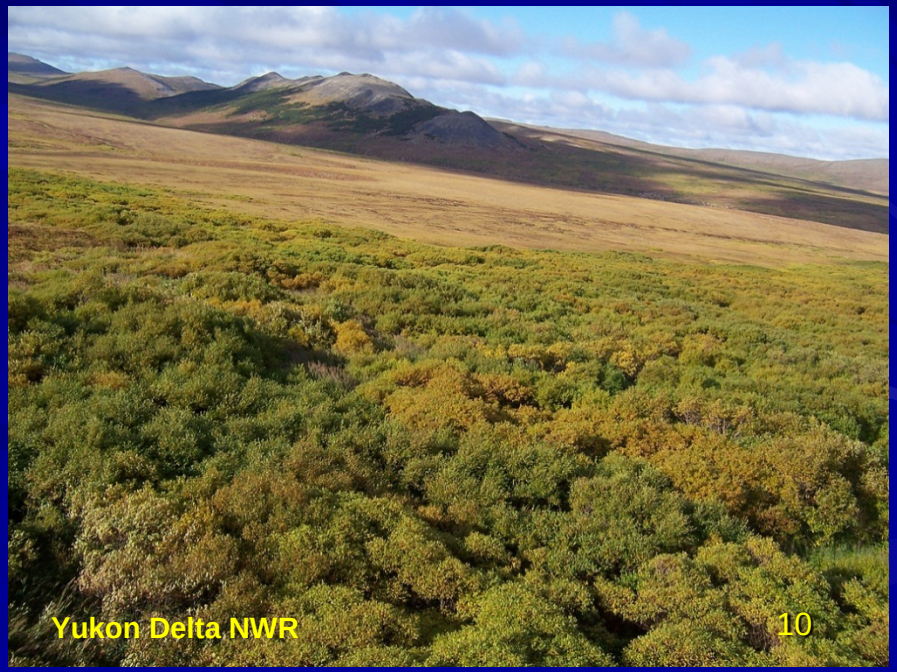


© CNHP

Shrub-Herb Tundra 17-11 ka
Dwarf Birch
Willow
Blueberry
Labrador tea
Crowberry
Cottongrass
Sedges
Grass
Tundra herbs

Alder shrubland 11-8 ka





White Spruce 8 ka

Black Spruce 5 ka

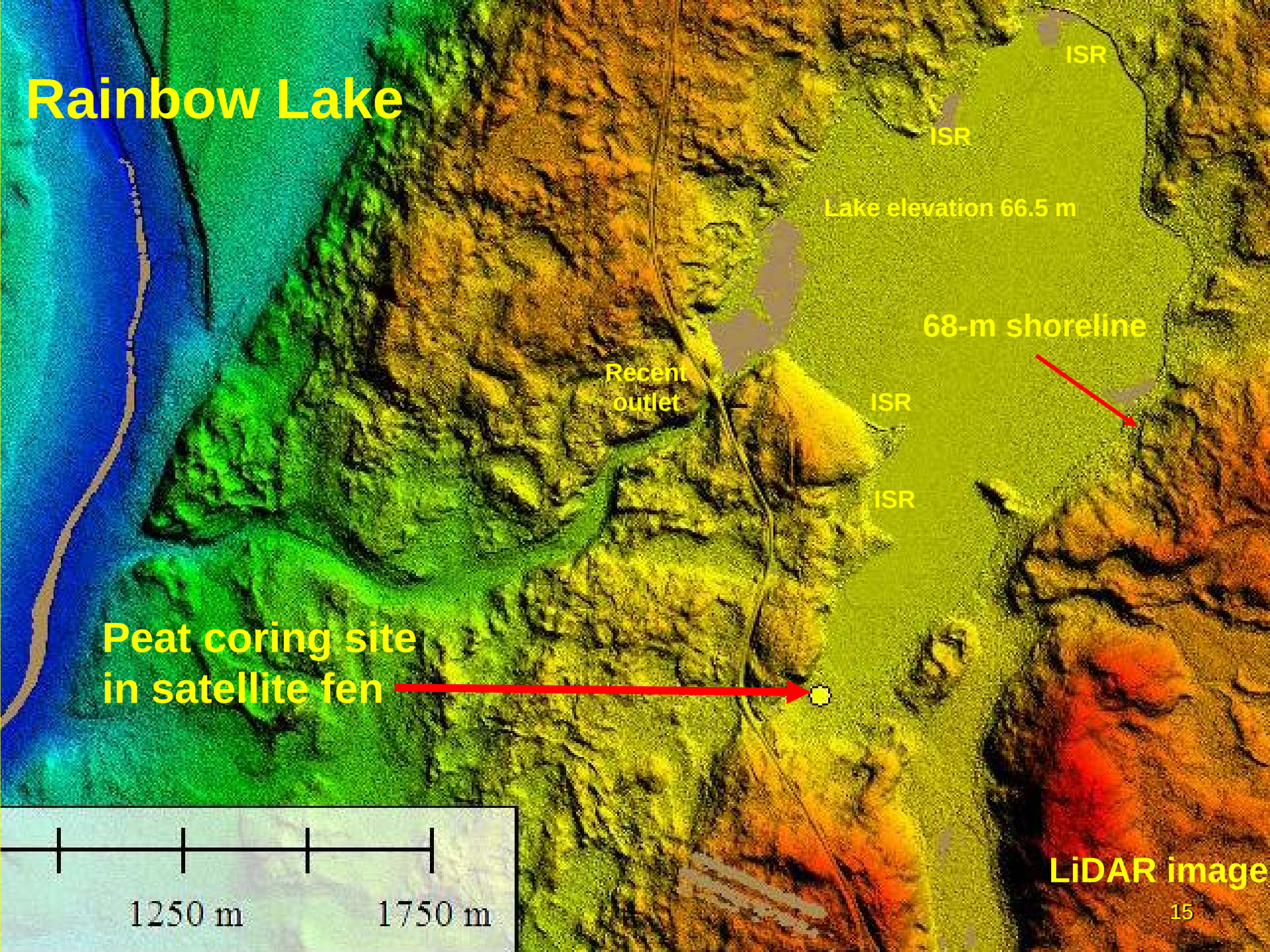
Sitka Spruce 2 ka

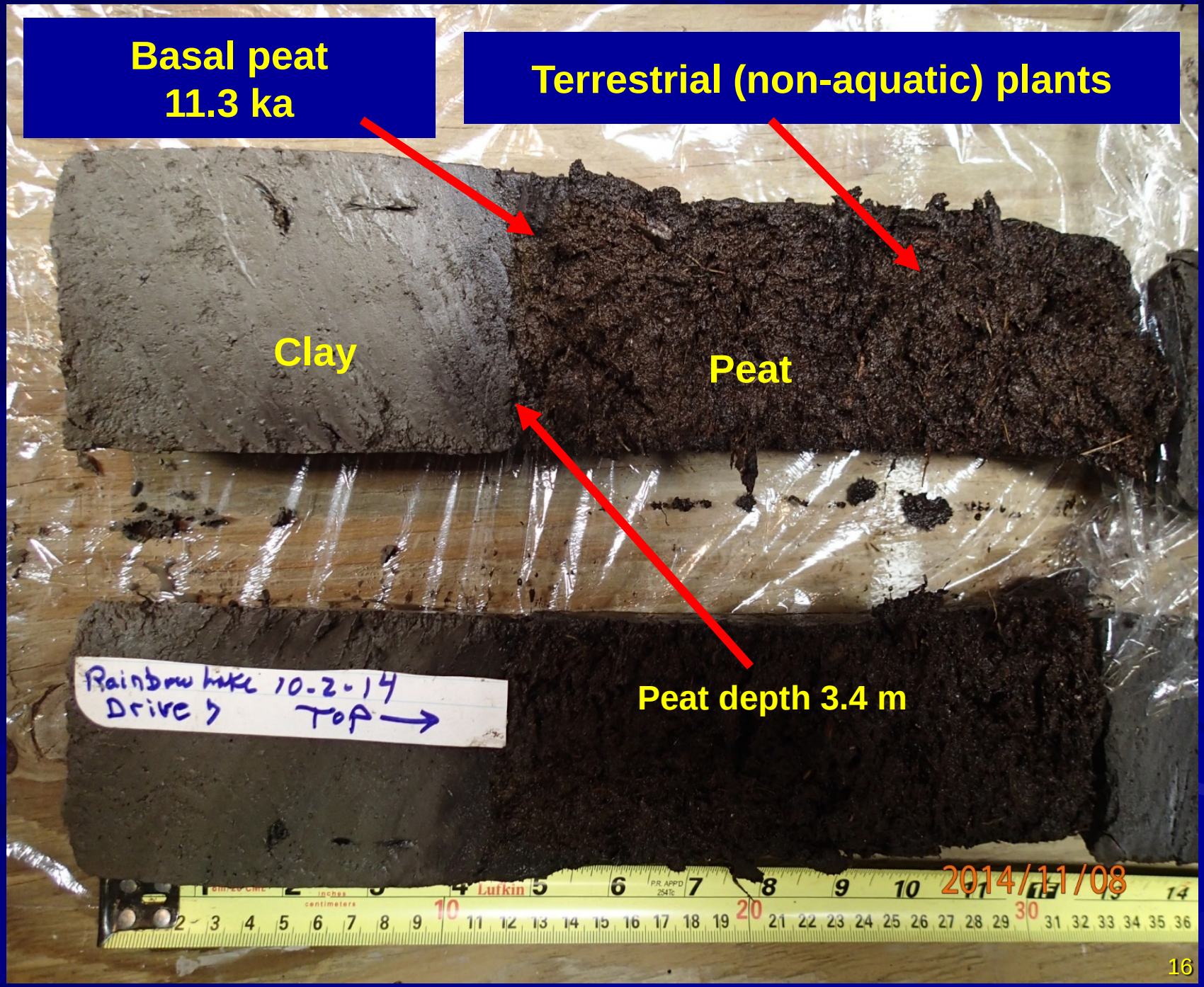
Lutz Spruce (Sitka-White Spruce hybrid)

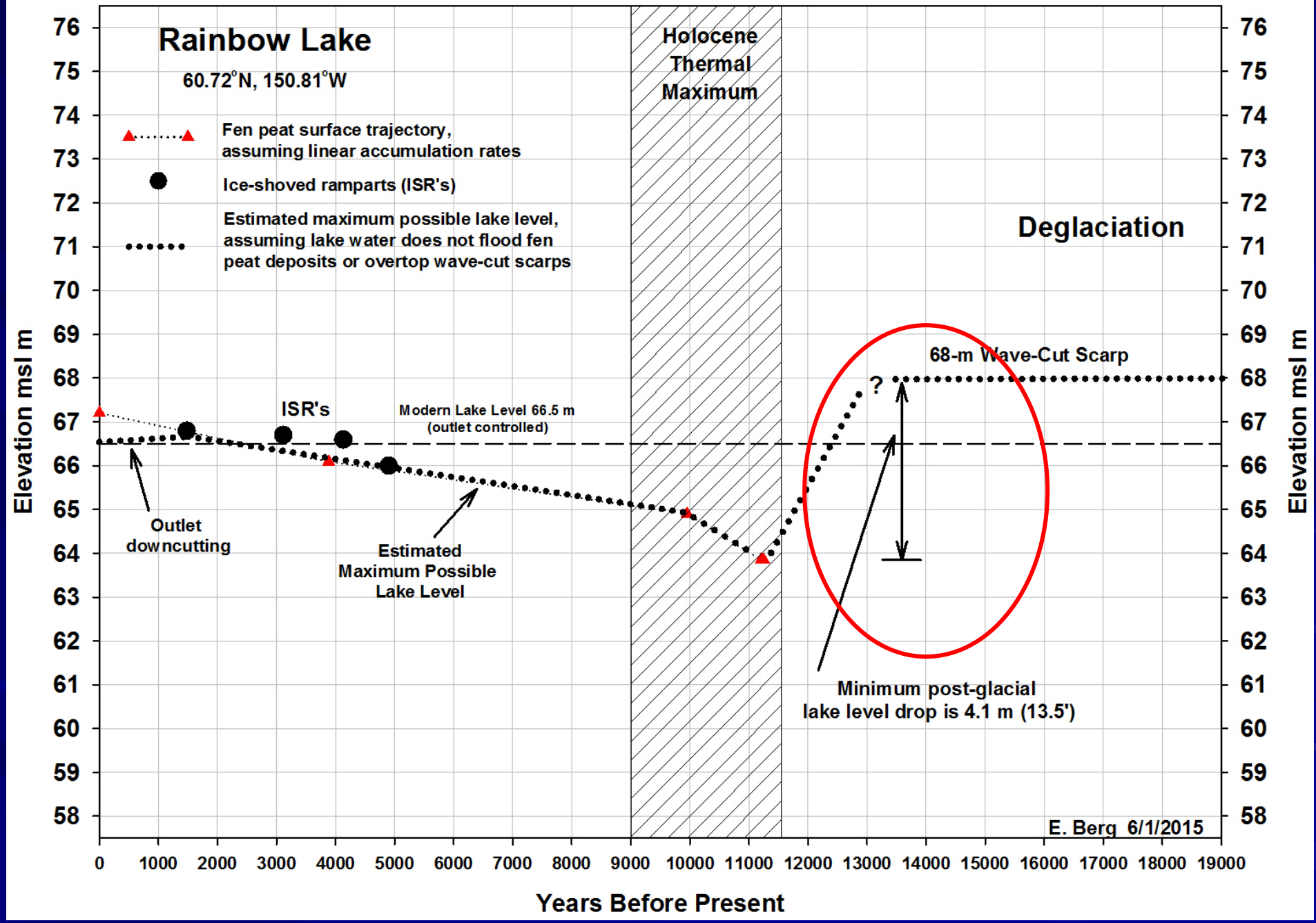
Paleo Lake Levels from Satellite Fen Peats

Rainbow Lake

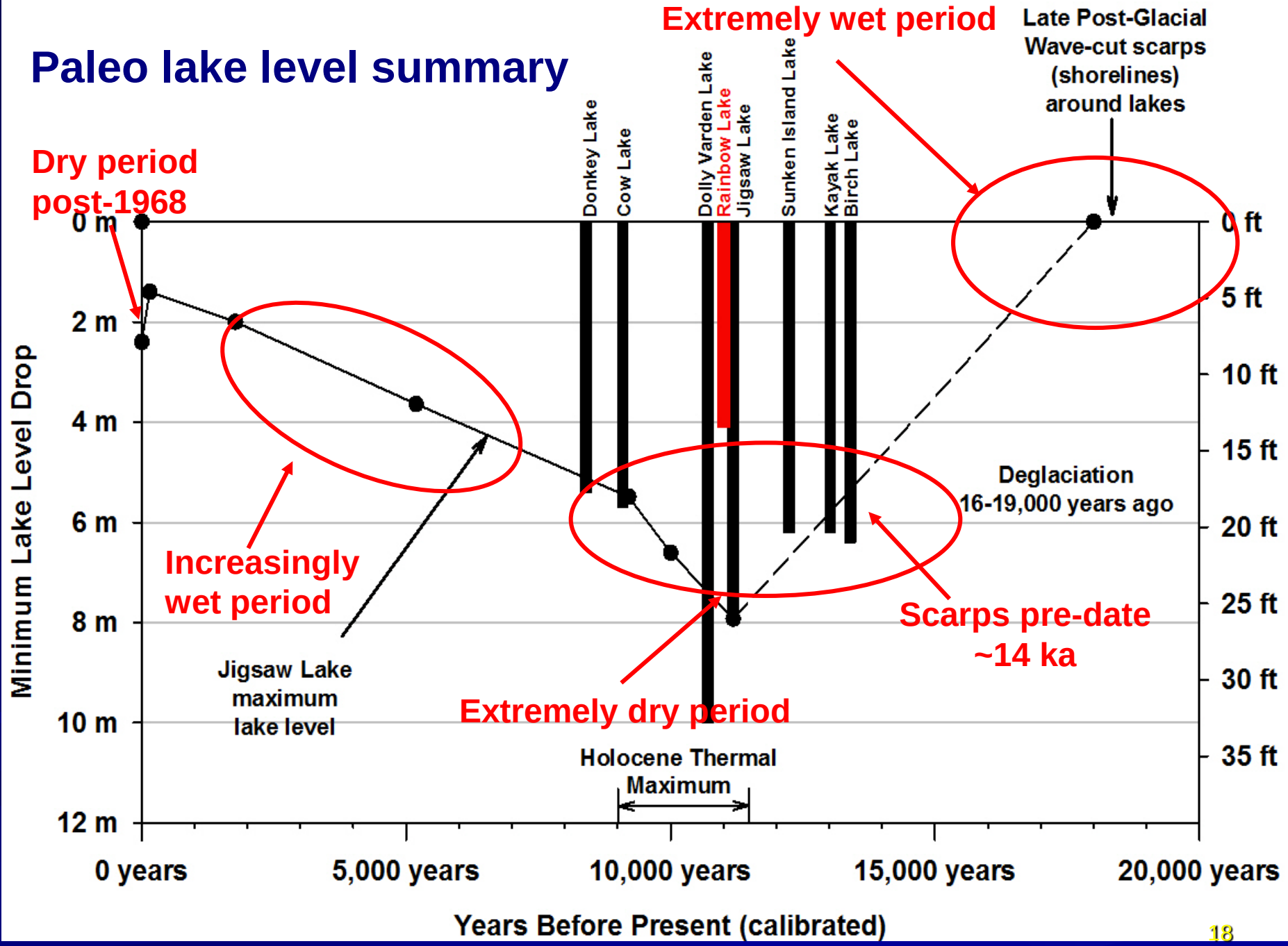
Satellite fen


Rainbow Lake
ISR
ISR
Lake elevation 66.5 m
68-m shoreline
Recent
outlet
ISR
ISR
Peat coring site
in satellite fen
1250 m
1750 m
LiDAR image

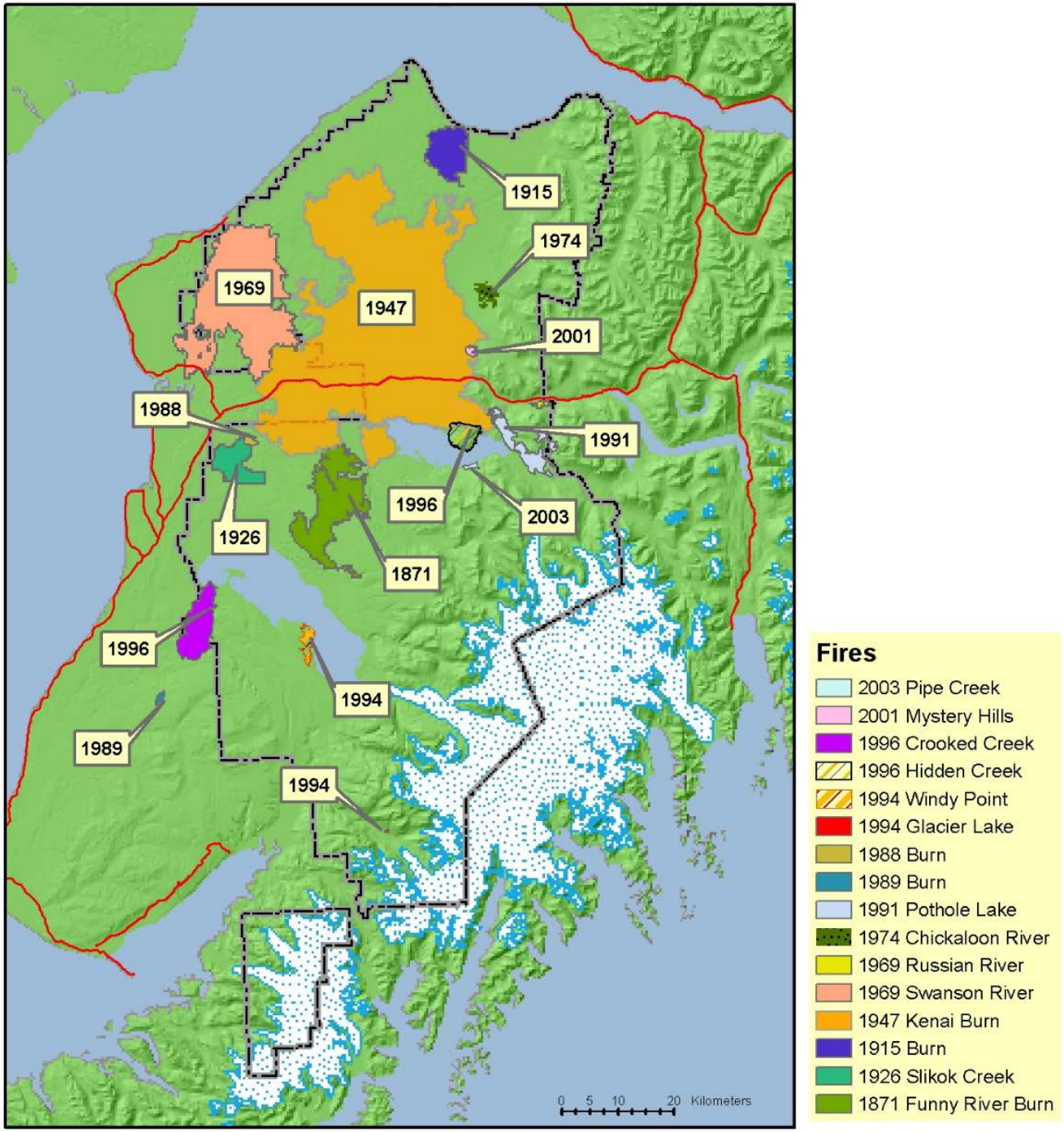

Basal peat
11.3 ka
Terrestrial (non-aquatic) plants
Clay
Peat
Peat depth 3.4 m
Rainbow Lake 10-2-14
Drive 7
Top
2014/11/08


Rainbow Lake
60.72°N, 150.81°W
Fen peat surface trajectory, assuming linear accumulation rates
Ice-shoved ramparts (ISR's)
Estimated maximum possible lake level, assuming lake water does not flood fen peat deposits or overtop wave-cut scarps
Holocene Thermal Maximum
Deglaciation
68-m Wave-Cut Scarp
?
ISR's
Modern Lake Level 66.5 m (outlet controlled)
Outlet downcutting
Estimated Maximum Possible Lake Level
Minimum post-glacial lake level drop is 4.1 m (13.5')
E. Berg 6/1/2015
Elevation msl m
Years Before Present

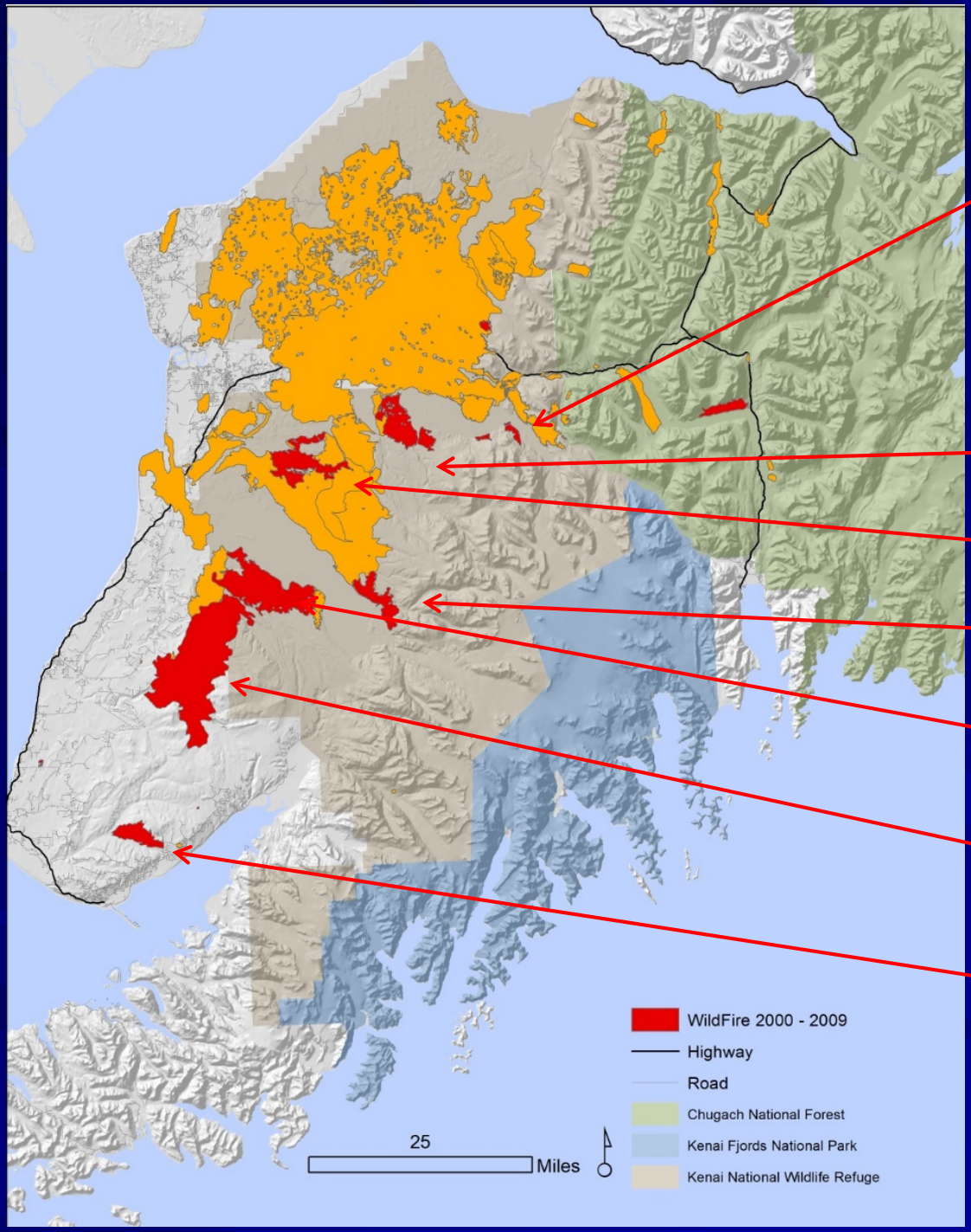
Paleo lake level summary



Fire History on the Kenai



Historical Fires up to 2003



2000's Fires

2005 Irish Channel

2005 King County Creek

2009 Shantatilik Creek

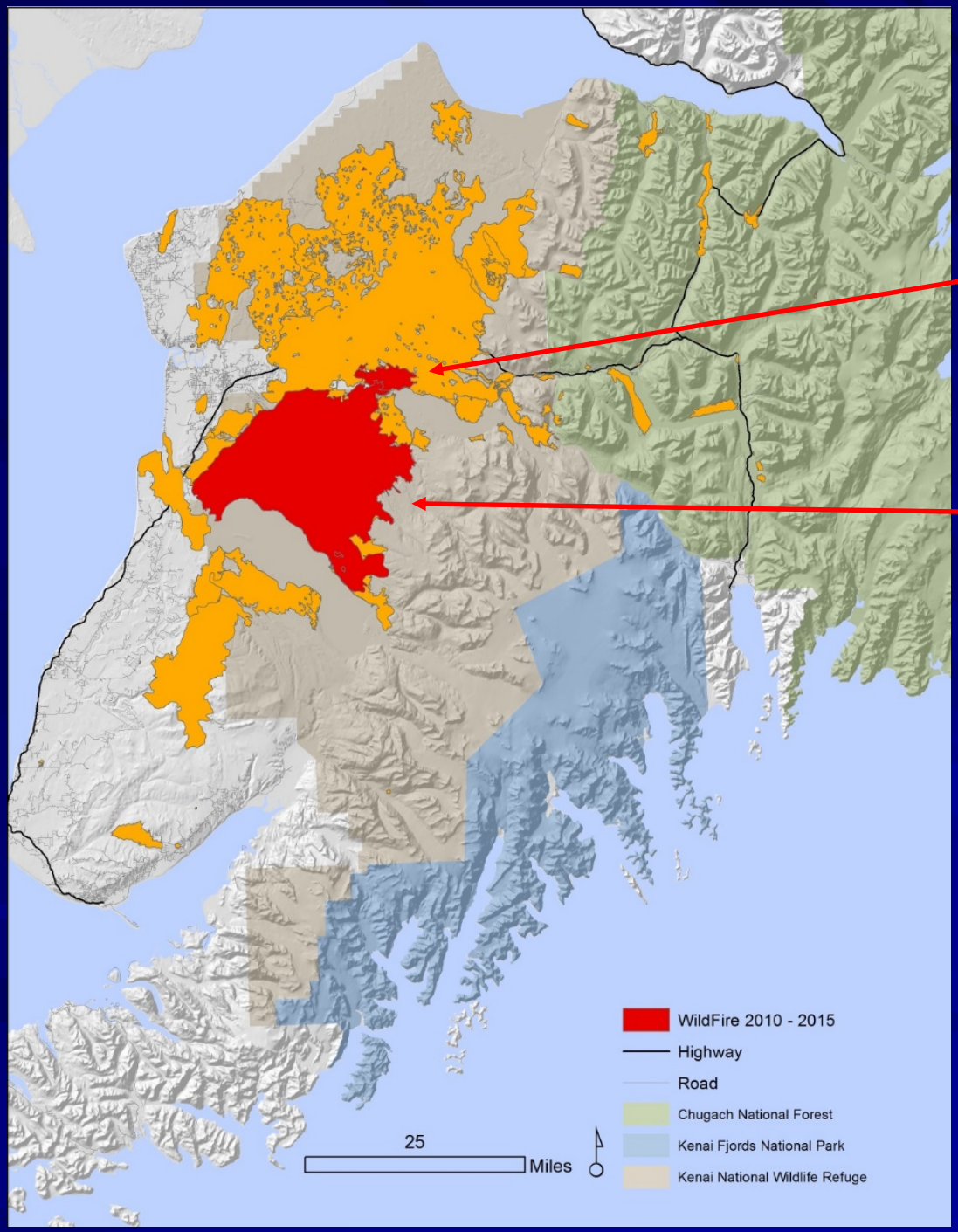
2005 Glacier Creek

2005 Fox Creek

2007 Caribou Hills

2005 Tracy Avenue

2010's Fires



2015 Card Street

2014 Funny River

Three Vegetation-Fire Regimes

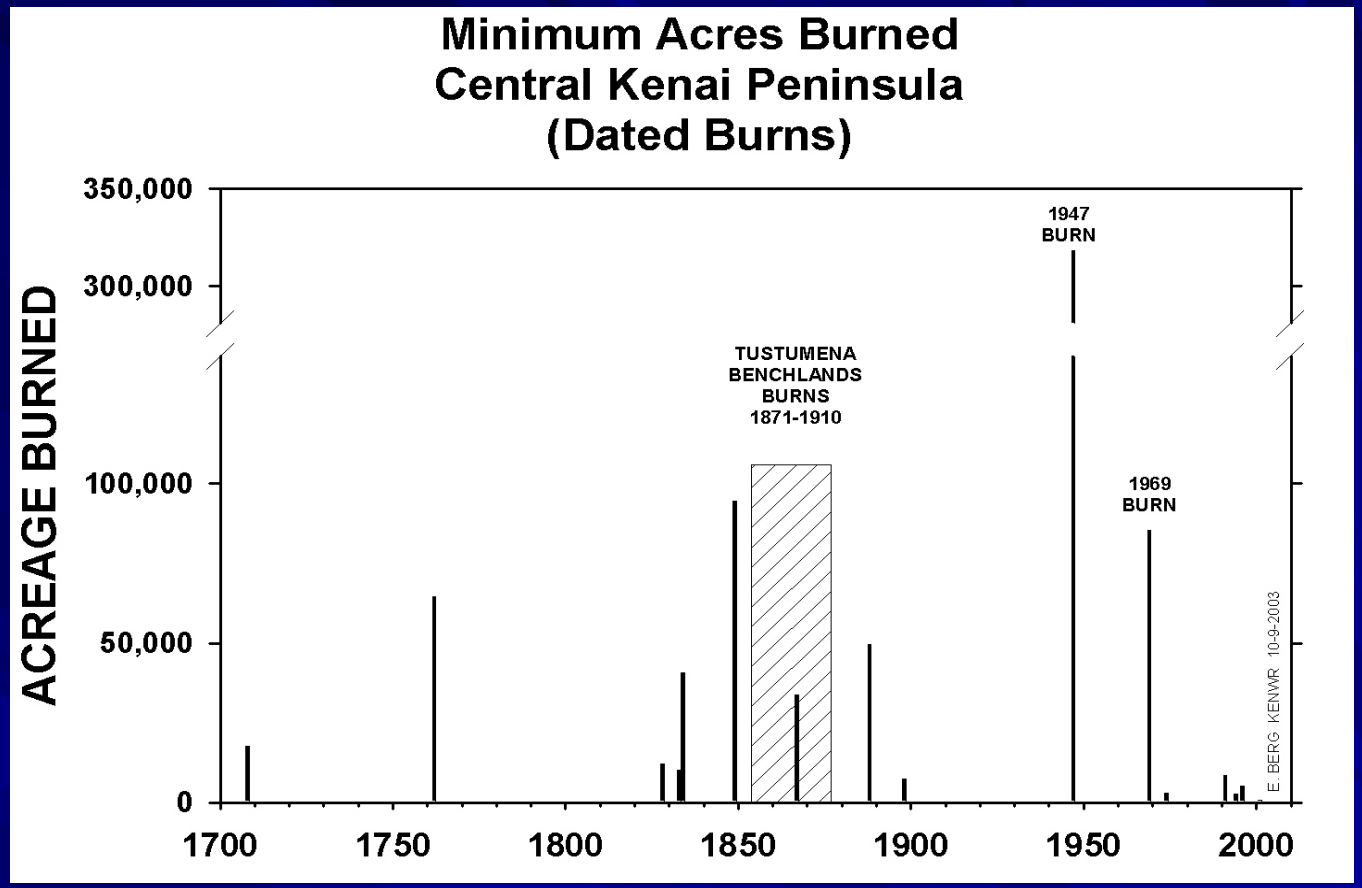
FOREST TYPE	METHOD	FIRE-RETURN-INTERVAL
Black Spruce	Fire Scars	80 years
Mixed White Spruce & Hardwoods	Lake Sediment Charcoal	130 years
White/Lutz Spruce	Soil Charcoal	400-600 years

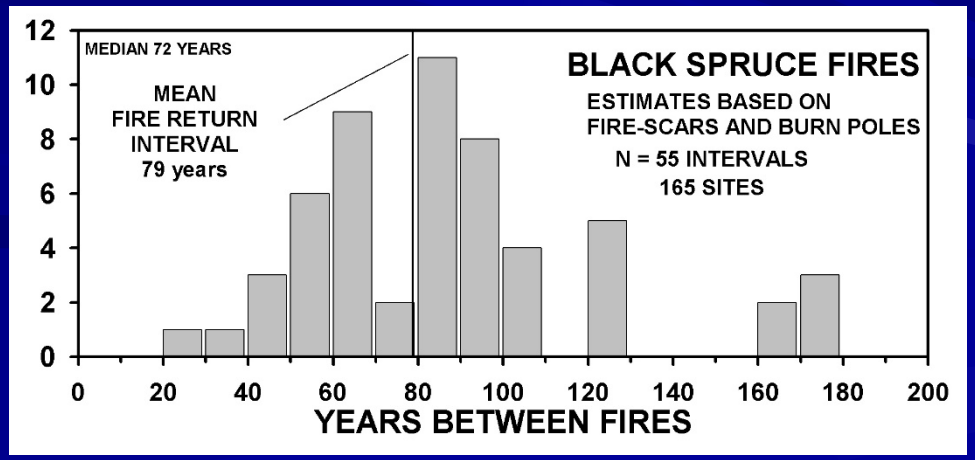
De Volder 1999, Anderson et al. 2006, Berg & Anderson 2006

Andy De Volder MS thesis 1999

Black Spruce

12 fires dated



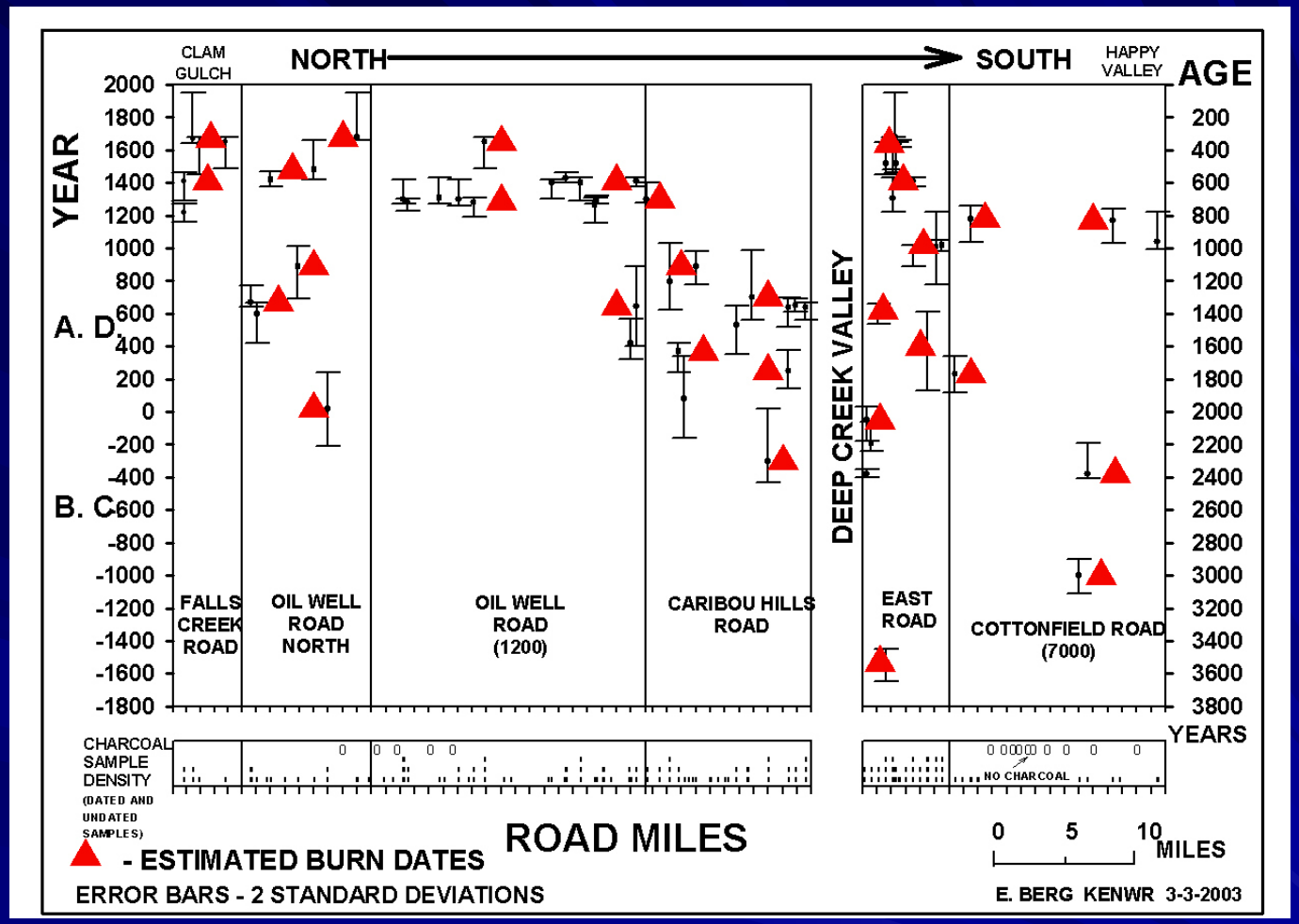


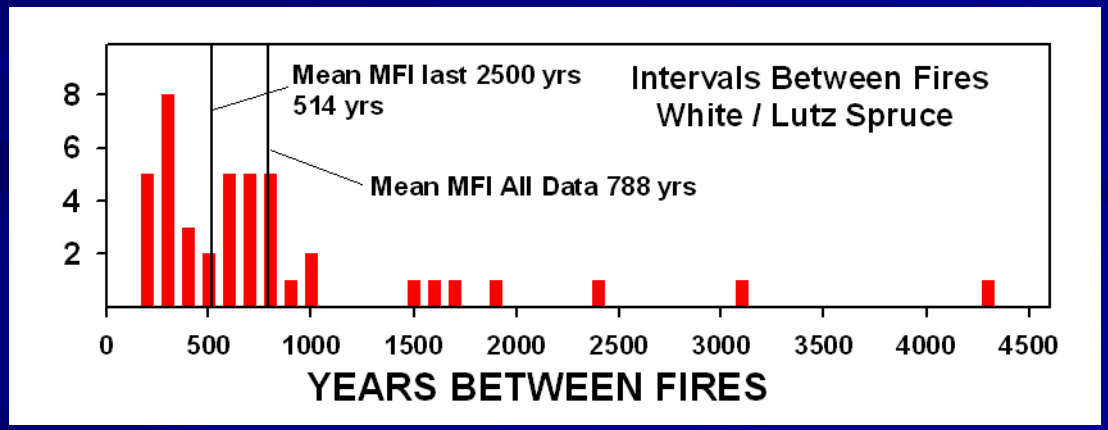
Throw Mounds – searching for soil charcoal

Berg & Anderson 2006

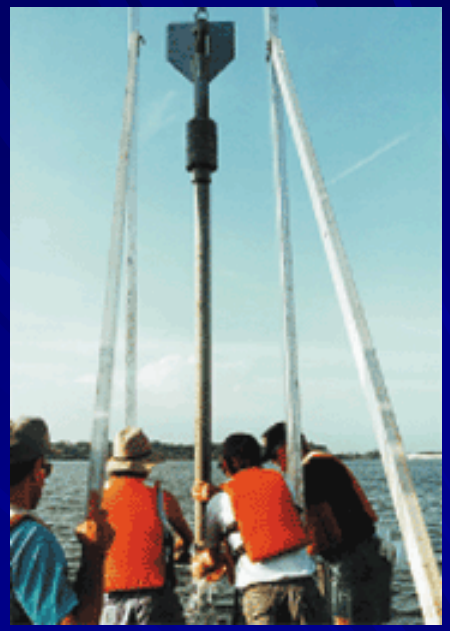
Soil charcoal flake

Soil charcoal results



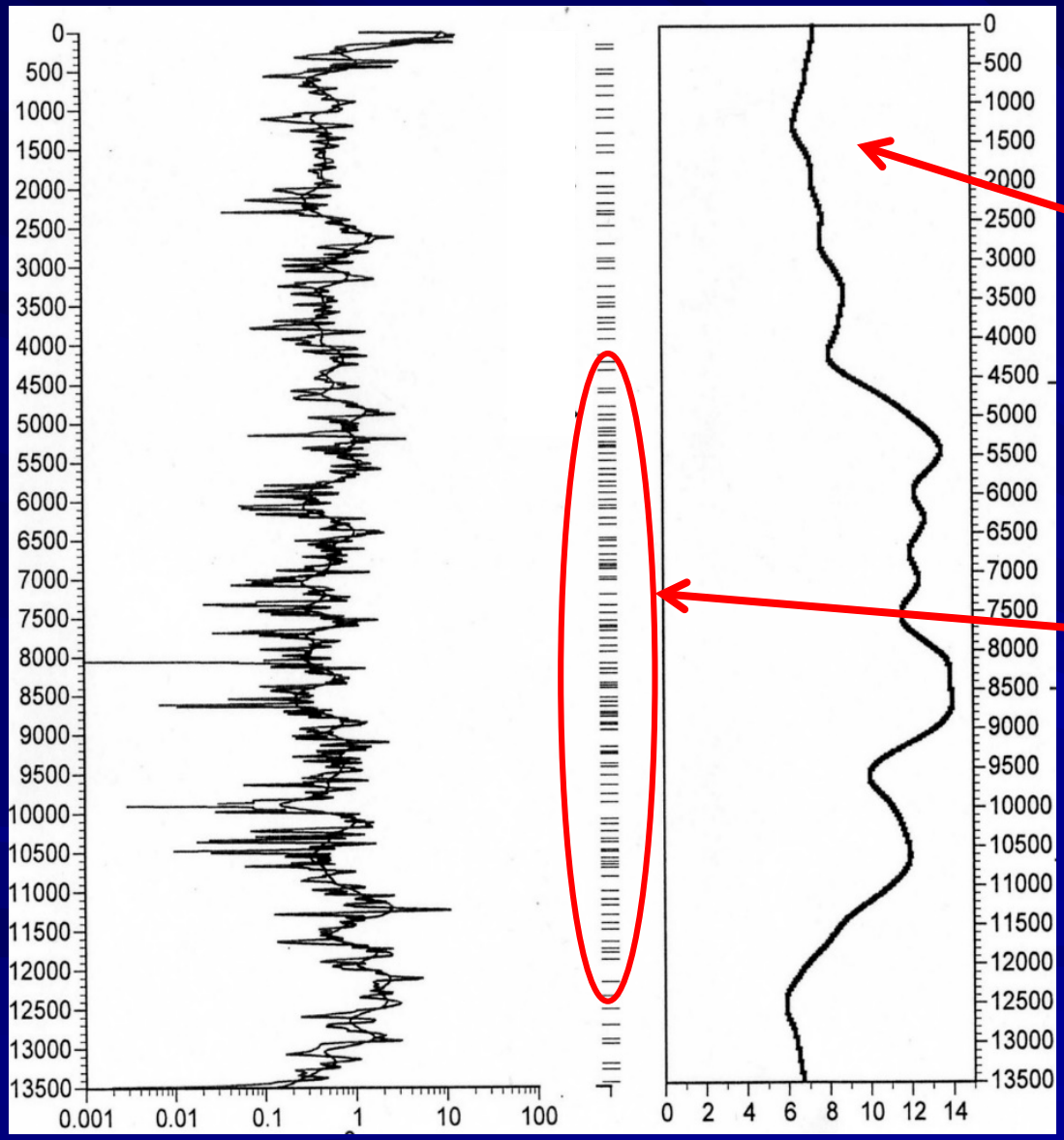


Lake Sediment Cores



- Long cores of lake bottom sediments
- Radiocarbon dating of charcoal
- Provides a “Fire Event Frequency,” rather than dates of specific fires
- Cannot estimate the size of a burn from the charcoal in lake sediments

Paradox Lake Fire Record



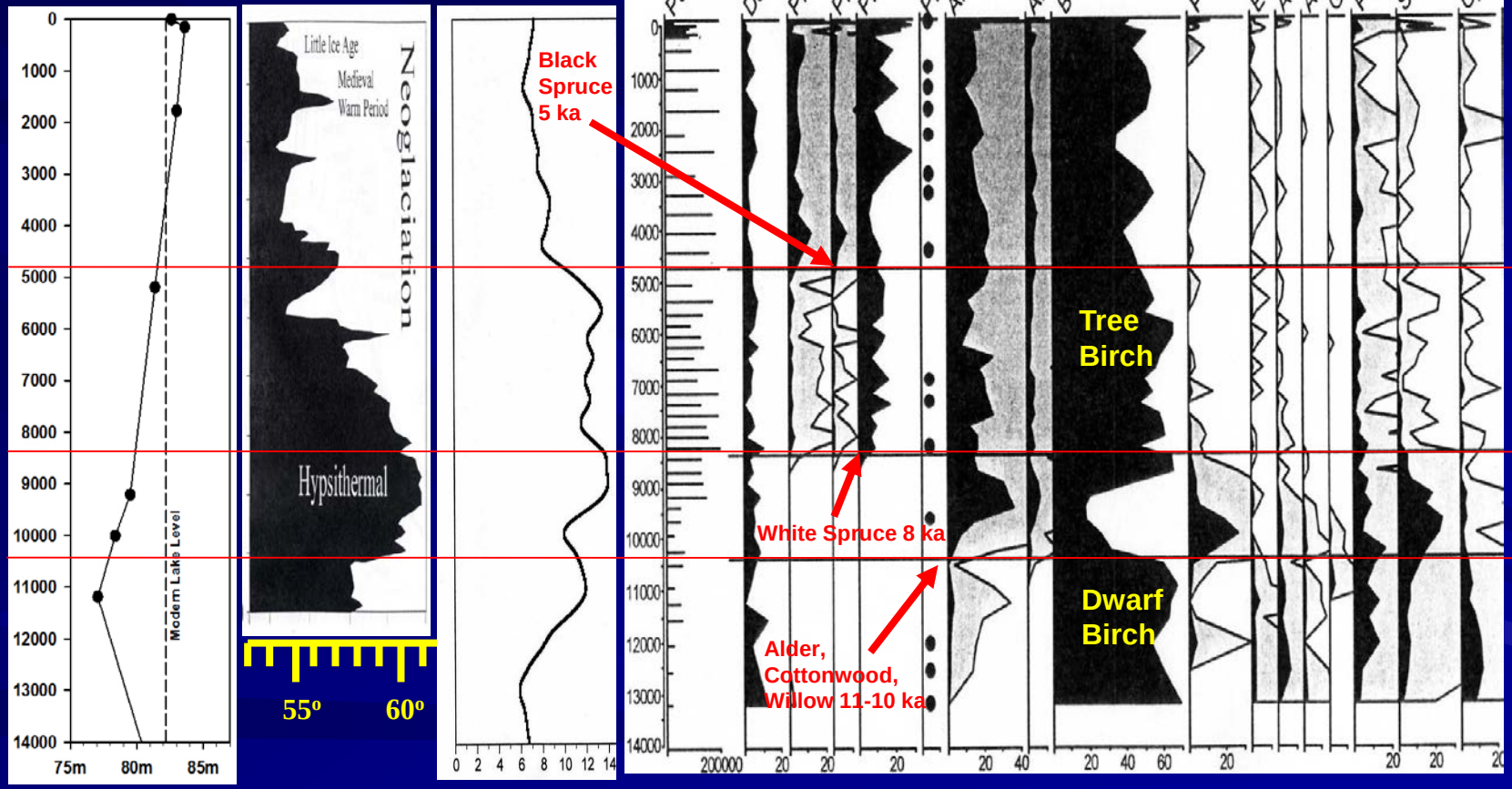
Modern fire frequency is 7.6 fires/1000 years, or fire-return-interval of 130 years. (Last 5000 years)

Fire frequency here was 12-14 fires/1000 years, or fire-return-interval of 70-80 years. (12,000 – 5000 years ago)

Anderson et al 2006

Paradox Lake vegetation zones over last 14,000 years

Lake Level m (Jigsaw Lake) | **Temperature** (southern Alaska) | **Fires** per 1000 yrs



White spruce, black spruce, & birch forest

White spruce – birch forest

Alder – *Populus* shrub tundra

Dwarf birch shrub tundra

Spruce bark beetle outbreak history

Figure 4 - An adult spruce beetle.

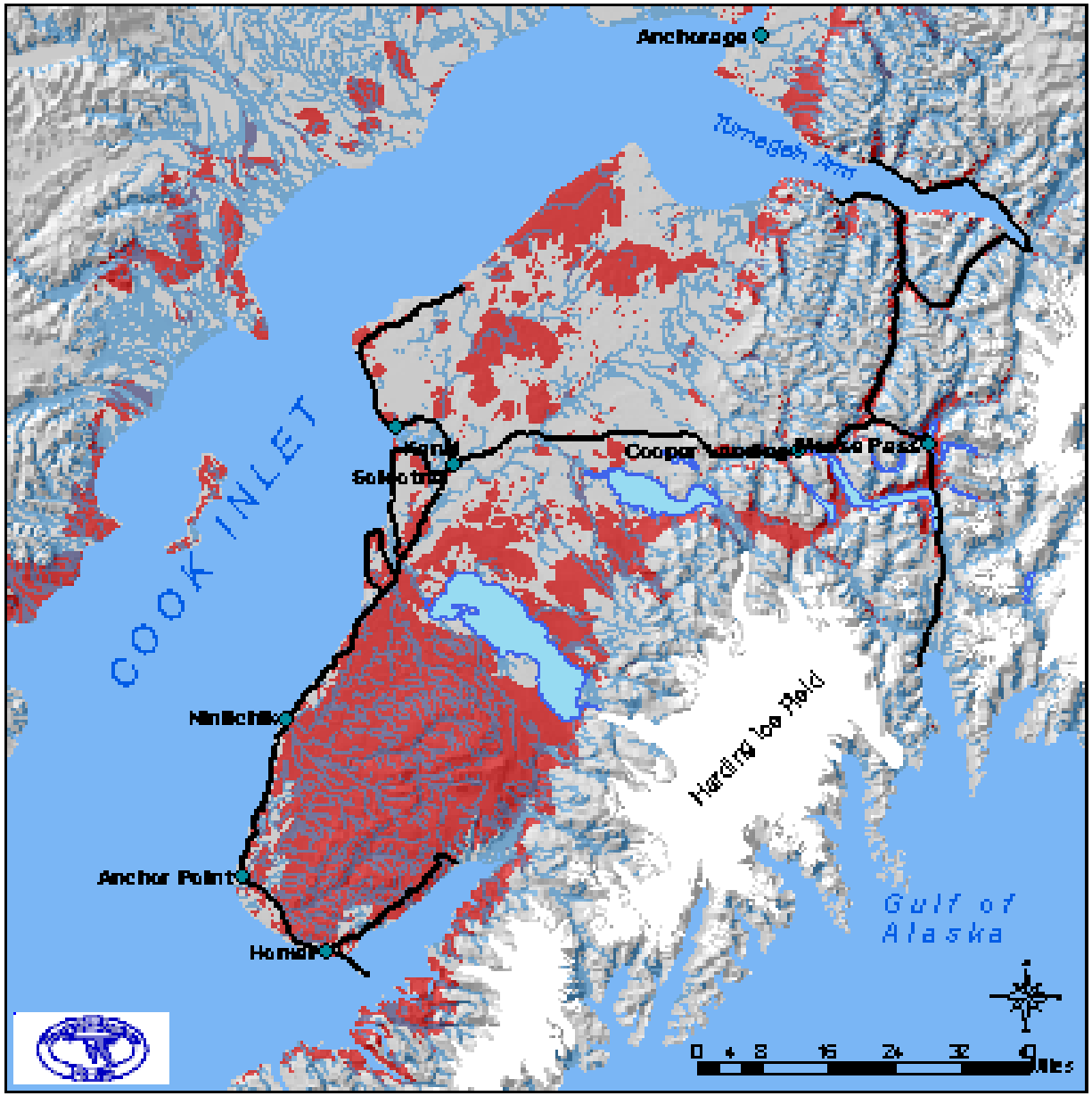
Figure 5 - Spruce beetle eggs along side of egg gallery.

Figure 6 - Spruce beetle larval galleries.

Figure 1 -- Yellowish orange and reddish colors of faded spruce are evidence of an intense spruce beetle infestation in Alaska.

Kenai Cumulative Outbreak

Total Beetle Kill
3.0 million acres
in Southcentral Alaska
and
1.1 million acres
on the Kenai



Spruce
Bark Beetle
1989-2002

History of Spruce Bark Beetle Outbreaks in Alaska

In 1993 we knew about a few past outbreaks:

- Copper River Valley 1920s

- Haines Road (Yukon) 1940s

- Northern Kenai 1970s

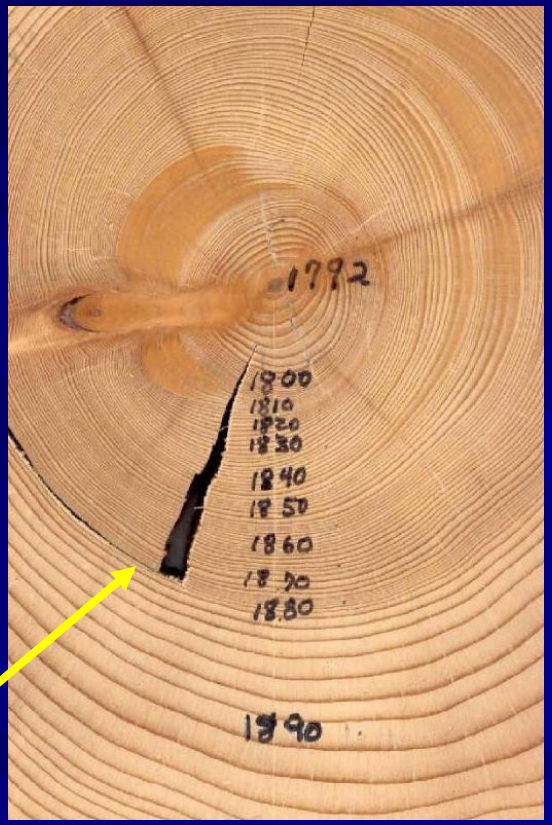
To get a longer outbreak record, we imported a tree-ring method from Colorado which used growth releases to document outbreaks along the Front Range in the 1850s and 1940s.

Growth Releases in Tree-rings

- **Bark beetles kill the larger trees first.**

- **Smaller trees are released from competition, and grow faster.**

An Extreme Example of a Growth Release



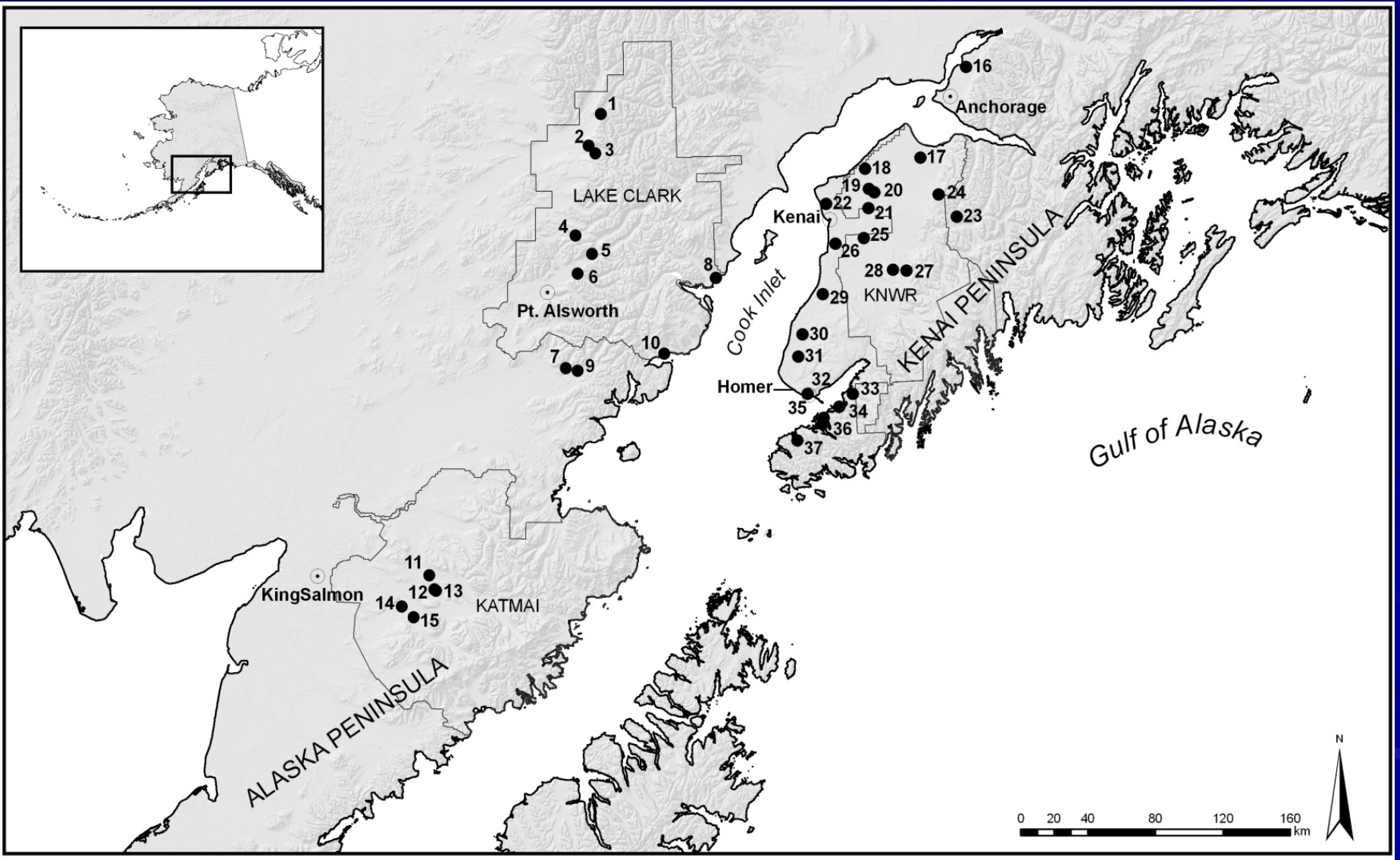
1884 Release

Tree-ring Methods

- We measured tree-ring widths in hundreds of increment core samples from 37 stands.

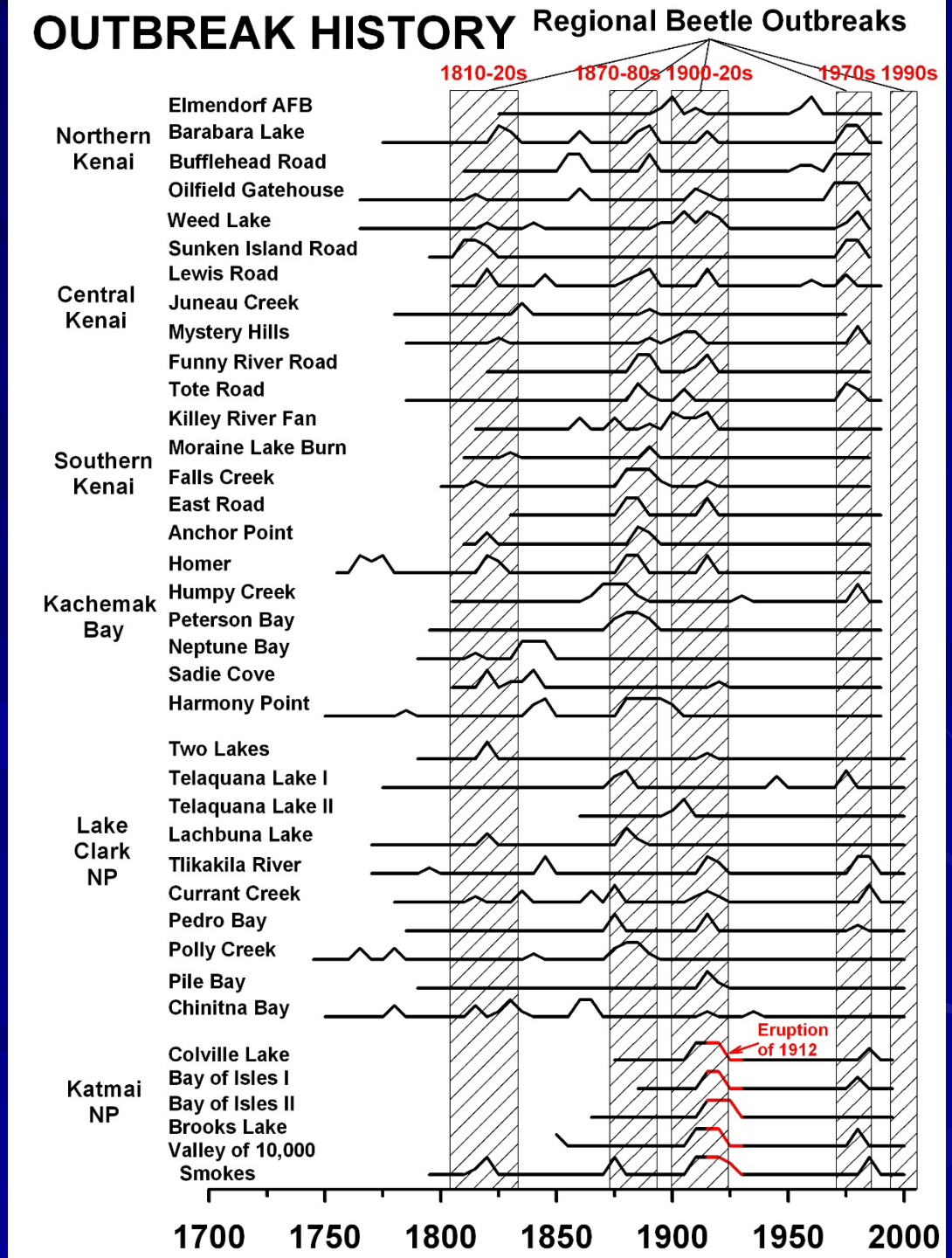
- Ring widths were measured to 0.001 mm with a dissecting microscope and a sliding bench micrometer.

Outbreak History Study Sites

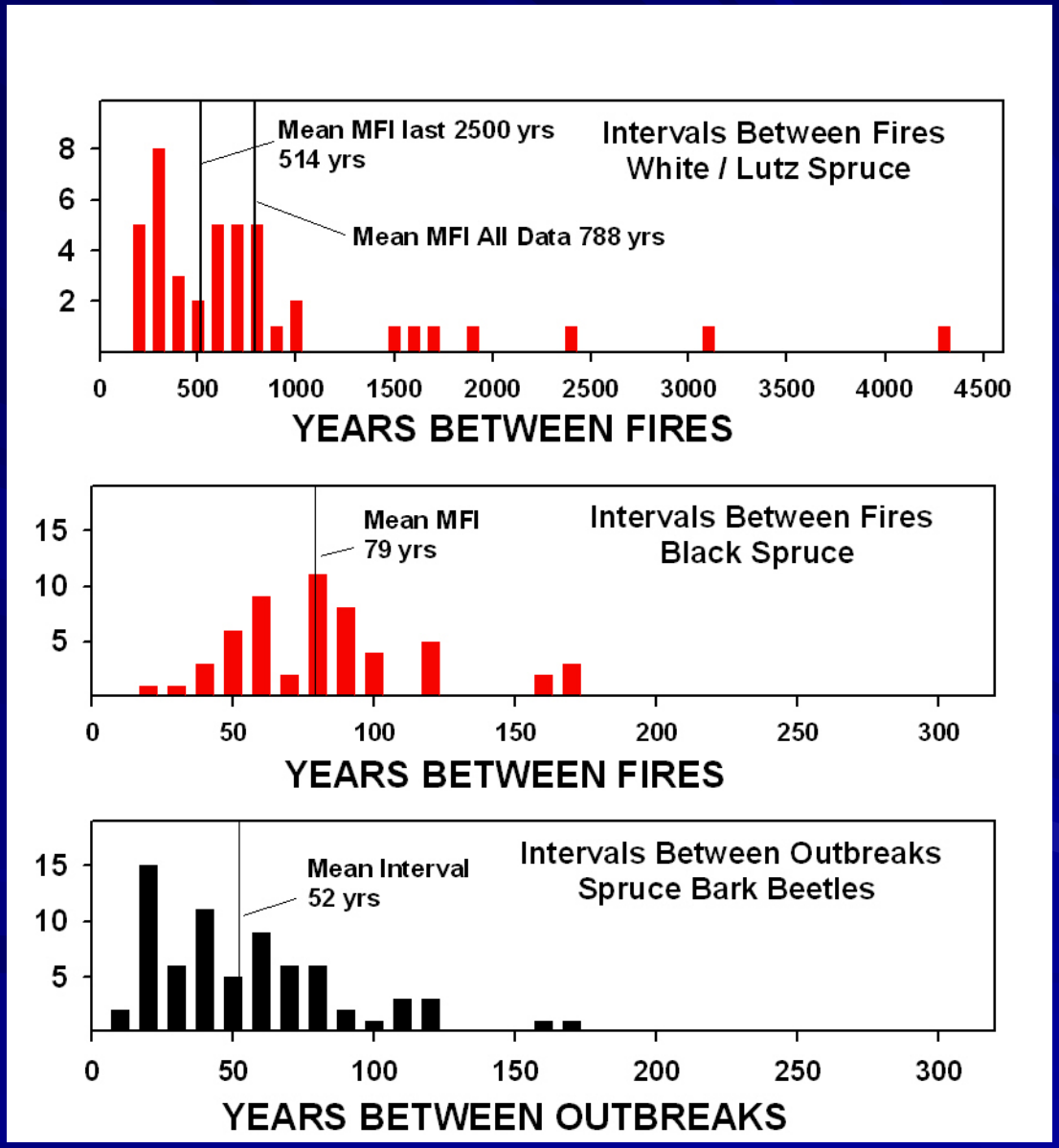


Kenai studies 1994-2002 22 sites (with Chris Fastie)
Katmai & Lake Clark studies 2006-2007 15 sites (with Rosemary Sherriff & Amy Miller)

Spruce Bark Beetle Outbreak Summary



N = 37 sites


Mean MFI last 2500 yrs
514 yrs
Intervals Between Fires
White / Lutz Spruce
Mean MFI All Data 788 yrs
8
6
4
2
0
500
1000
1500
2000
2500
3000
3500
4000
4500
YEARS BETWEEN FIRES
Mean MFI
79 yrs
Intervals Between Fires
Black Spruce
15
10
5
0
50
100
150
200
250
300
YEARS BETWEEN FIRES
Mean Interval
52 yrs
Intervals Between Outbreaks
Spruce Bark Beetles
15
10
5
0
50
100
150
200
250
300
YEARS BETWEEN OUTBREAKS

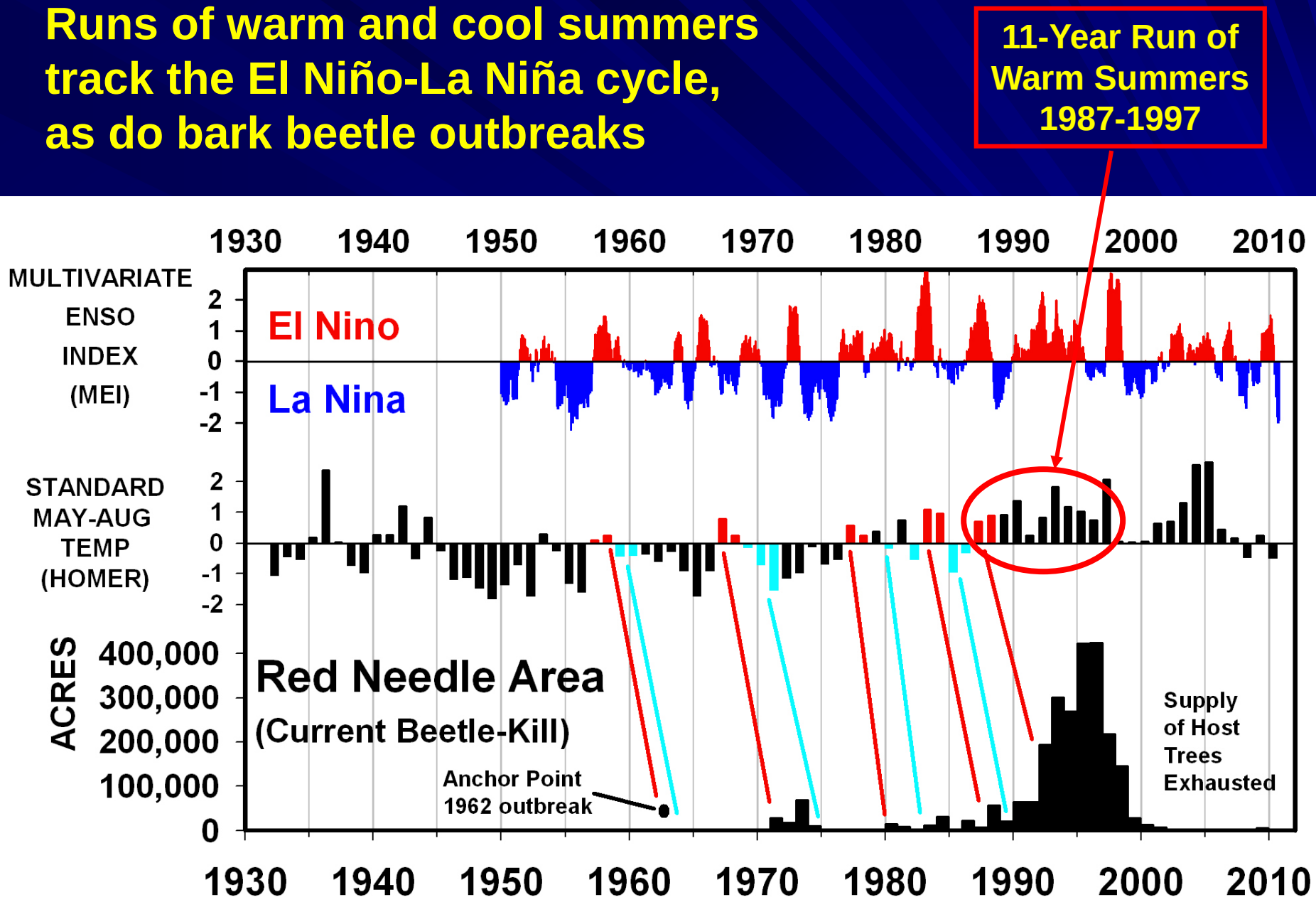
Bark Beetles and Runs of Warm Summers

Two factors are critical:

(1) A Loaded Gun – The forests must be mature or very mature

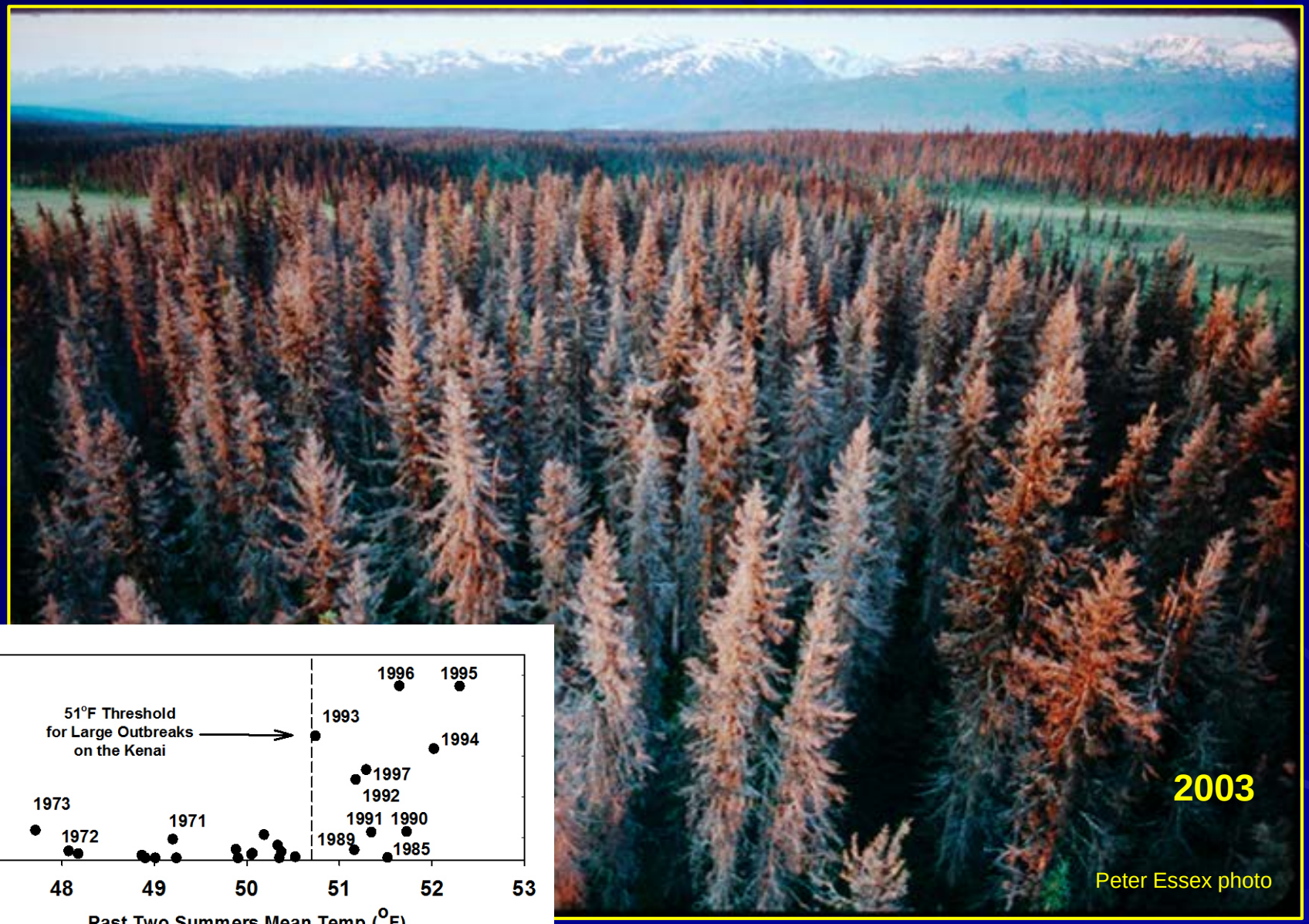
(2) A Trigger – a run of 2 or more warm summers can initiate an outbreak

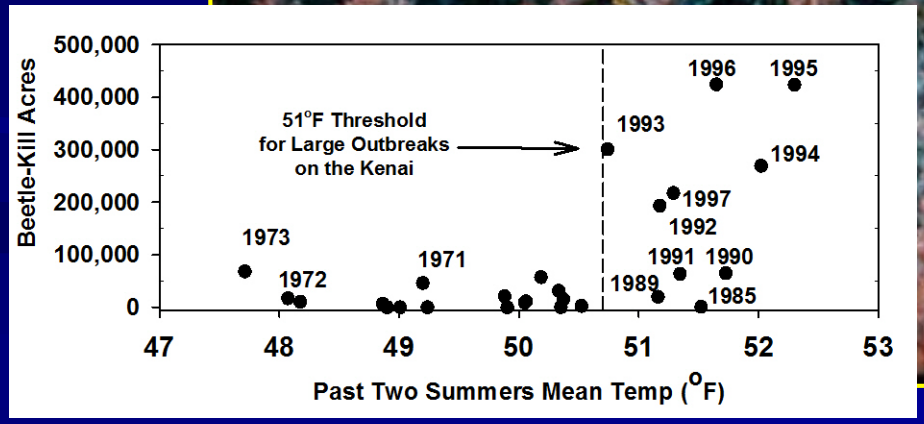
Runs of warm and cool summers track the El Niño-La Niña cycle, as do bark beetle outbreaks



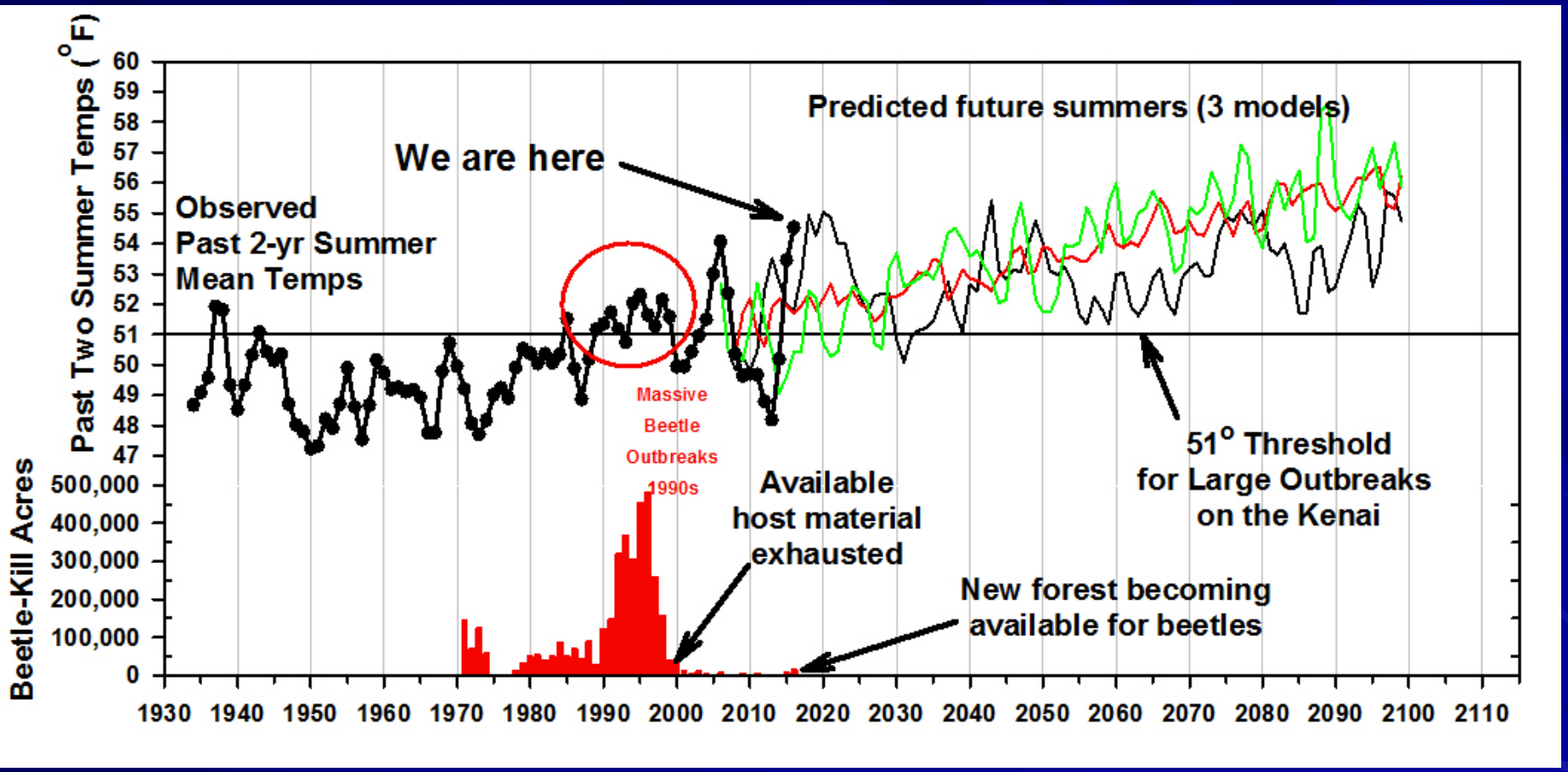
Southern Kenai Peninsula

Spruce Bark Beetle in White/Lutz Spruce in Kachemak Bay

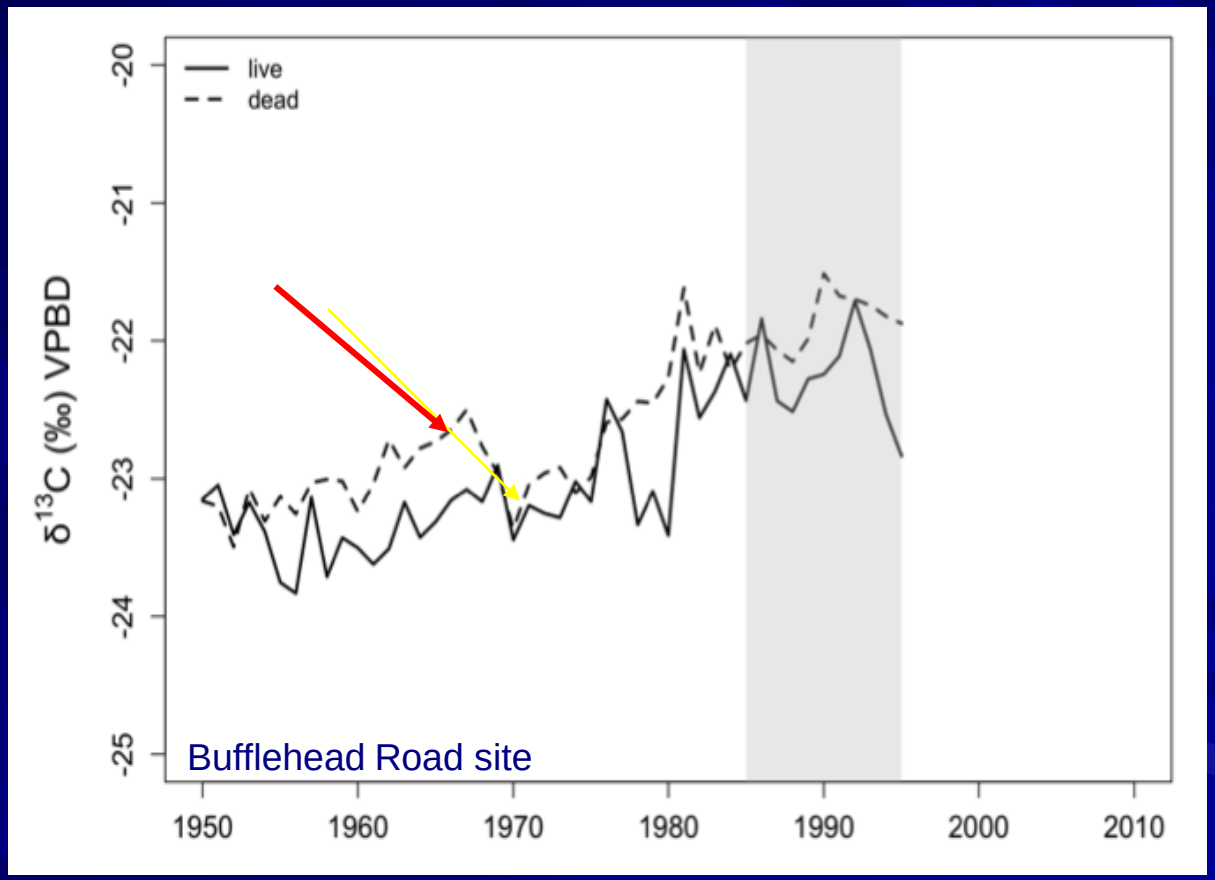




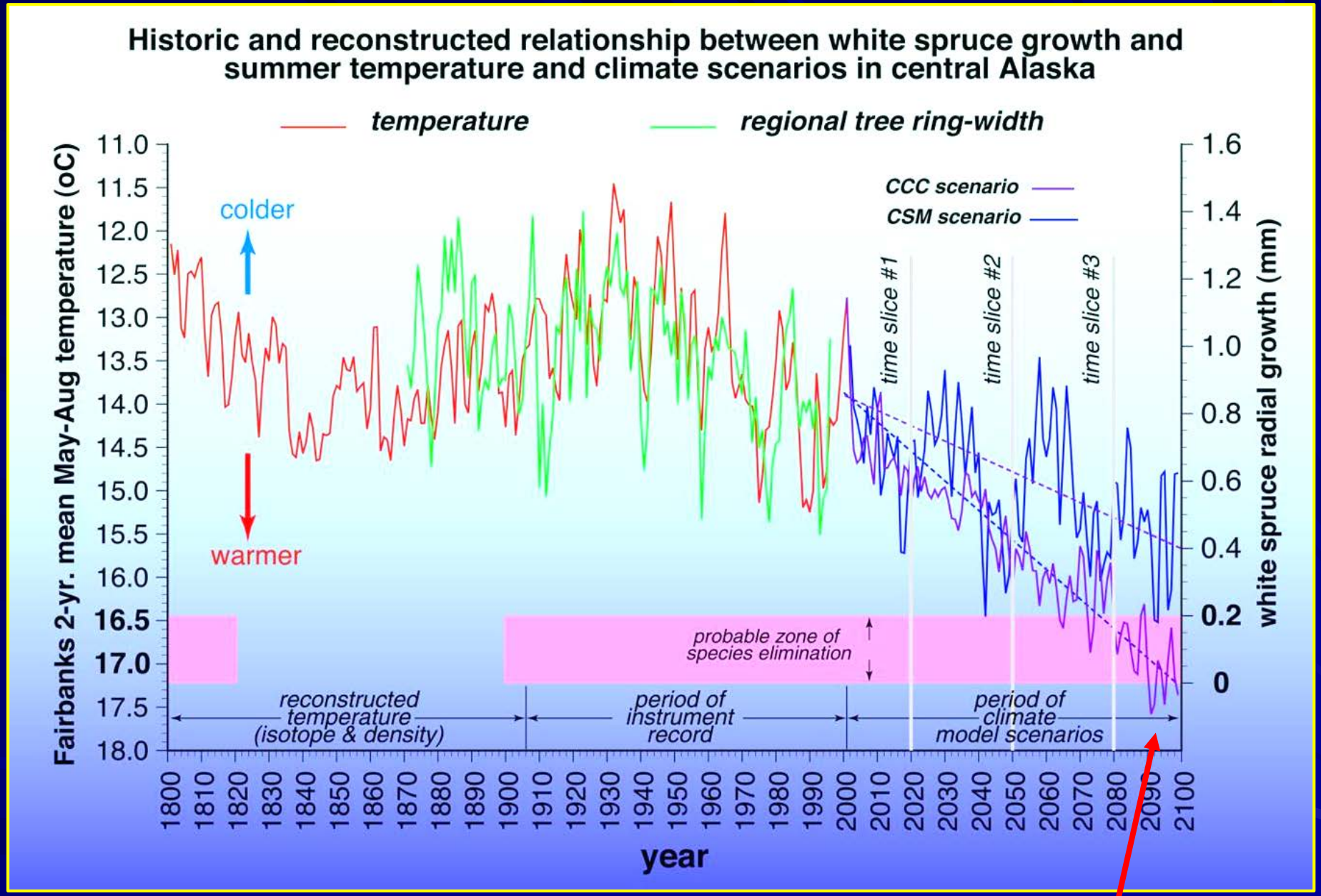
Berg et al. 2006


Past Two Summer Temps (°F)
60
59
58
57
56
55
54
53
52
51
50
49
48
47
Beetle-Kill Acres
500,000
400,000
300,000
200,000
100,000
0
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
Predicted future summers (3 models)
We are here
Observed
Past 2-yr Summer
Mean Temps
Massive
Beetle
Outbreaks
1990s
Available
host material
exhausted
New forest becoming
available for beetles
51° Threshold
for Large Outbreaks
on the Kenai

New study:
Excess ^{13}C in tree-rings indicates drought stress in beetle-killed white spruce

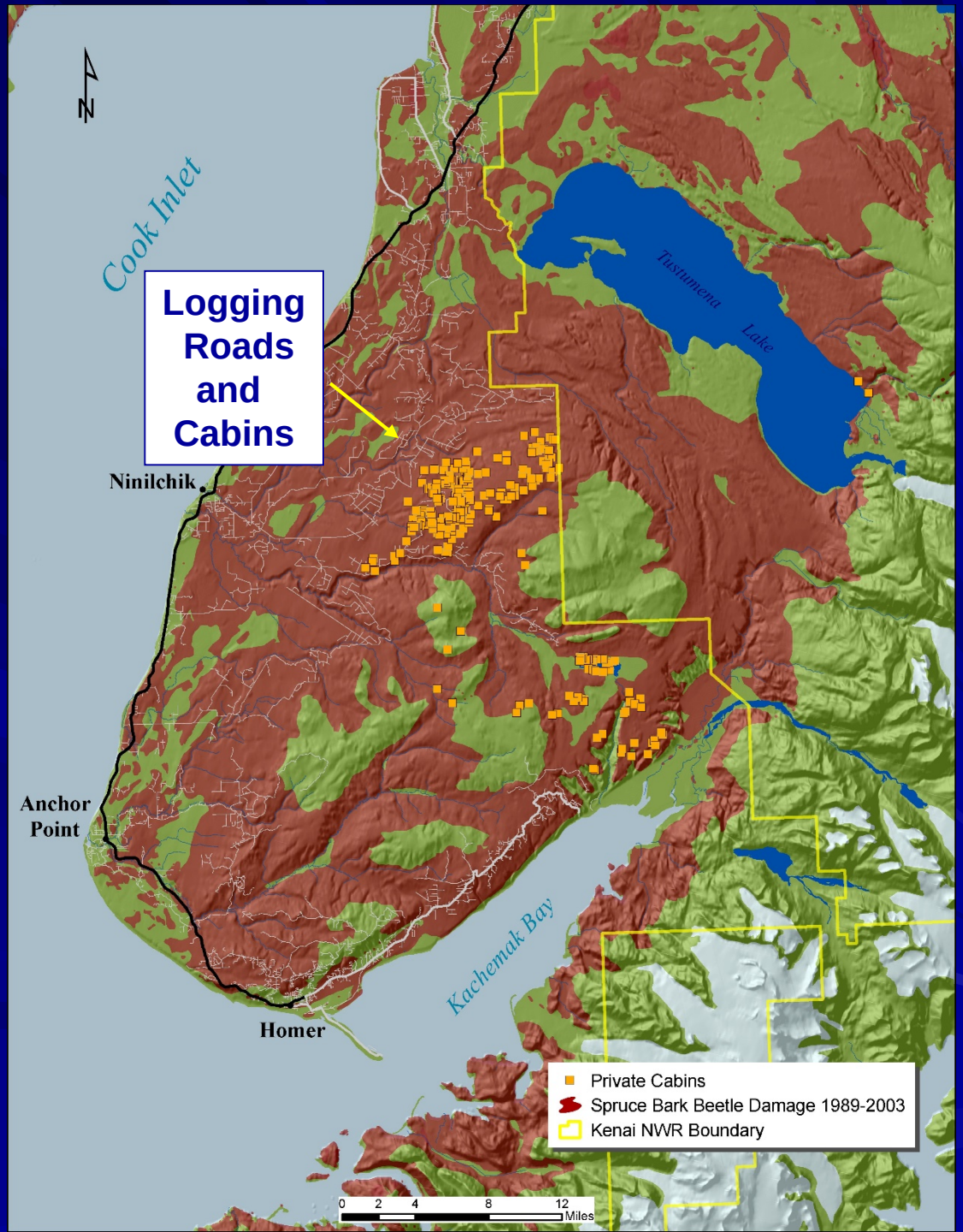


Csank, Miller, Sherriff, Berg & Welker (in press) Tree-ring isotope chronologies reveal drought sensitivity in trees killed during south-central Alaska insect outbreaks. *Ecological Applications*



Tree ring-widths go to 0 mm at 2100 due to drought stress

Subdivision and Cabin Fever Follow Logging of Beetle-killed Forest



A New Savannah in the Logged Areas?

East of Ninilchik

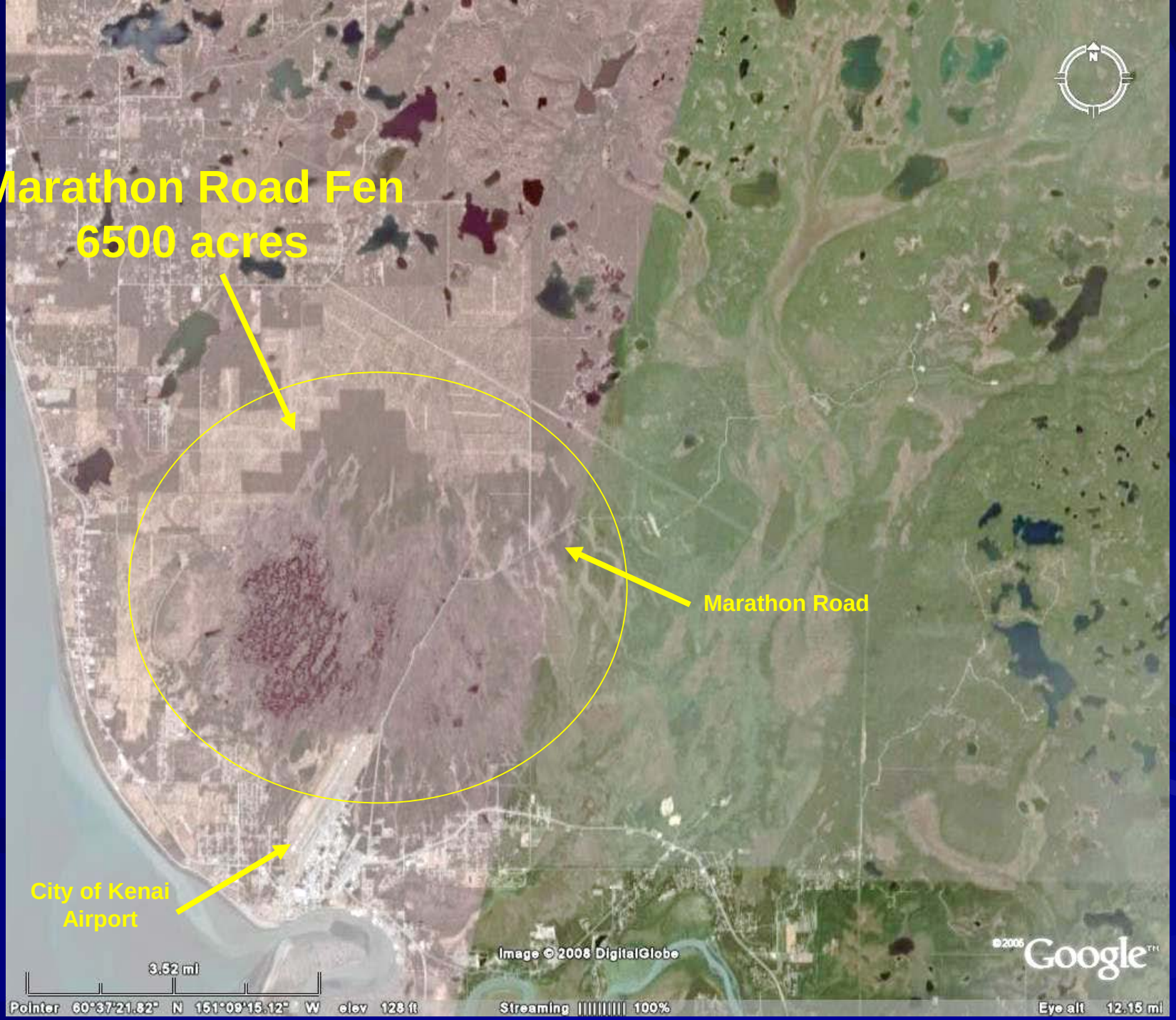
2005 photos

Drying Lakes & Wetlands on the Kenai Lowlands

Old Shoreline
Jigsaw Lake
(a closed-basin lake)

Old Waterlines
Jigsaw Lake
(a closed-basin lake)

Old Shoreline (1989)
Bulls-Eye Kettle
(a closed-basin pond)


Marathon Road Fen
6500 acres
Marathon Road
City of Kenai
Airport
3.52 mi
Image © 2008 DigitalGlobe
©2006 Google
Pointer 60°37'21.82" N 151°09'15.12" W elev 128 ft
Streaming 100%
Eye alt 12.15 mi

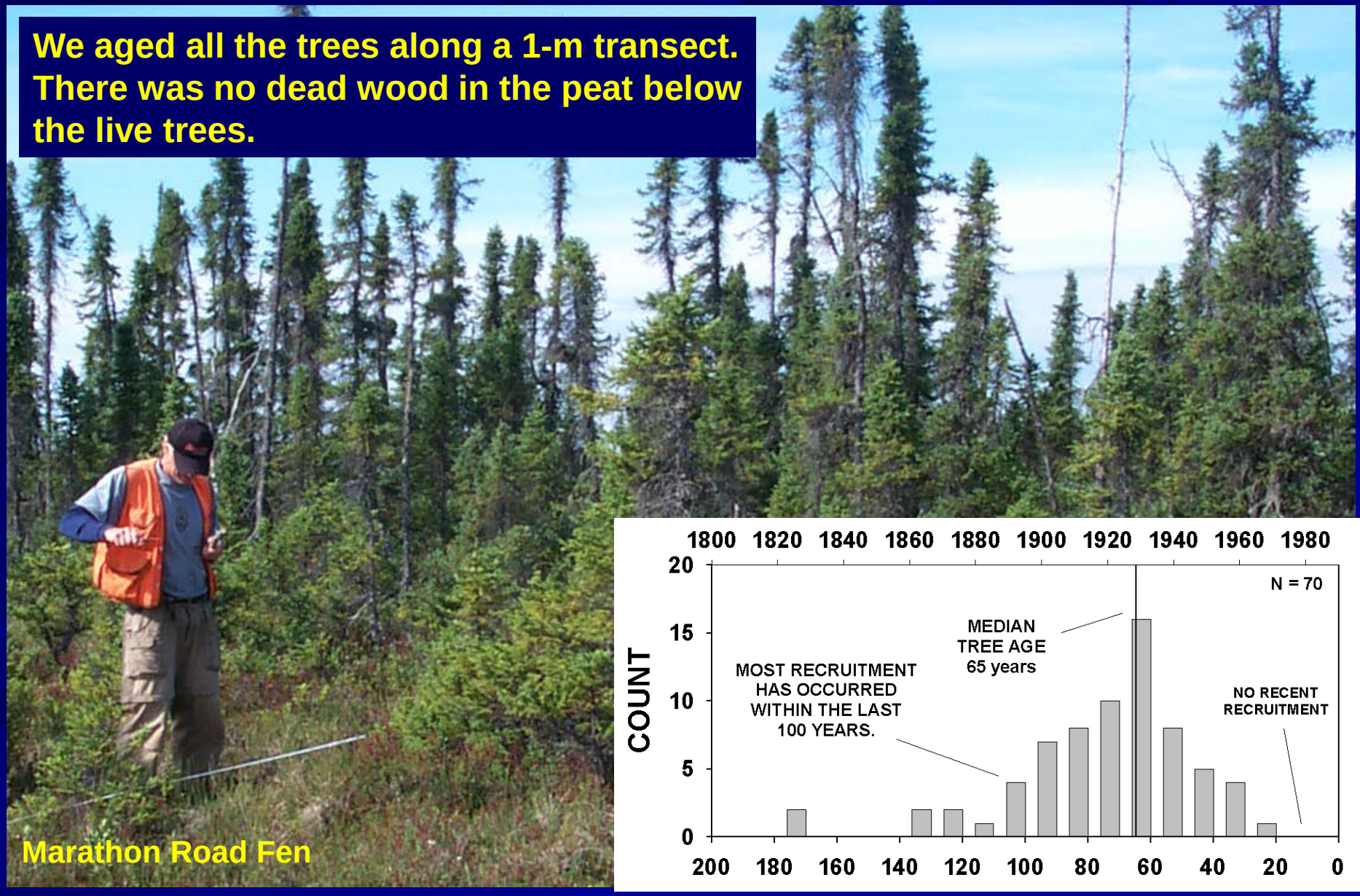
Black Spruce Islands

Black spruce islands cover 10% of this large flat peatland of 6500 acres.

These islands are “first-time forests” with no old wood underneath them.

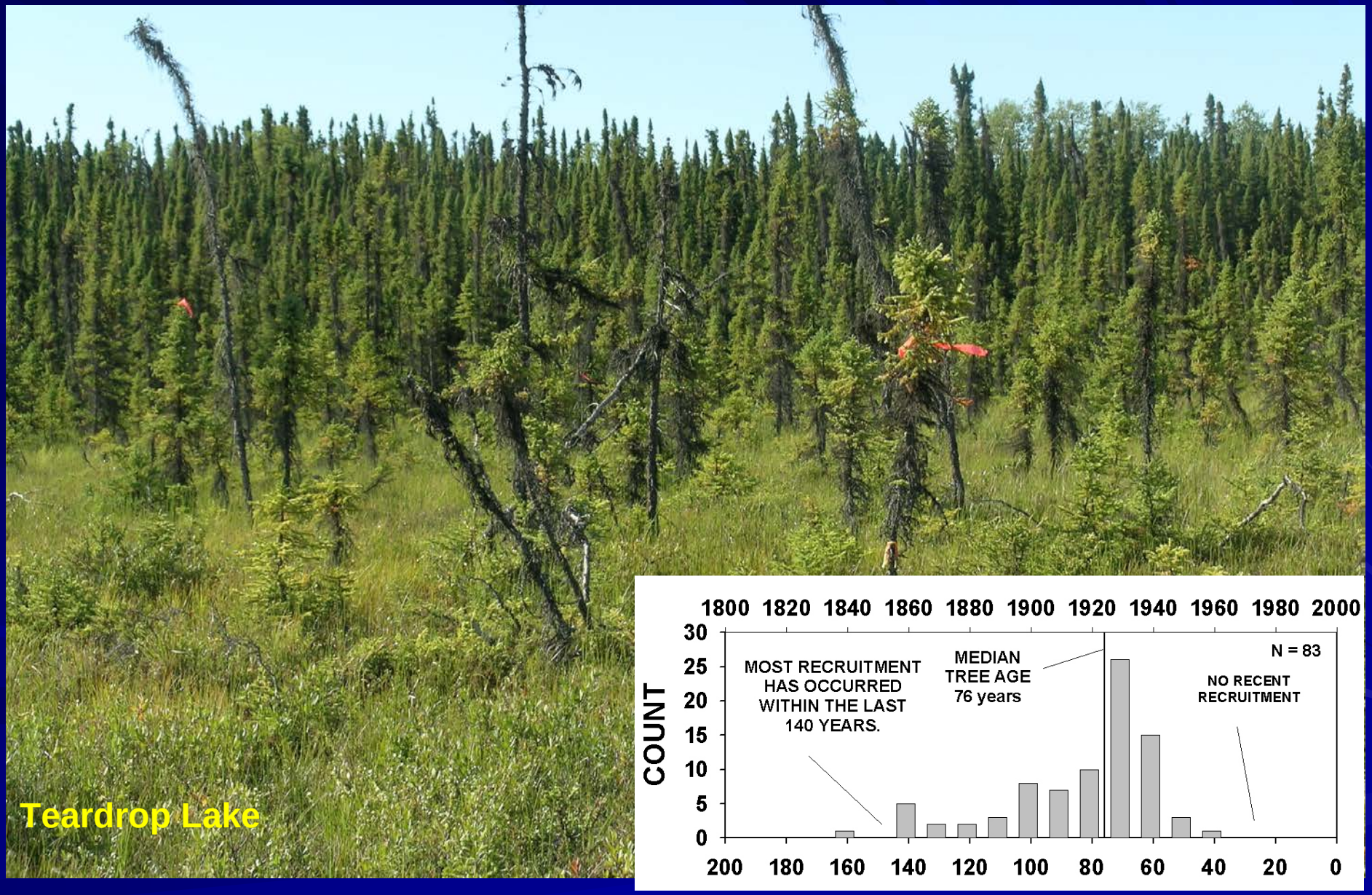
Black Spruce Invasion of Wetlands I

We aged all the trees along a 1-m transect. There was no dead wood in the peat below the live trees.



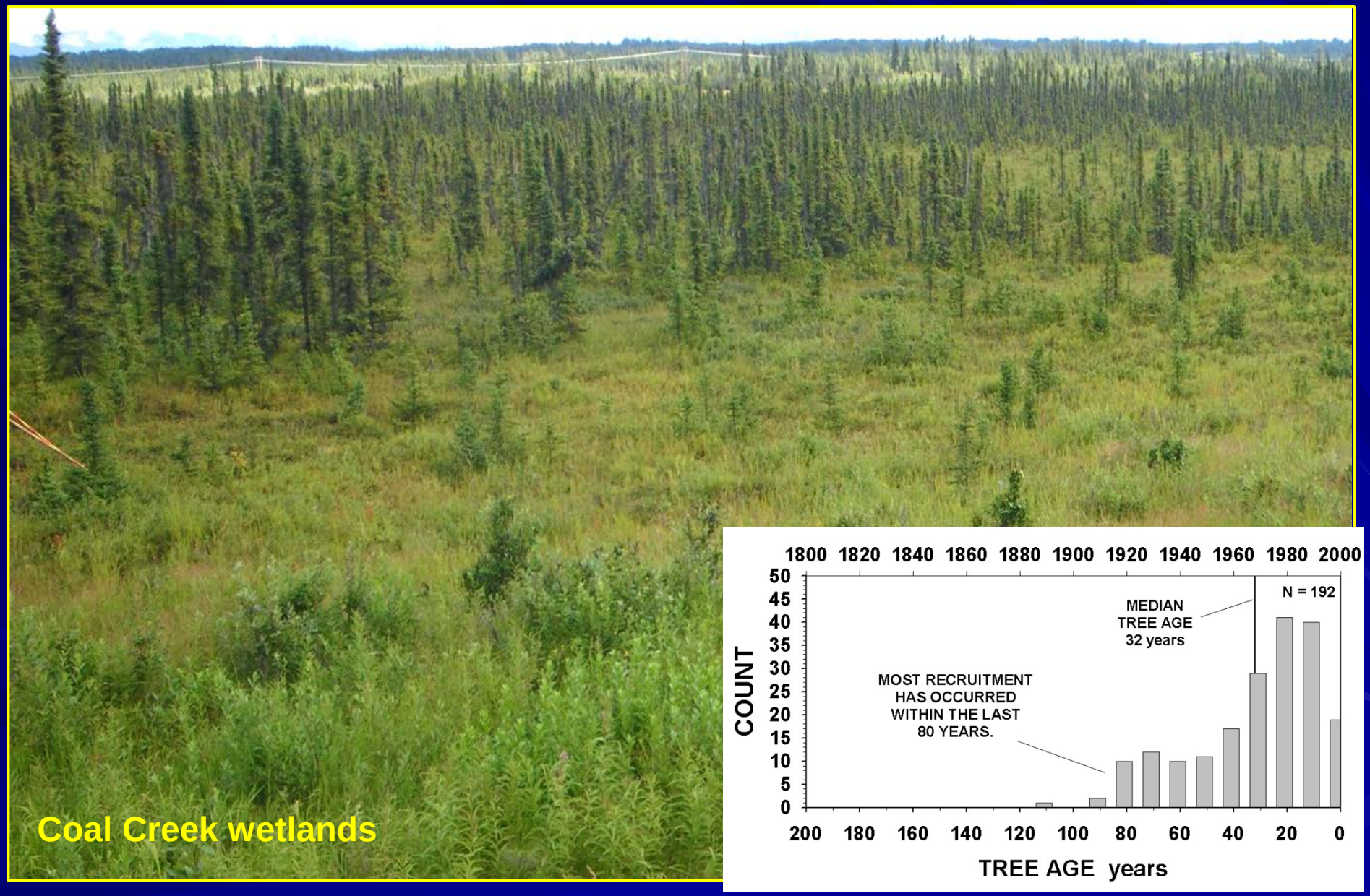
Marathon Road Fen

Black Spruce Invasion of Wetlands II

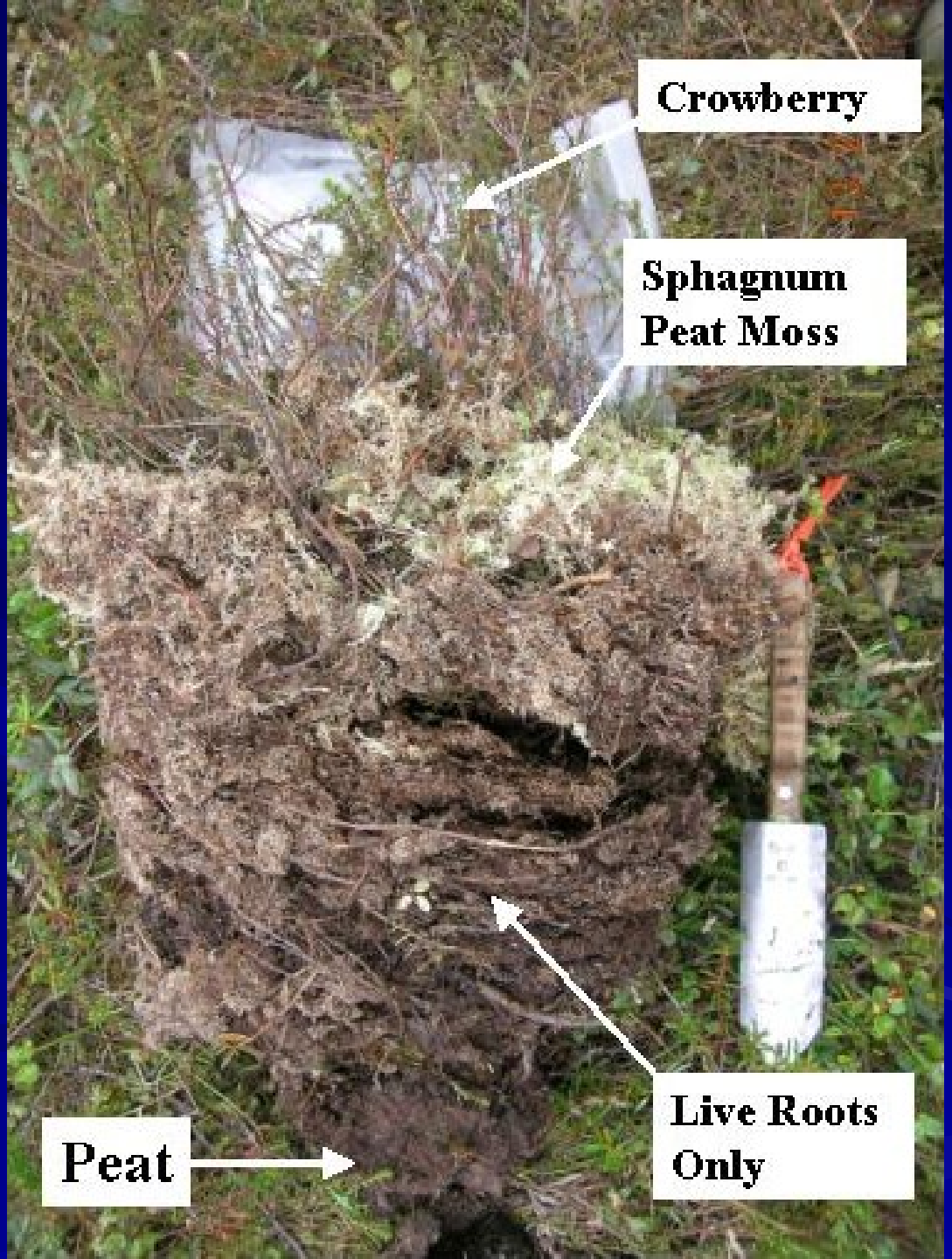


Black Spruce Invasion of Wetlands III

Black Spruce Invasion of Wetlands III



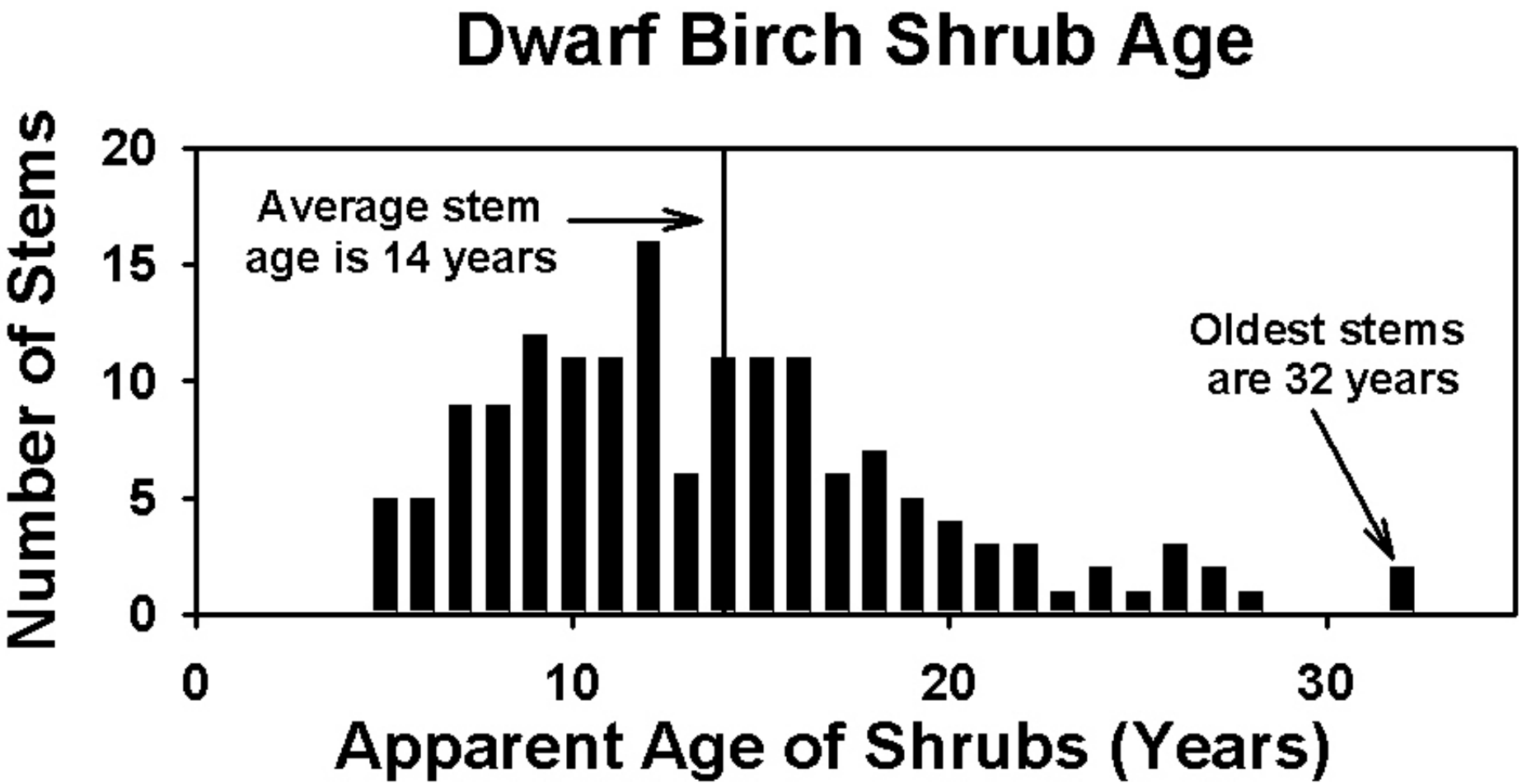
Shrub Invasion of Wetlands



No dead roots means only new shrubs in this wetland

Dwarf Birch

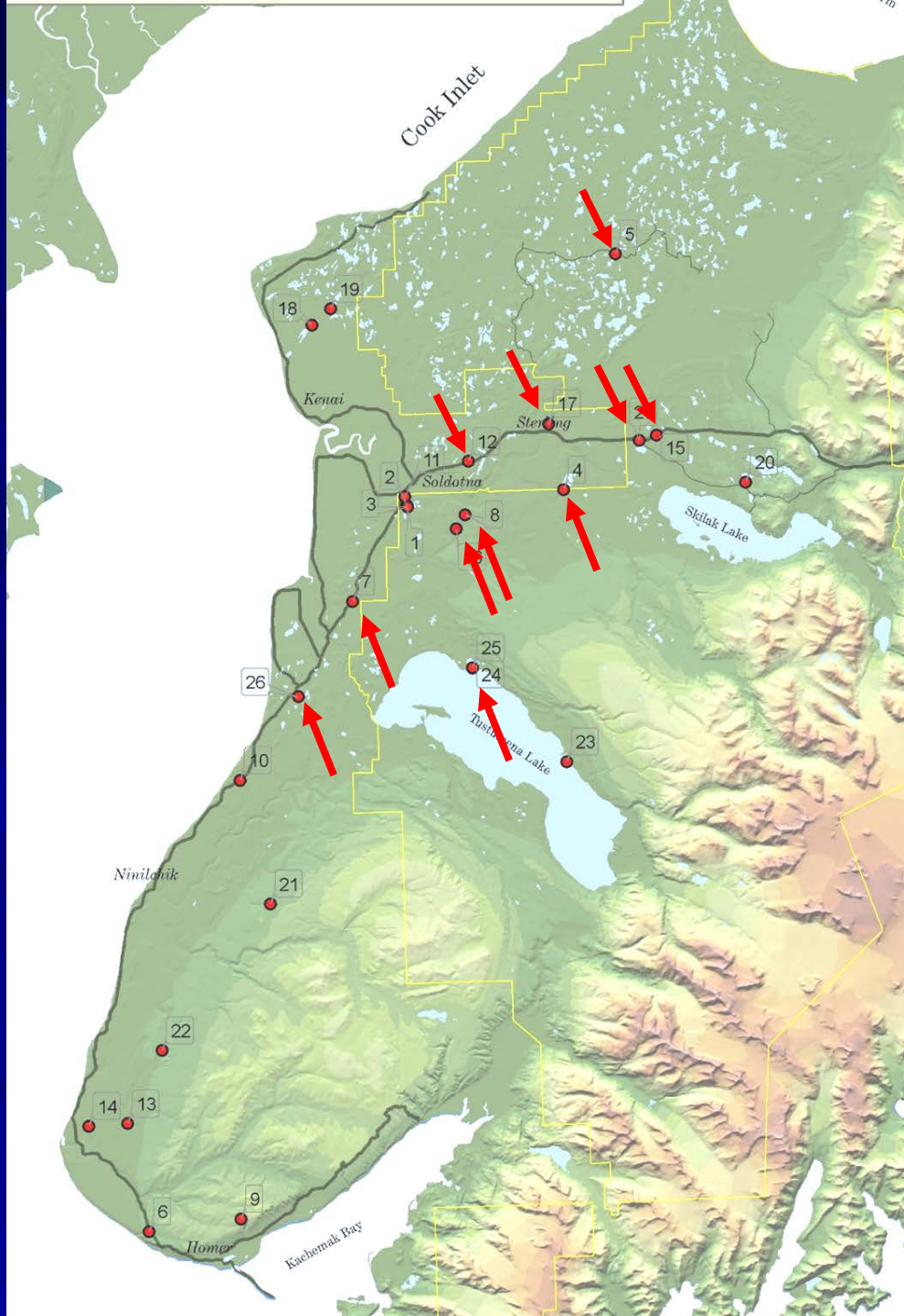
A prominent wetland shrub invader

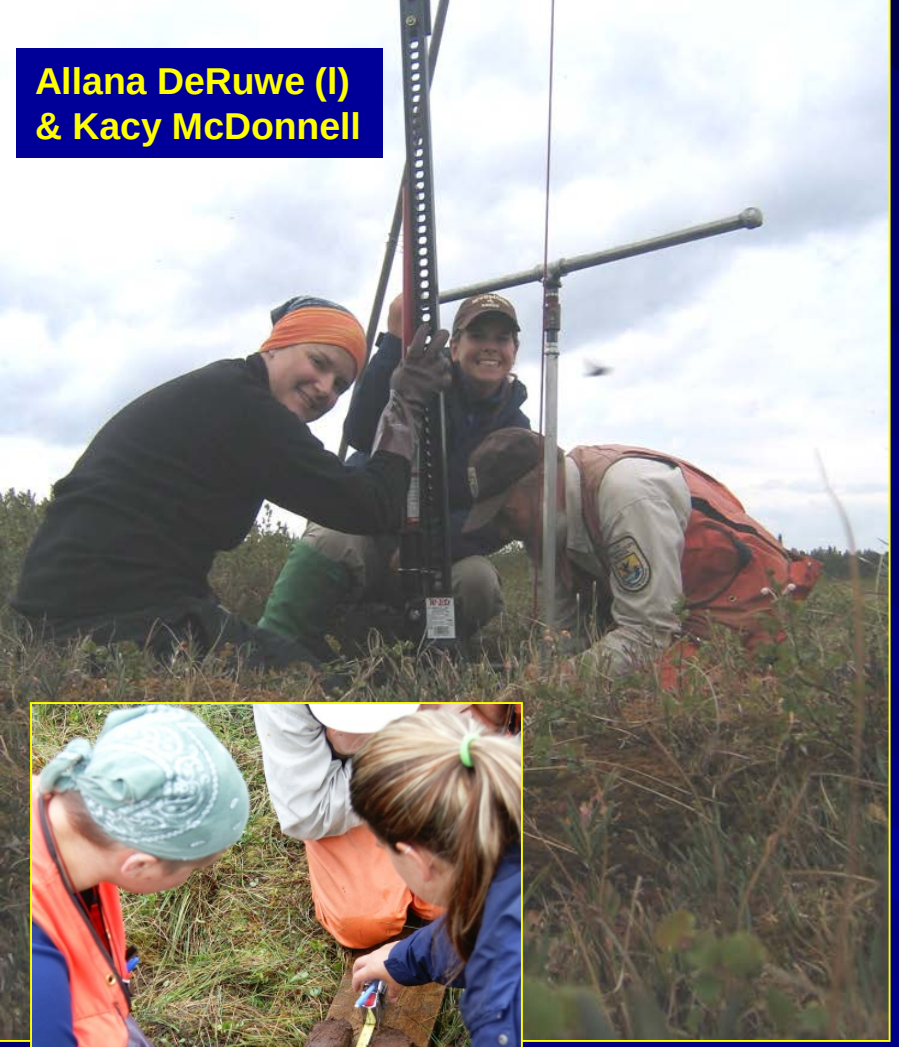


3 Sites, N = 157 stems

Study Sites

- 26 Peat Core Sites
- 11 Aerial Photo Sites





Allana DeRuwe (l)
& Kacy McDonnell

Peat Coring

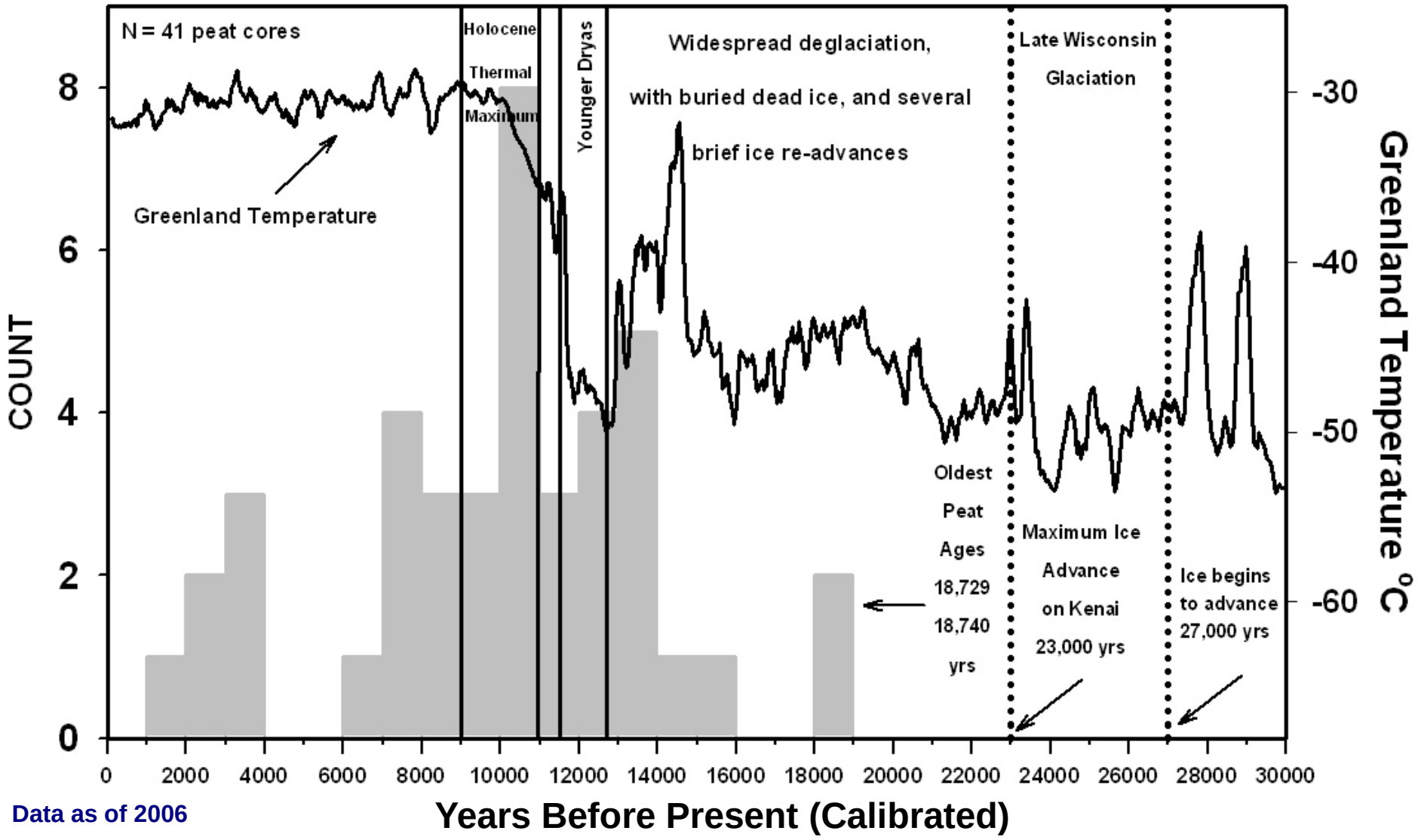
Soil Plugs

Top (below soil plug)

Middle section

Lower section
3 in
Glacial mud
~19,000 years old

Histogram of Basal Peat Ages



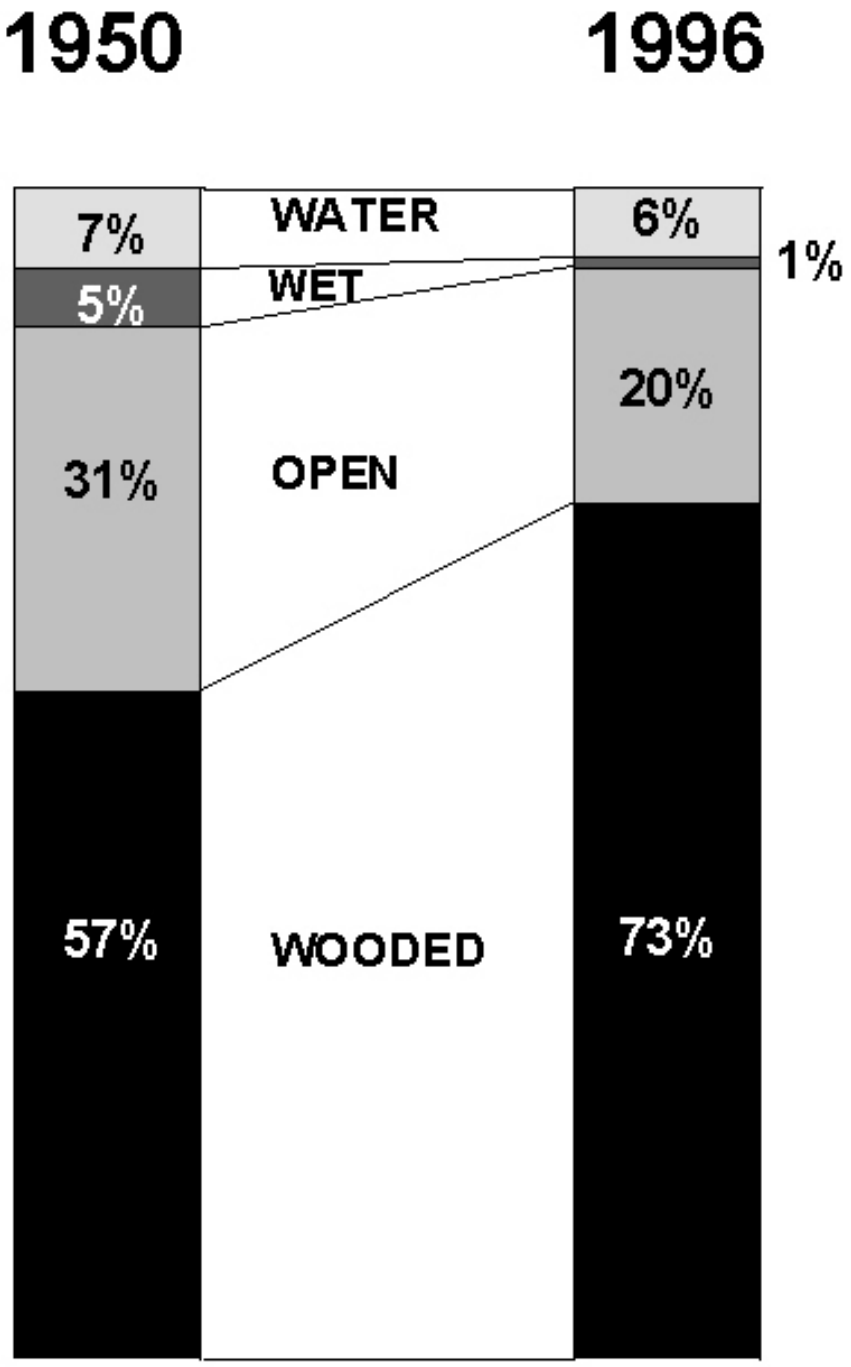
Data as of 2006

Quantifying the Recent Drying of the Kenai Lowlands

We need rates of change for modeling the future.

Aerial photo comparison of moisture/vegetation status at 1113 random points on the Kenai Lowlands:

Every category is drying out.



Eric Klein MS Thesis (APU) 2004

2nd Aerial Photo Study: Two Approaches

(1) Wetland edge ecotones: classification of vegetation on points on a rectangular grid

(2) Whole wetlands: digitized herbaceous edges

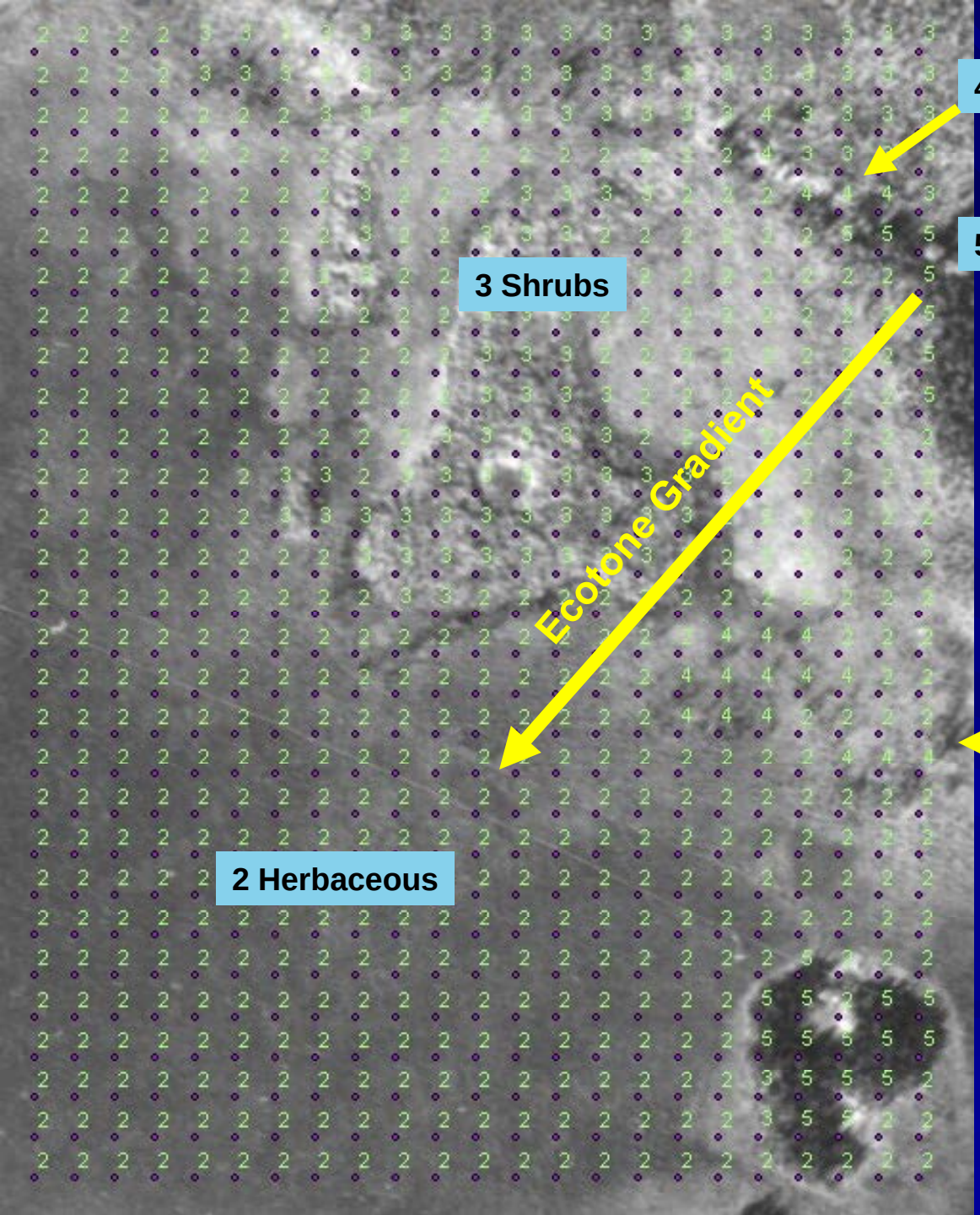
Kacy McDonnell MS Thesis (APU) 2007

1st Approach: Wetland Edge Ecotones

Cover Classes:

1 - Open Water
2 - Herbaceous
3 - Shrubs
4 - Open Woodland
5 - Closed Canopy Forest

600 points classified on each photo: 1951, 1968, and 1996

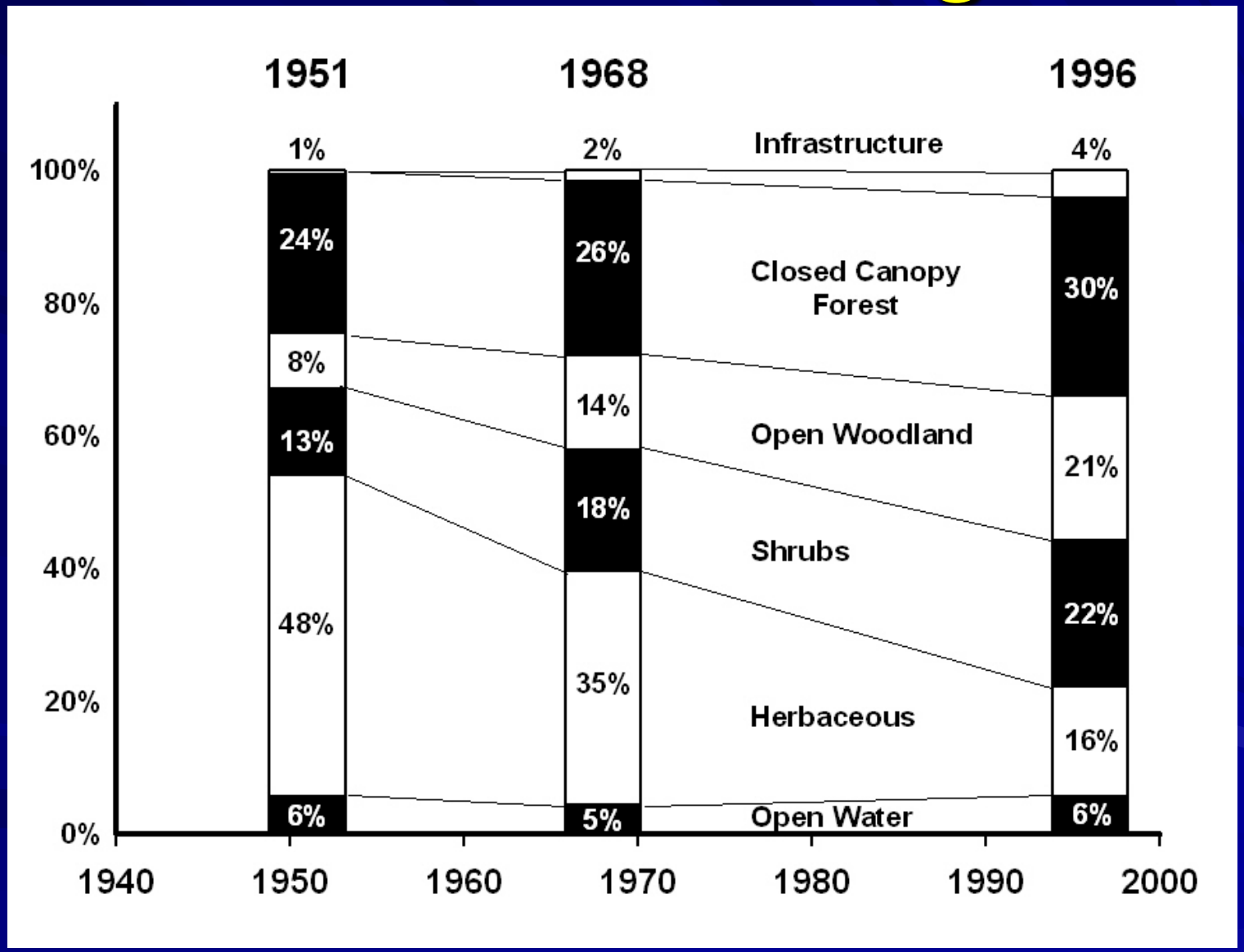


Brown's Lake Fen

15 meters between grid points (N = 660)

Points are classified on 1951, 1968 & 1996 aerial photos

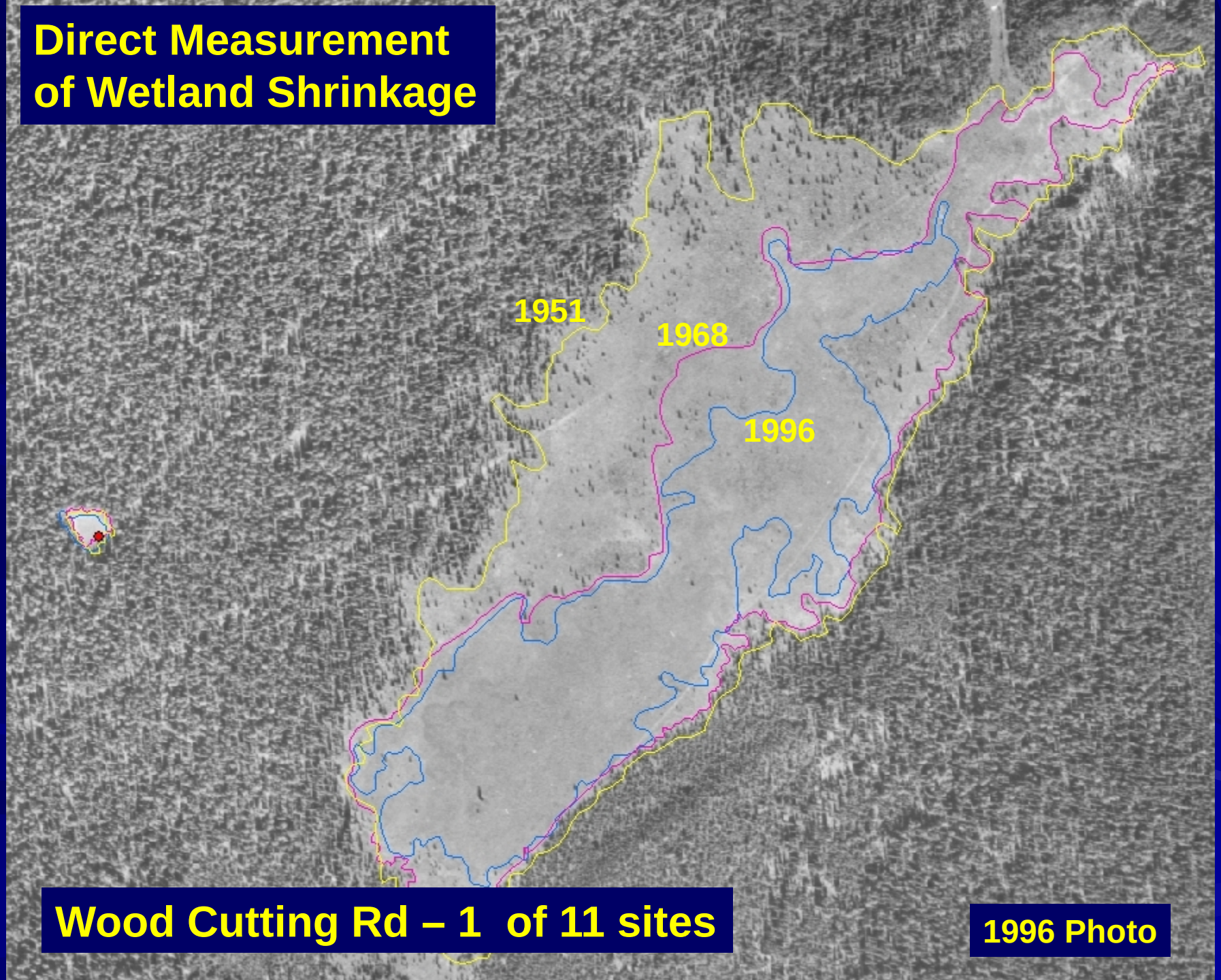
Ecotone Change



11 sites pooled, N = 21,780 points classified

2nd Approach: Measuring Whole Wetland Areas

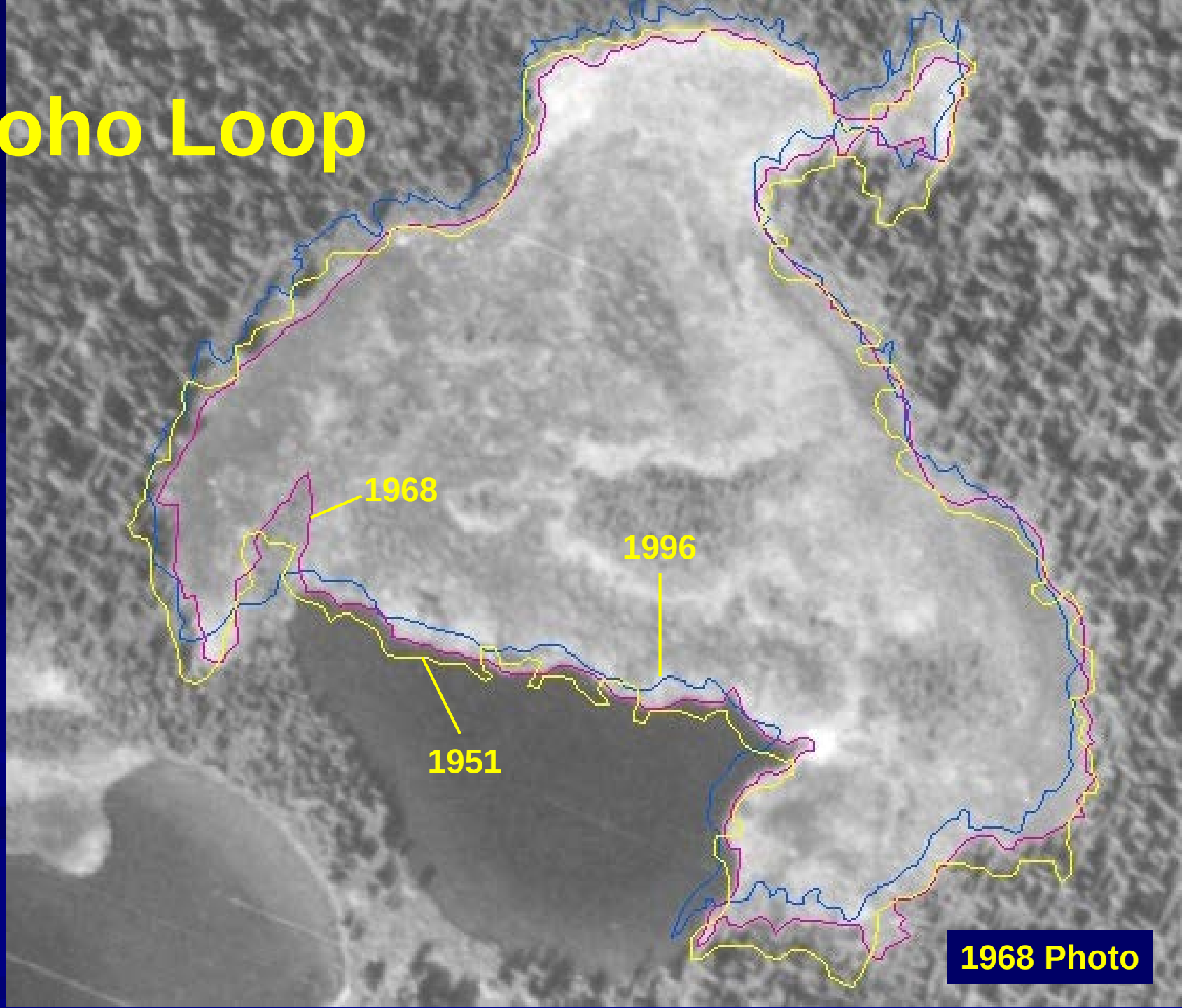
Direct Measurement of Wetland Shrinkage

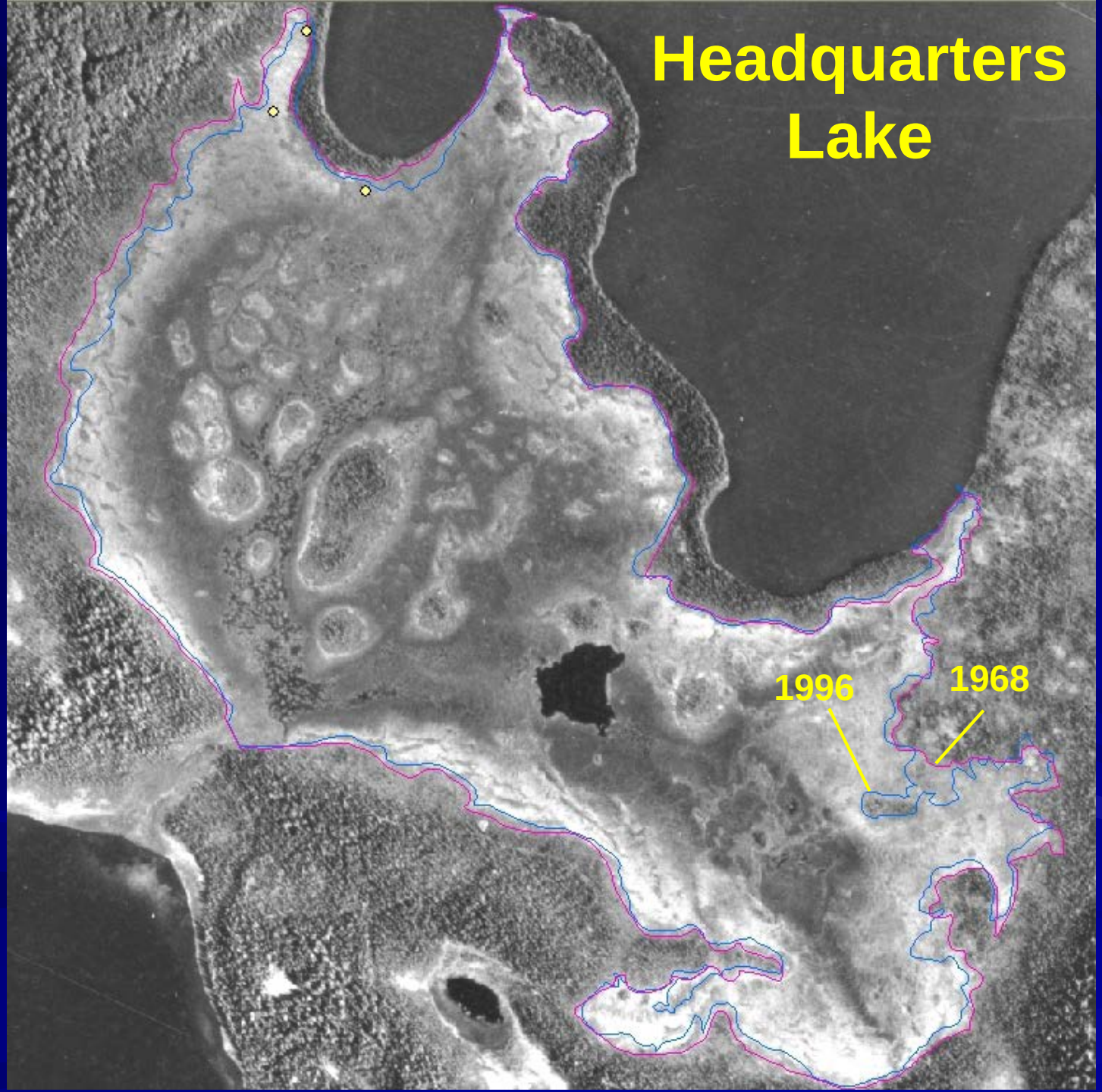


Wood Cutting Rd – 1 of 11 sites

1996 Photo

Coho Loop





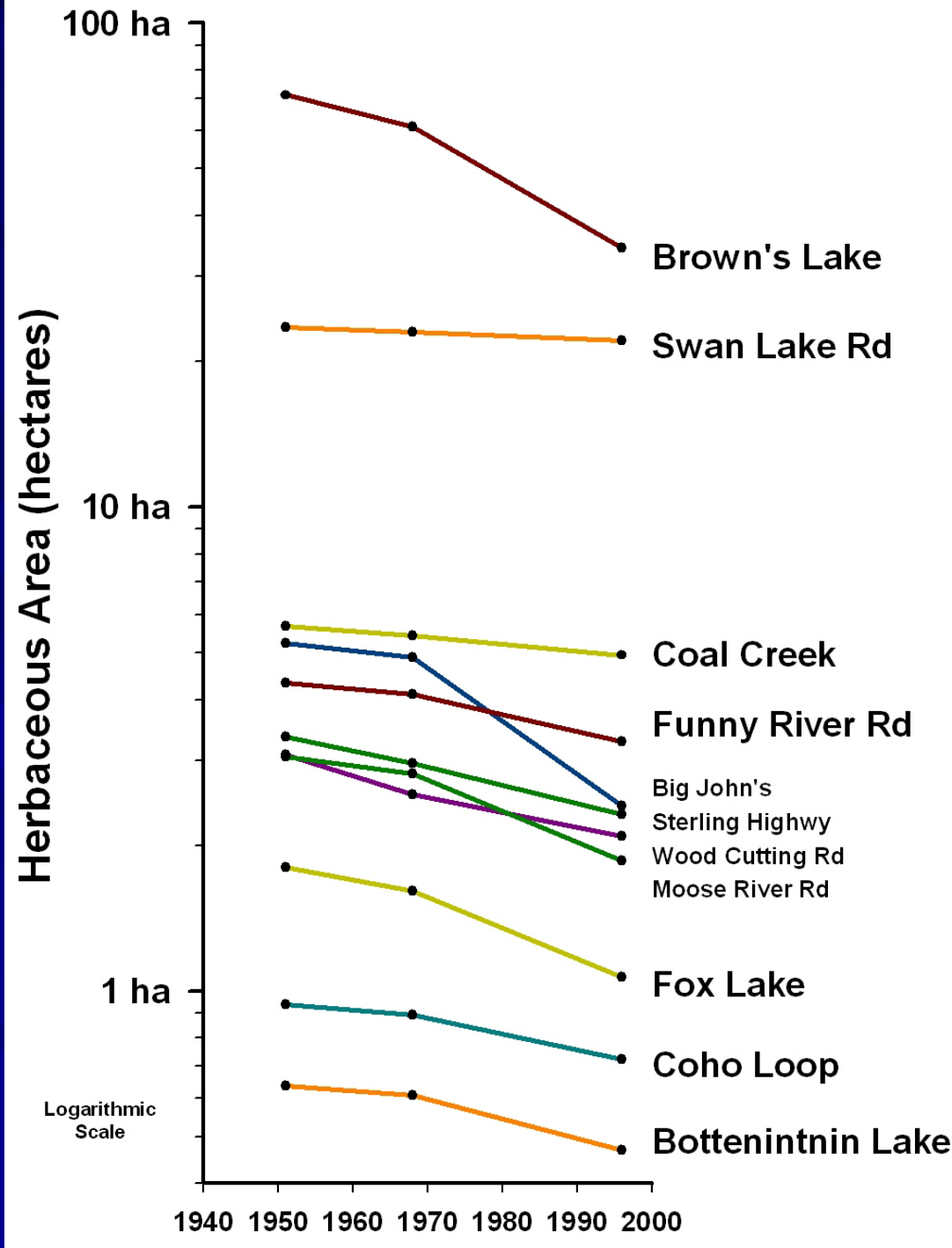
1996 Photo

Herbaceous Wetland Loss due to Woody Invasion

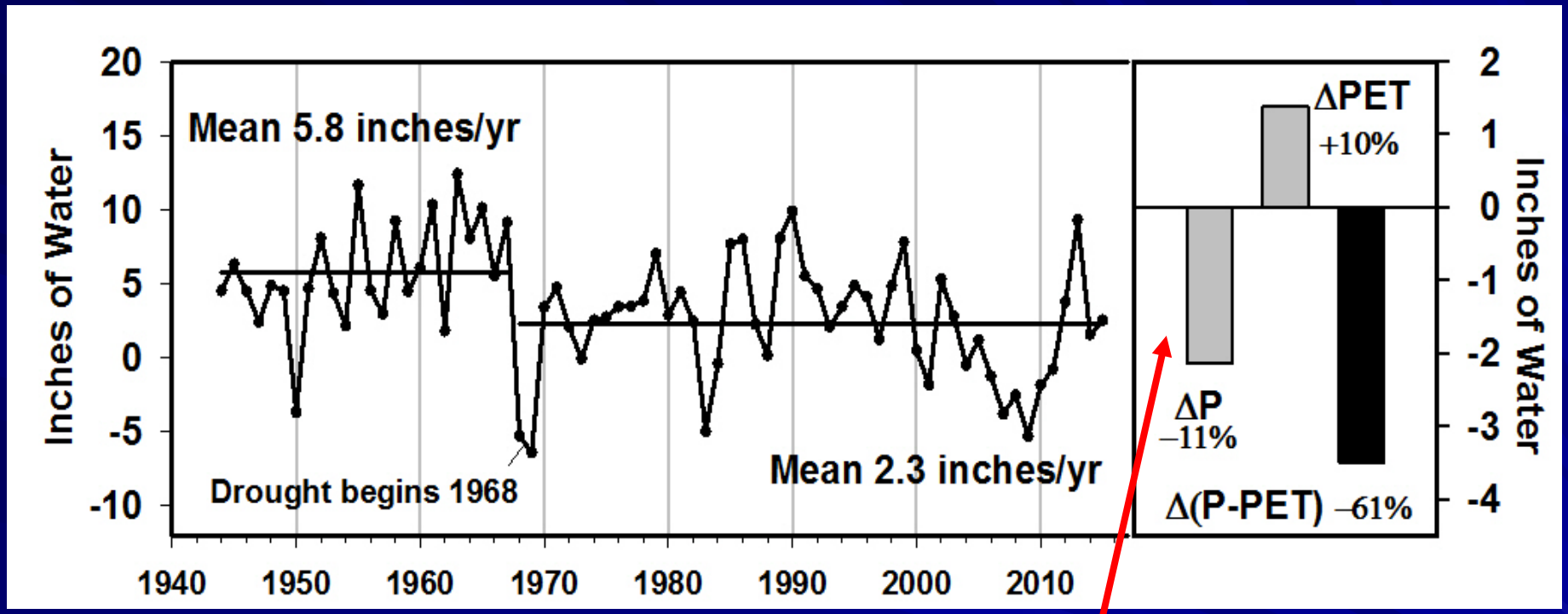
Accelerating Rates of Area Change:

1951-1968:
6.2 % loss/decade

1968-1996:
11.1 % loss/decade



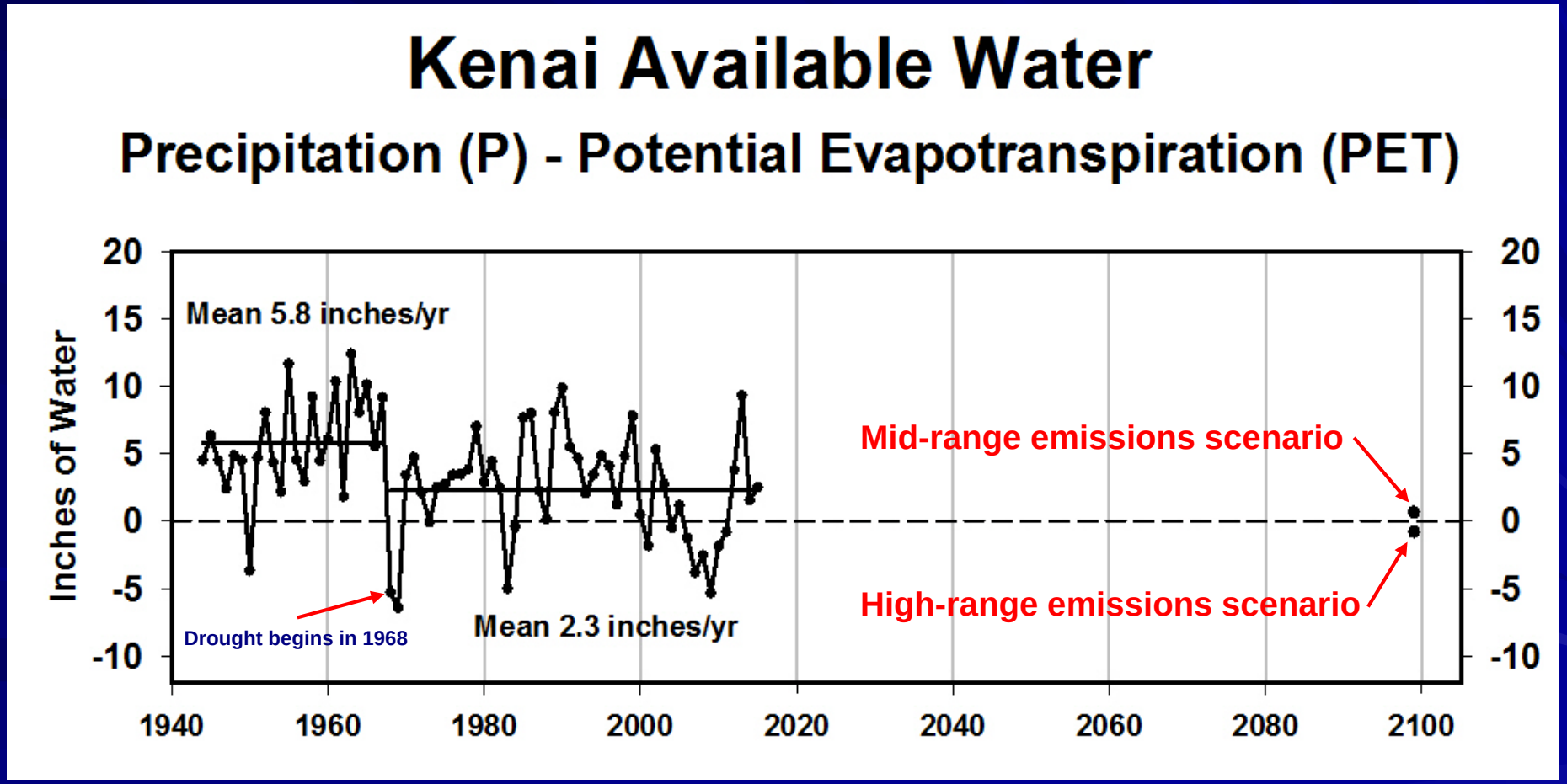
Kenai Available Water (P – PET)



% Decline in precipitation P is about equal to the increase in evapotranspiration (PET)

$$\frac{2.3}{5.8} = 39\%,$$ **or a 61% decline in available water**

Available water goes ~0 inches by 2099, according to the SNAP models



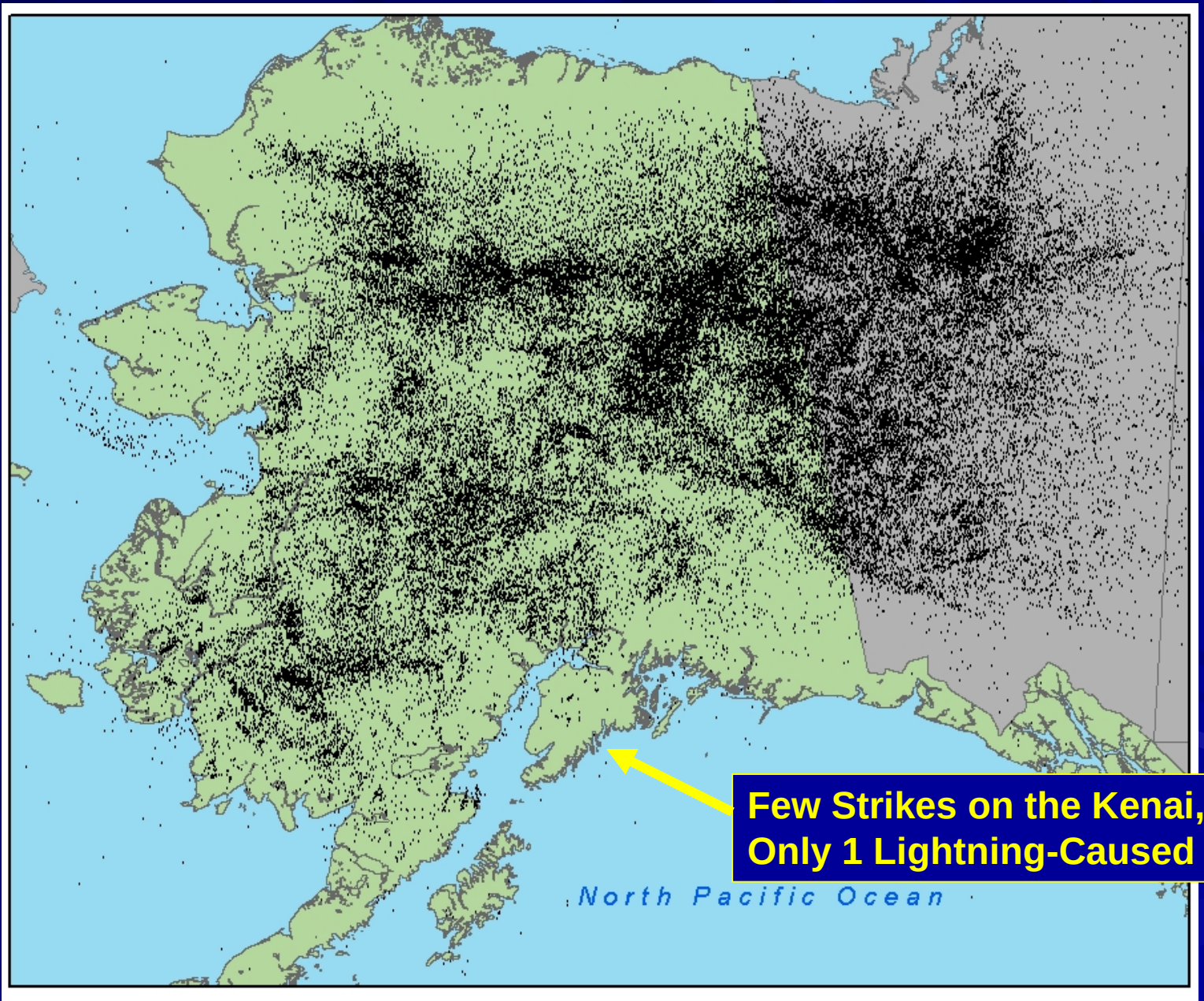
Take-Home Message:

Kenai Wetlands Show Extreme Recent Drying

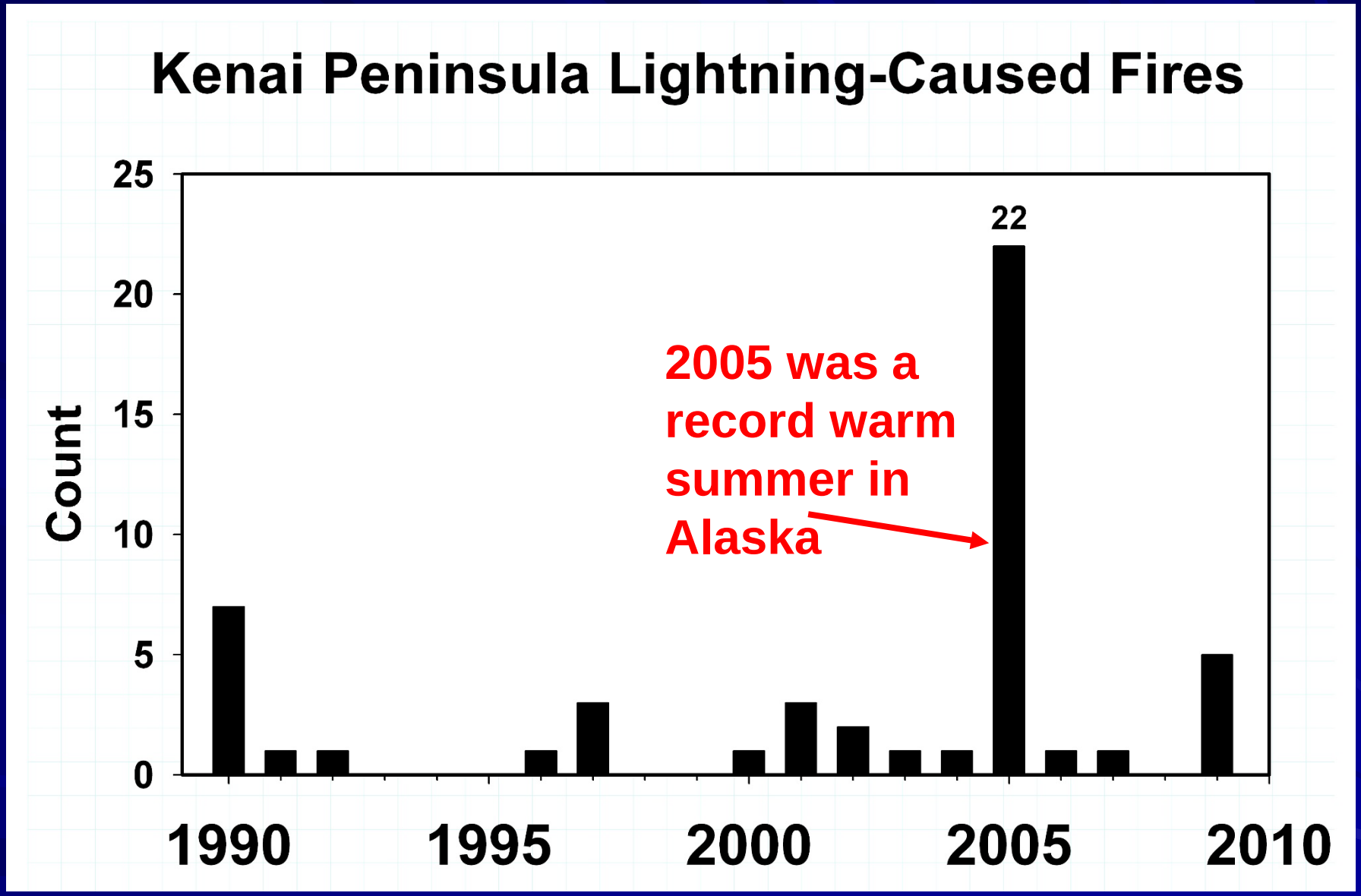
- **Peat cores show ~ 14,000 years of wet *Sphagnum*-sedge fen environment, with recent shrub invasion.**
- **Climate drying started at end of Little Ice Age in 1850s.**
- **Drying has accelerated since 1970s.**

Changing Fire Regimes

Lightning Strikes 2002 – A Normal Year



Few Strikes on the Kenai,
Only 1 Lightning-Caused Fire



Lightning is a new wildcard in the climate change deck.

Three types of fires on the Kenai

- **Type I: Dry spring fires, often pre-green-up, grass-supported, with *mild* burn severity, e.g., many post-2000 fires**
- **Type II: Normal-weather summer fires, with *moderate* burn severity, e.g., 1947 Skilak Lake**
- **Type III: Extremely dry summer fires with *extreme* burn severity, e.g., 1969 Swanson River, 1994 Windy Point, 1987 Skilak Rd prescribed burn**

Type I Dry Spring Fires

These fires typically occur in May when warm, sunny weather dries out last year's grass prior to green-up.

The soils are typically wet or perhaps even frozen.

There is very little mineral soil exposure.

The ash provides a pulse of nutrients that fertilize the grass and fireweed.

Caribou Hills Fire
June 2007

The spruce bark beetle outbreak of the 1990's has opened up forest canopies.

Grass thrives with more sunlight.

Dry spring grass-supported fires have become more common in the 2000's.

Grass-supported fires are similar to logging.

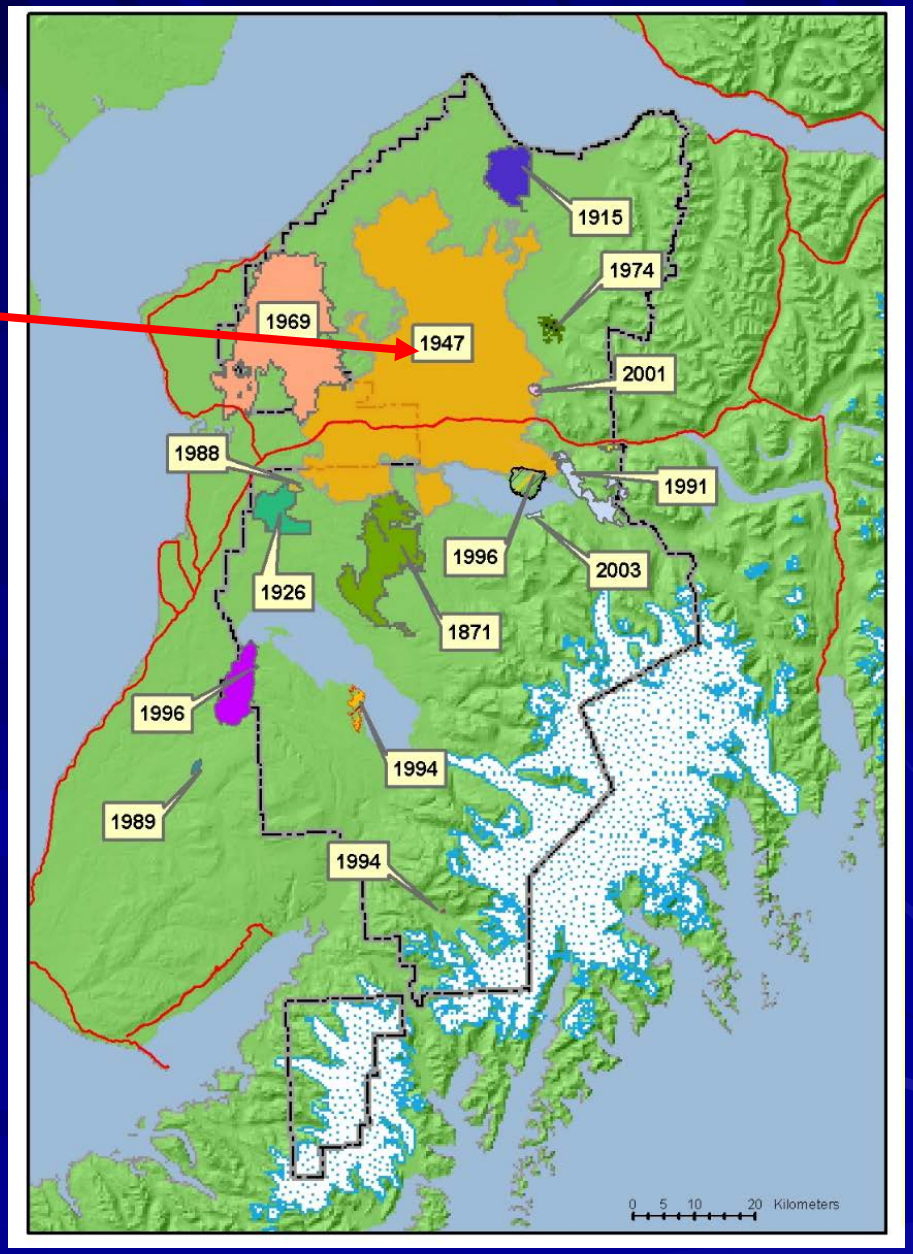
Type II Fire

The 1947 Kenai Fire occurred under normal summer weather conditions.

The fire burned from June into August, with very limited fire suppression.

310,000 acres burned. This was the largest known fire on the Kenai.

Burn severity was moderate, with occasional pockets of severe burn.



Type III Fire

The 1969 Swanson River Fire occurred under extremely dry conditions.

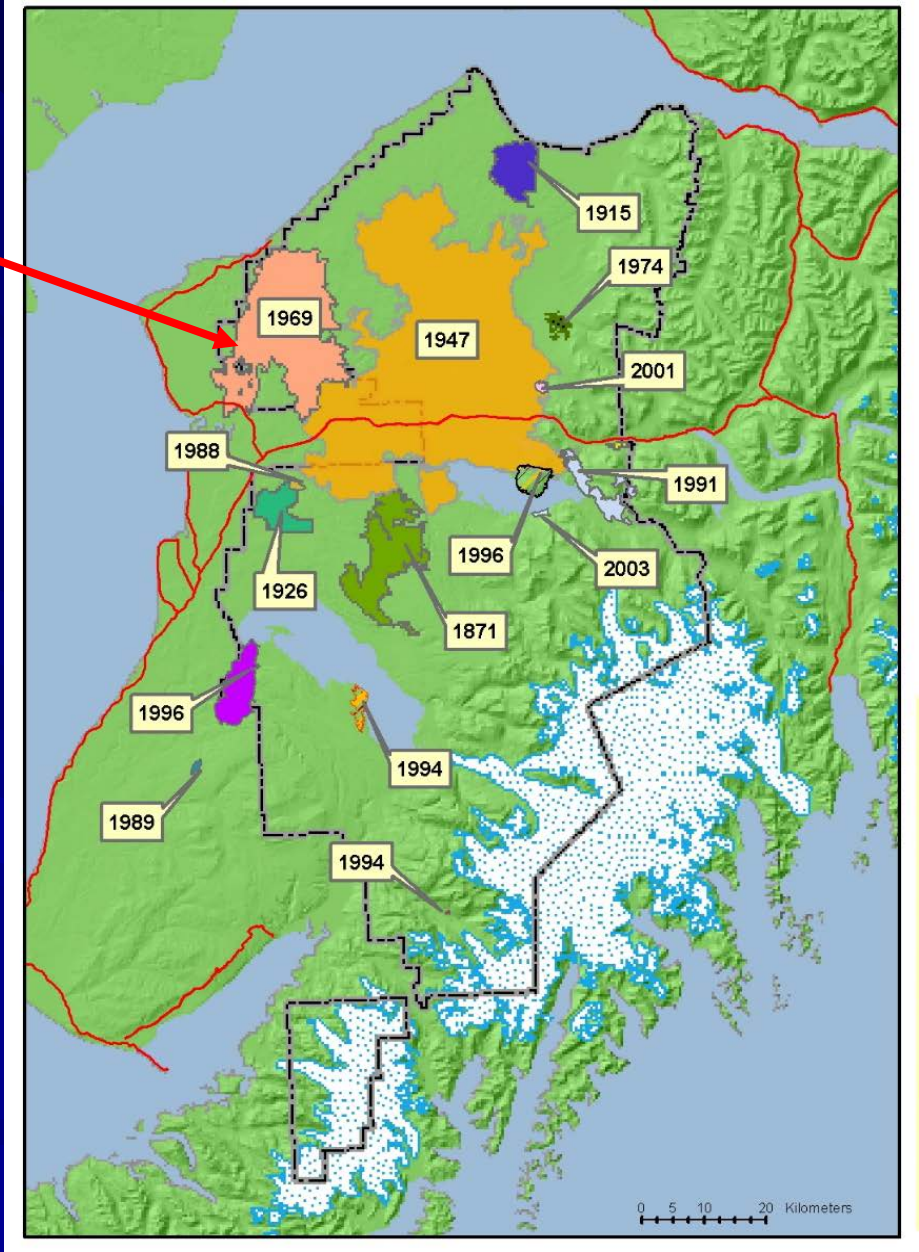
The fire burned through most of August.

69,000 acres burned.

Burn severity was extreme. Mineral soil was exposed over thousands of acres.

Birch recruitment was phenomenal.

The moose and hares loved it!

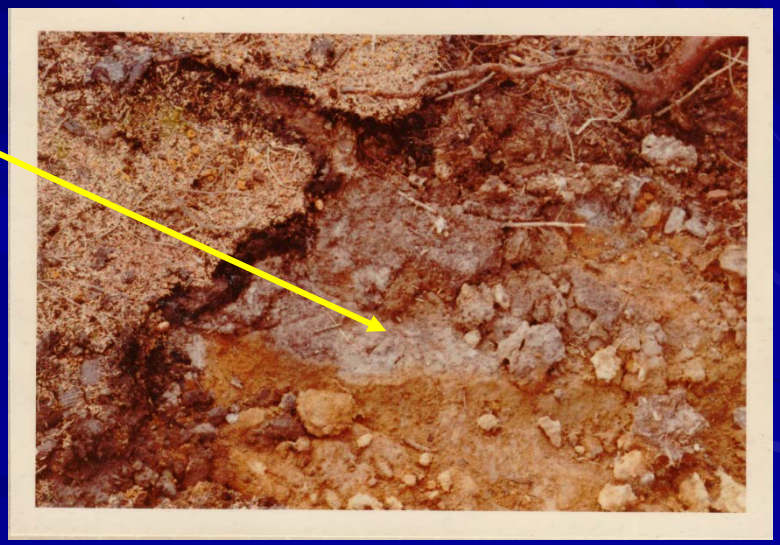


Extreme burn severity

1969 Swanson River Burn

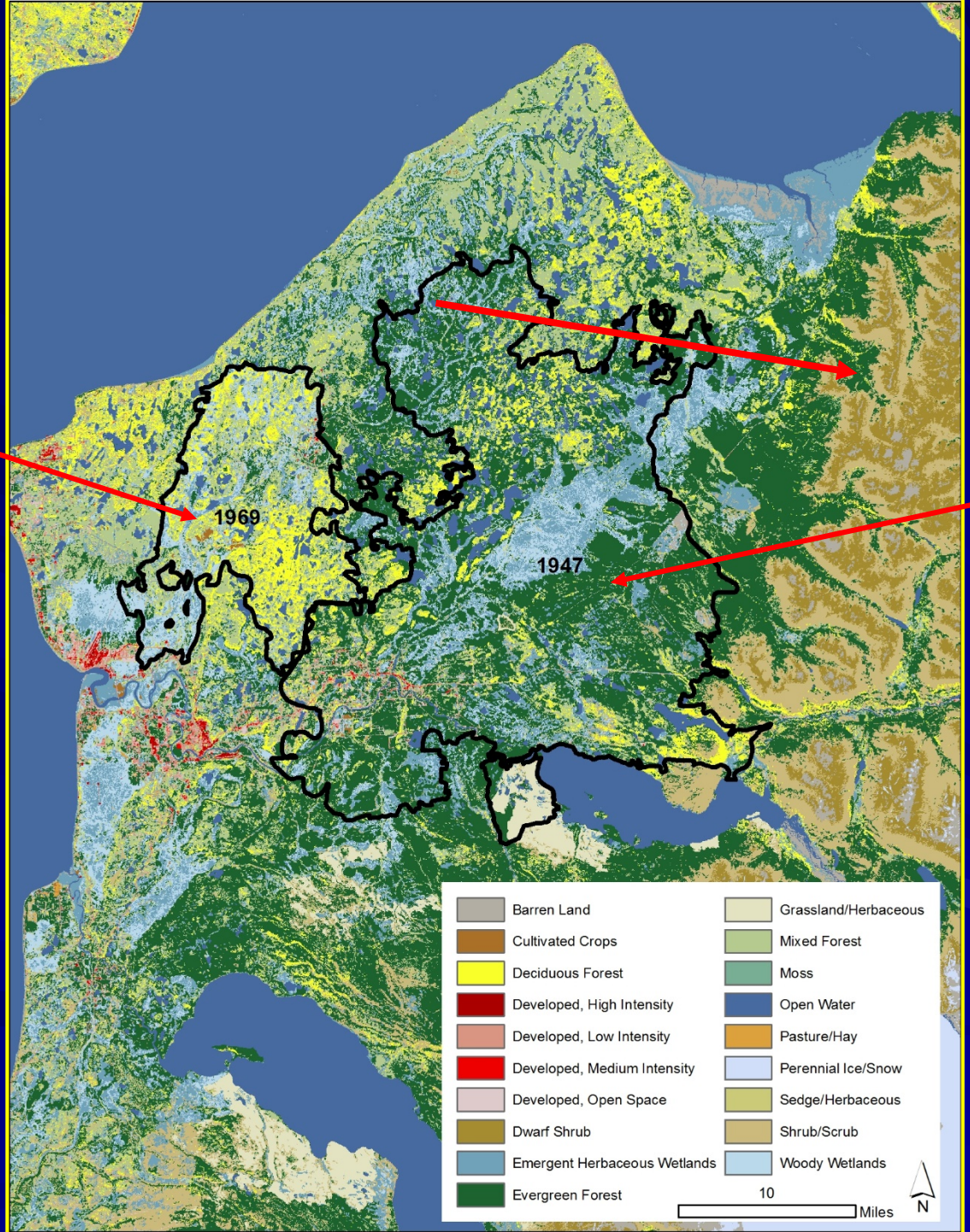
Exposed mineral soil

Burned soil



1970 photos

1969 Burn - Extreme burn severity created mostly hardwood (birch) forest



1947 Burn - Light to moderate burn severity created mostly spruce forest, with some hardwoods

2011 Landcover

Windy Point Burn – 10 years after a severe fire

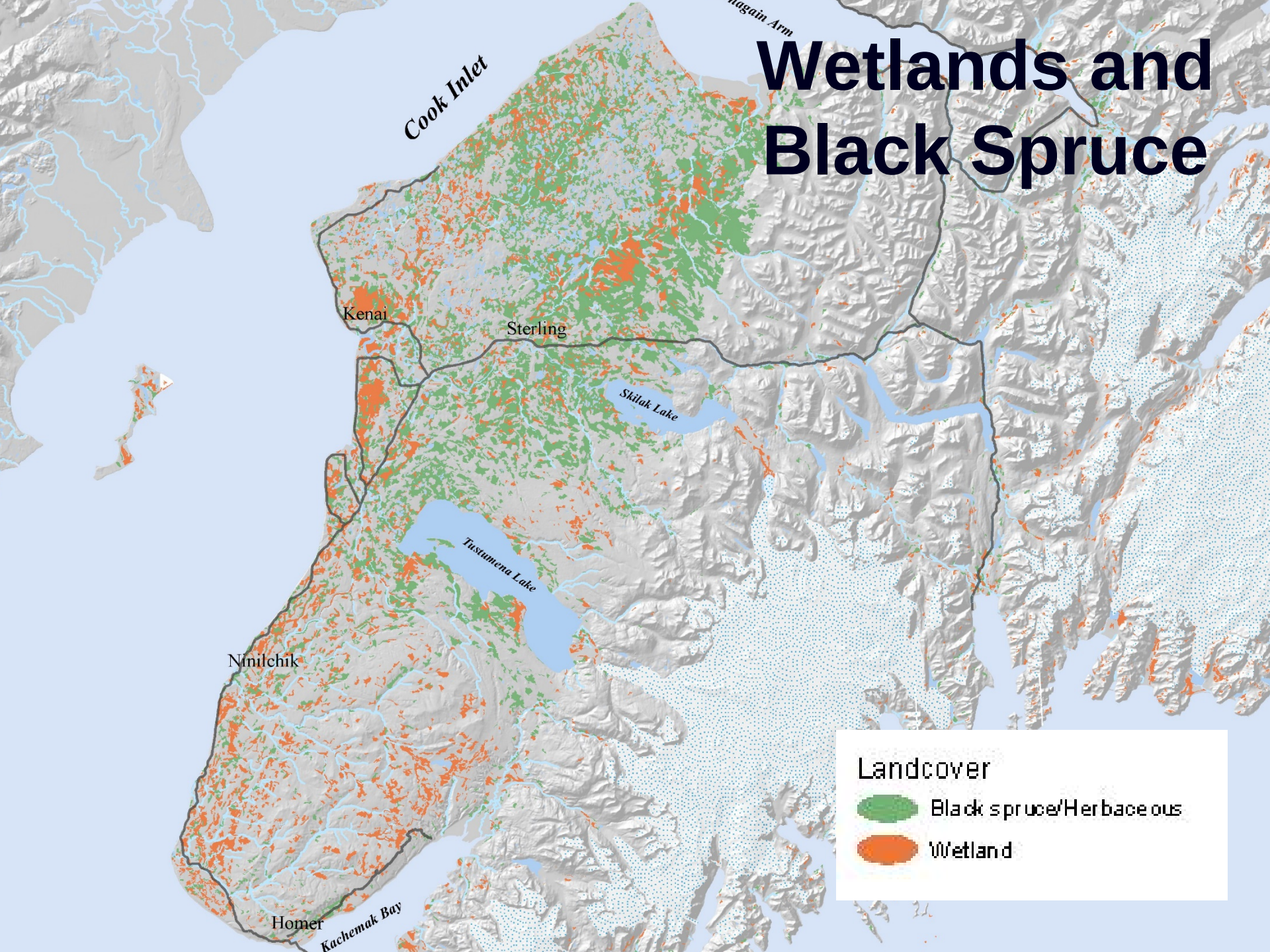
Doug Fisher and Ed Berg

2004 photo

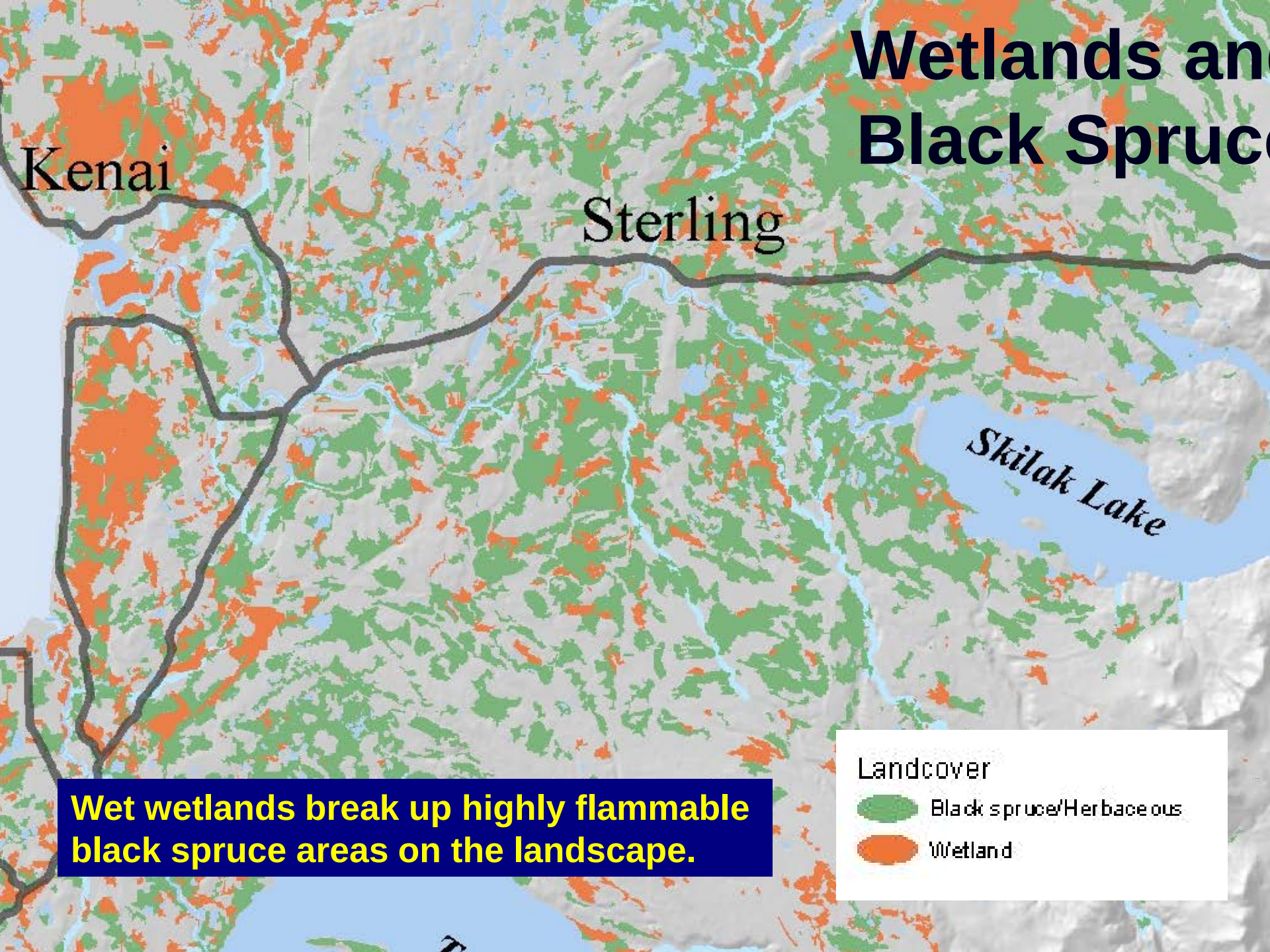
Fire Propagation

Continuity of Fuels

Wetlands and Black Spruce



Wetlands an
Black Spruc



Wet wetlands break up highly flammable black spruce areas on the landscape.

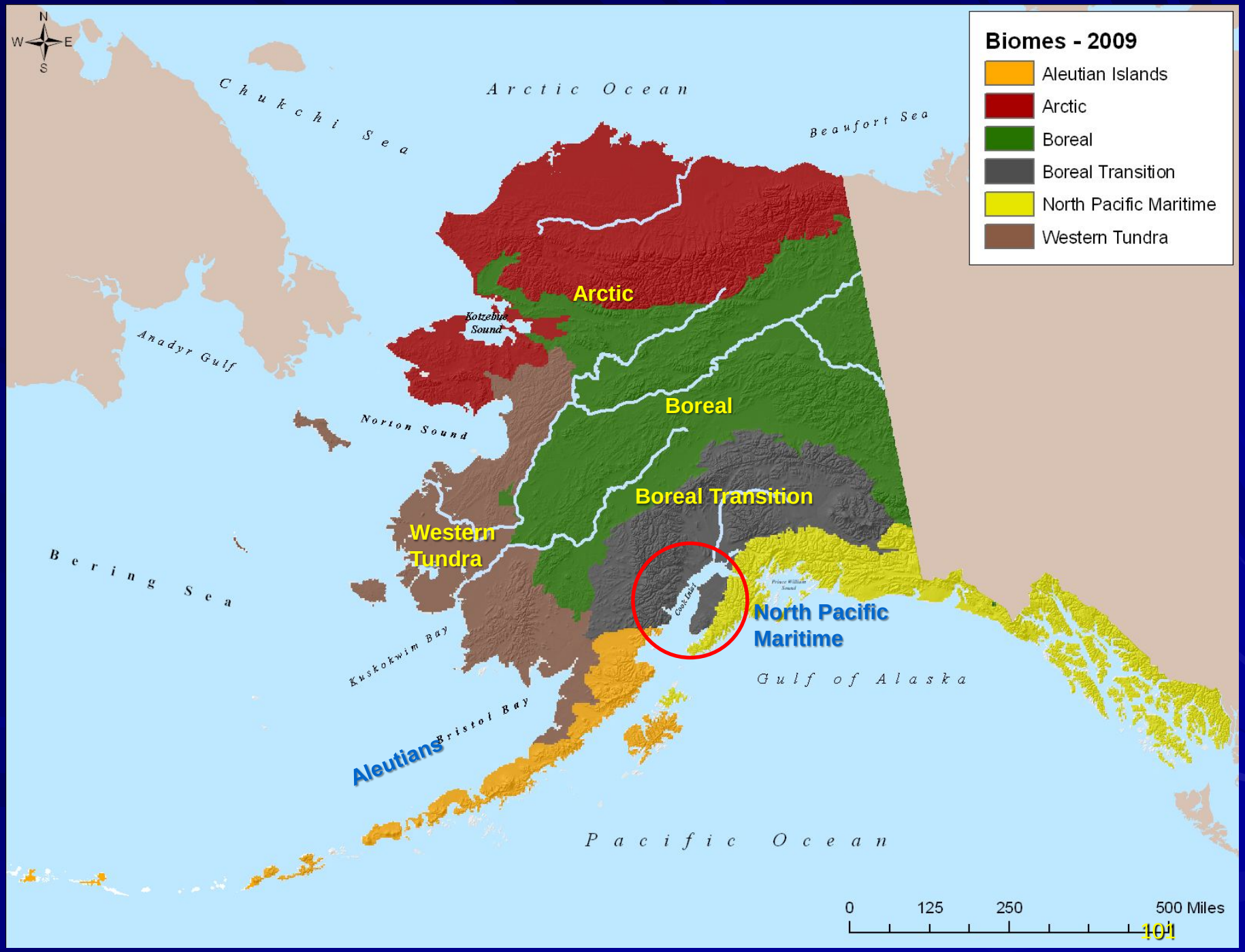
Bottom Line

The invasion of shrubs and black spruce into wetlands is converting *firebreaks* into *fuel bridges.*

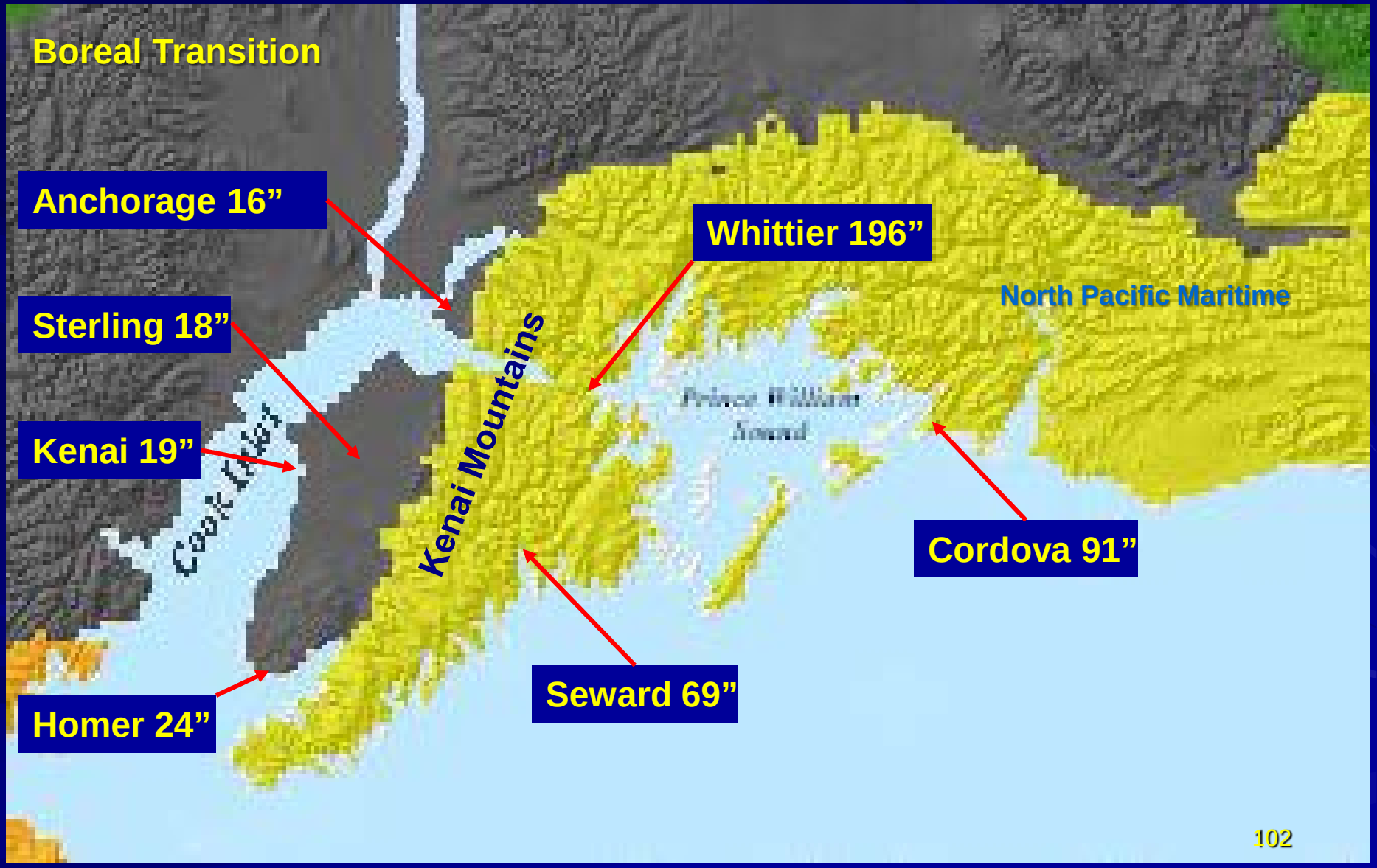
With a warmer and drier climate, fires will be more frequent and they will propagate more effectively across large areas of continuous fuels.

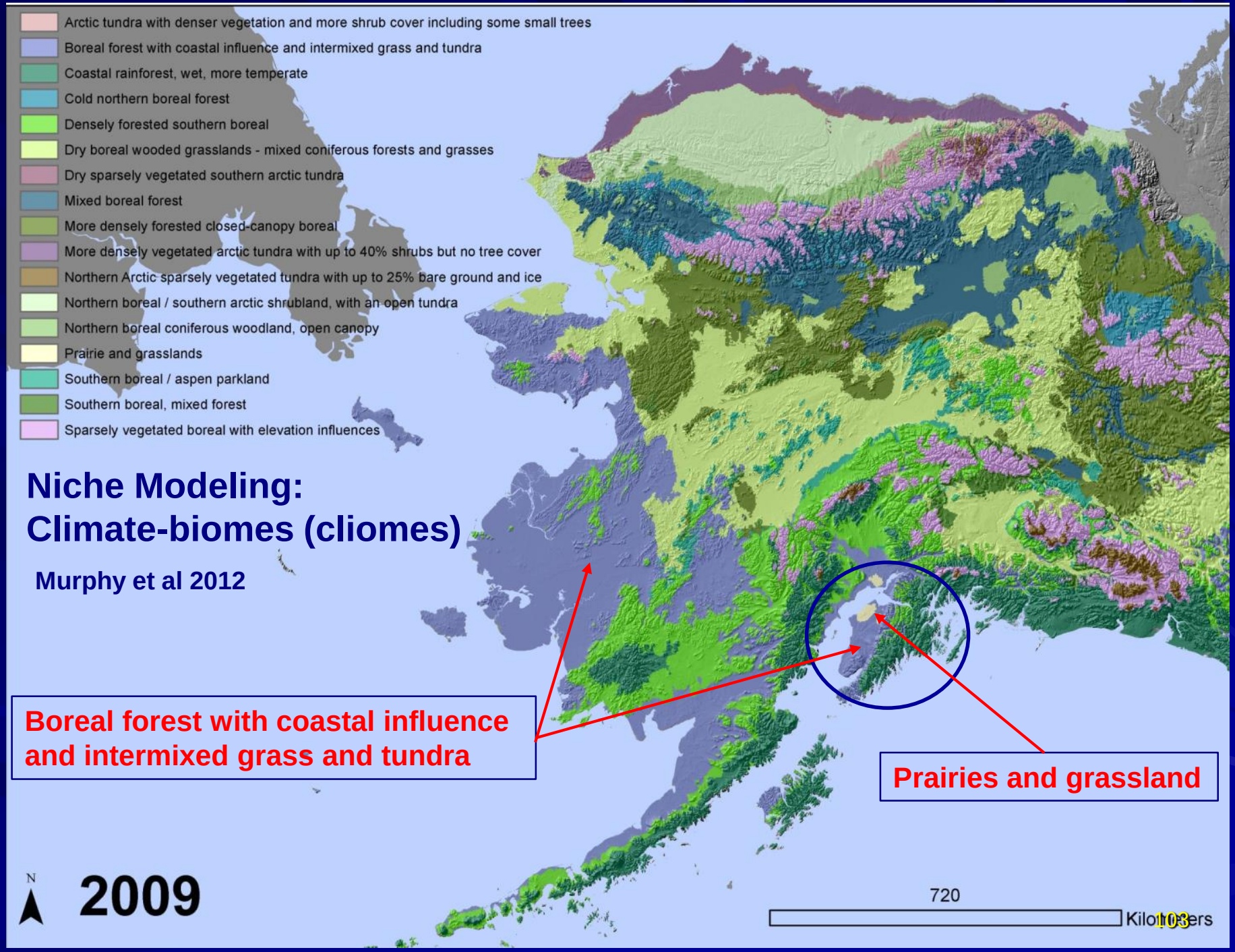
Modeling the Future

- To 2099
- Beyond 2099


Biomes - 2009
Aleutian Islands
Arctic
Boreal
Boreal Transition
North Pacific Maritime
Western Tundra
N
W
E
S
Arctic Ocean
Chukchi Sea
Beaufort Sea
Anadyr Gulf
Kotzebue Sound
Norton Sound
Bering Sea
Kuskokwim Bay
Bristol Bay
Gulf of Alaska
Pacific Ocean
Arctic
Boreal
Boreal Transition
Western Tundra
North Pacific Maritime
Aleutians
0
125
250
500 Miles

The western Kenai is in a very strong rainshadow from the Kenai Mountains.




Arctic tundra with denser vegetation and more shrub cover including some small trees
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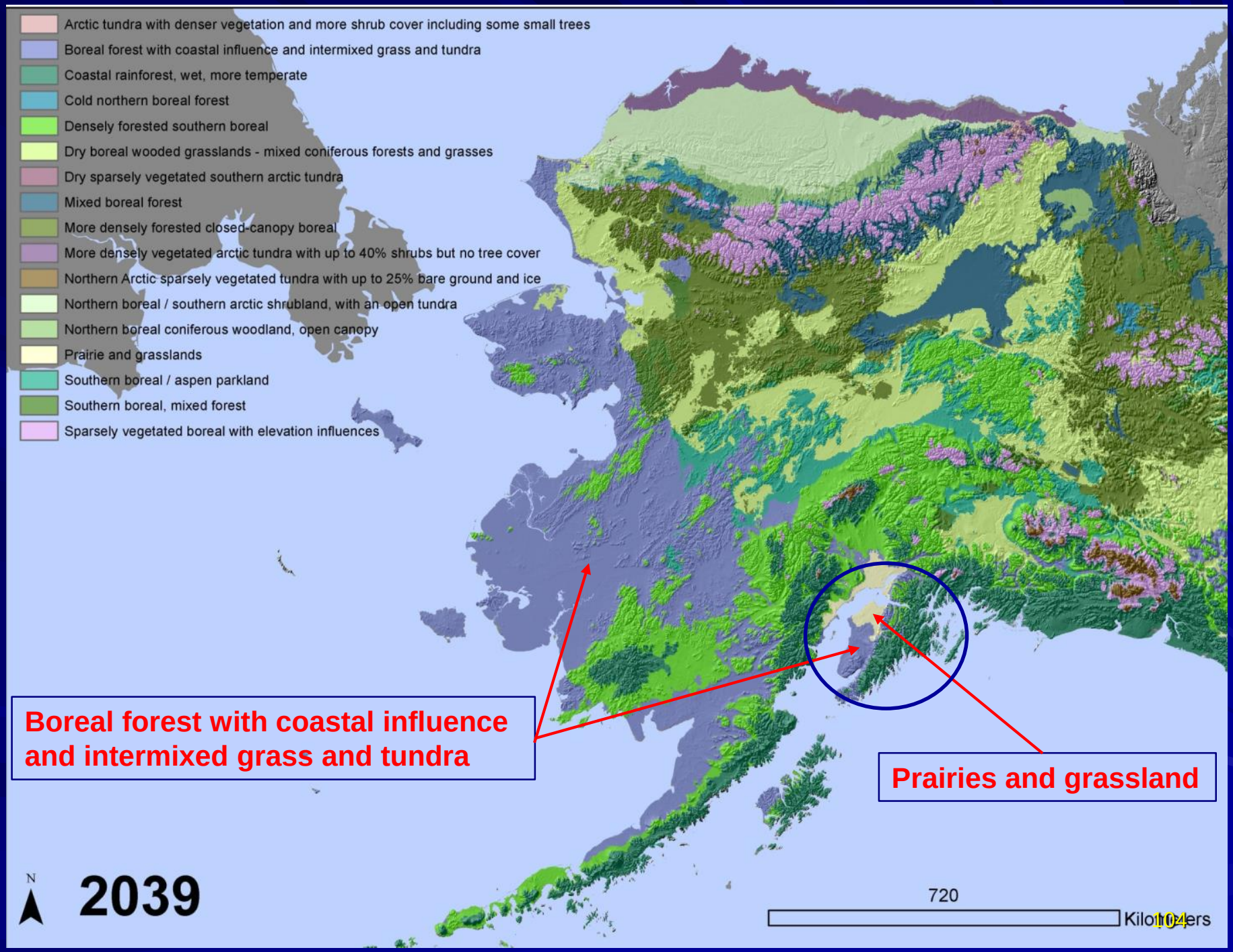
Sparsely vegetated boreal with elevation influences
Niche Modeling:
Climate-biomes (cliomes)
Murphy et al 2012
Boreal forest with coastal influence and intermixed grass and tundra
Prairies and grassland
N
2009
720
Kilometers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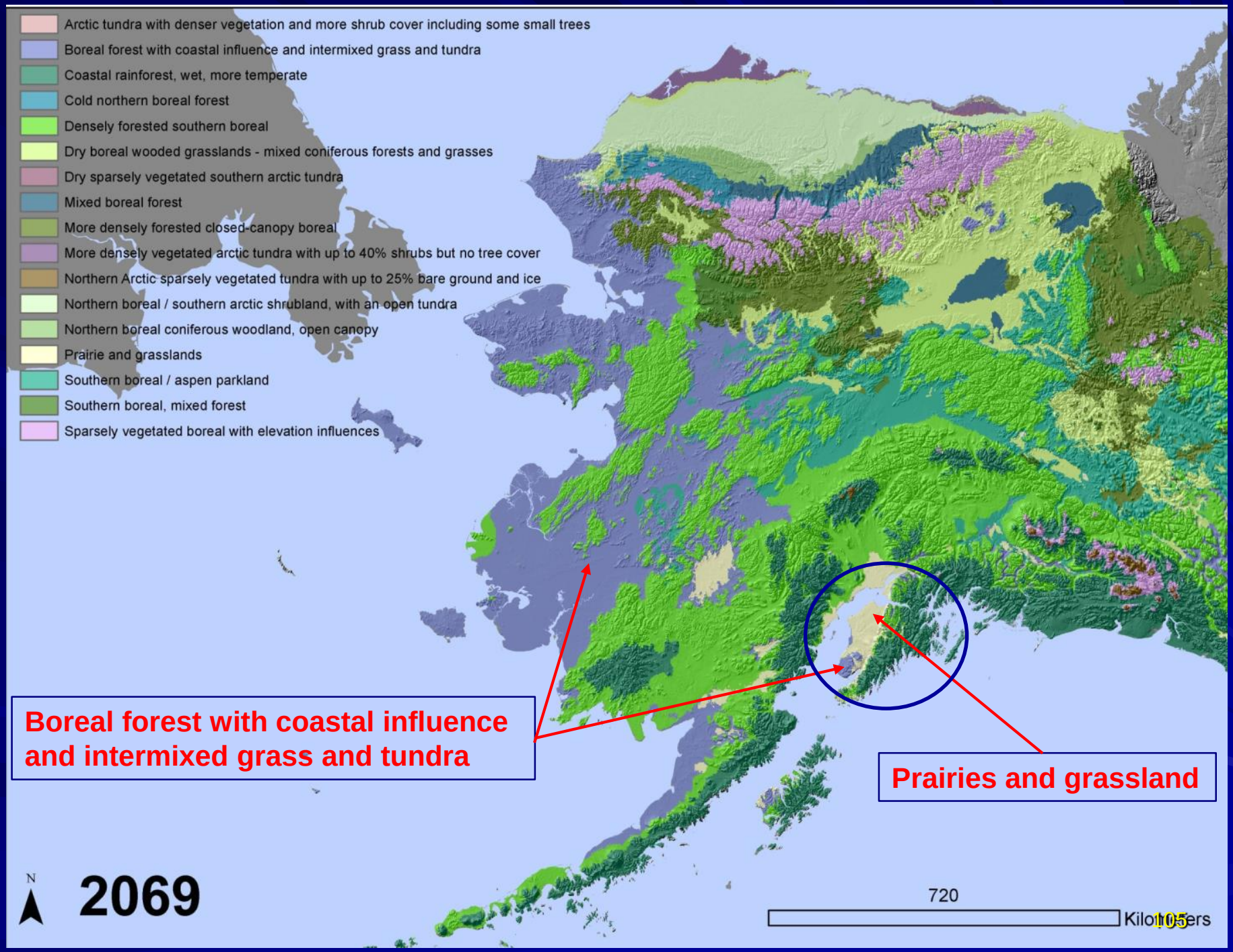
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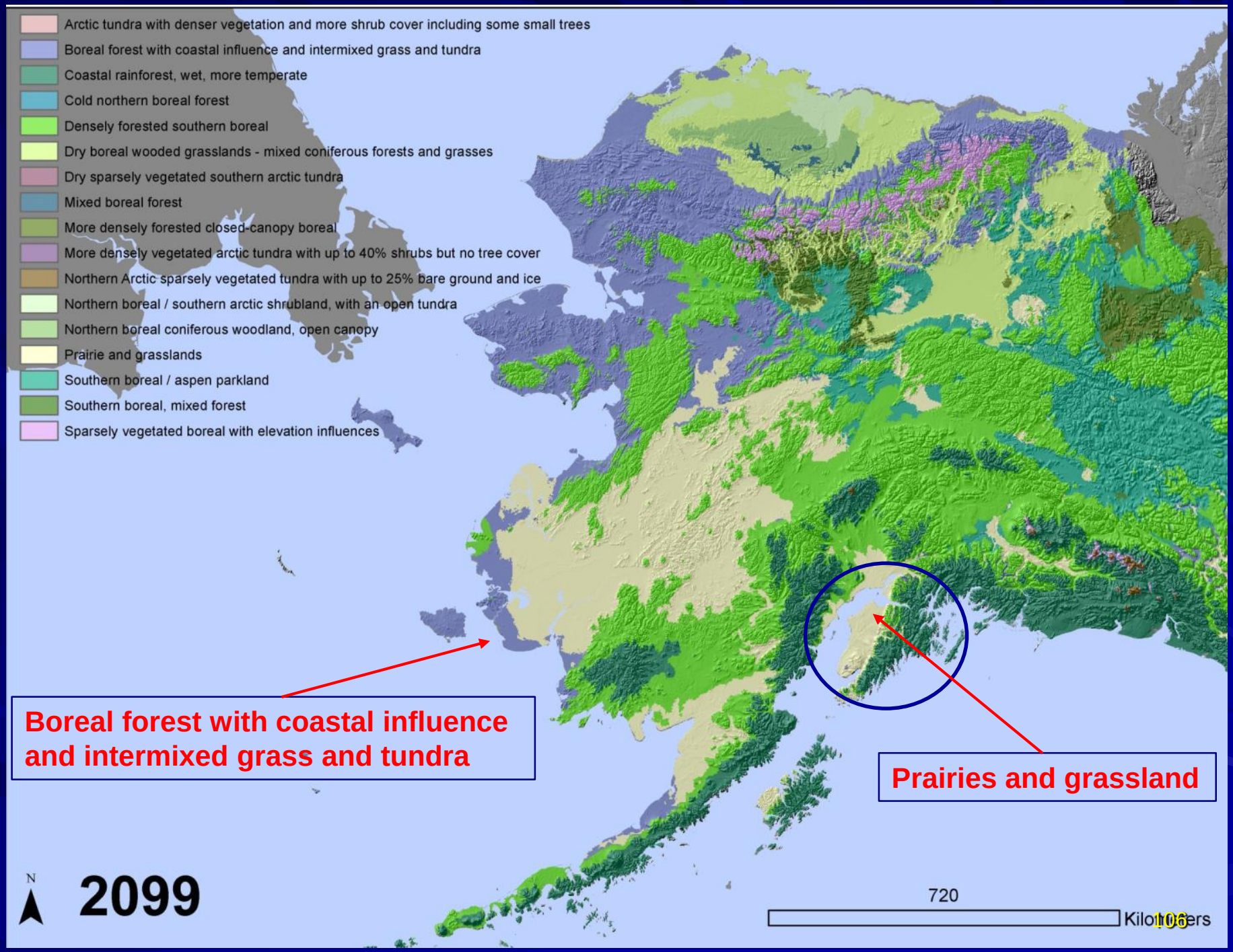
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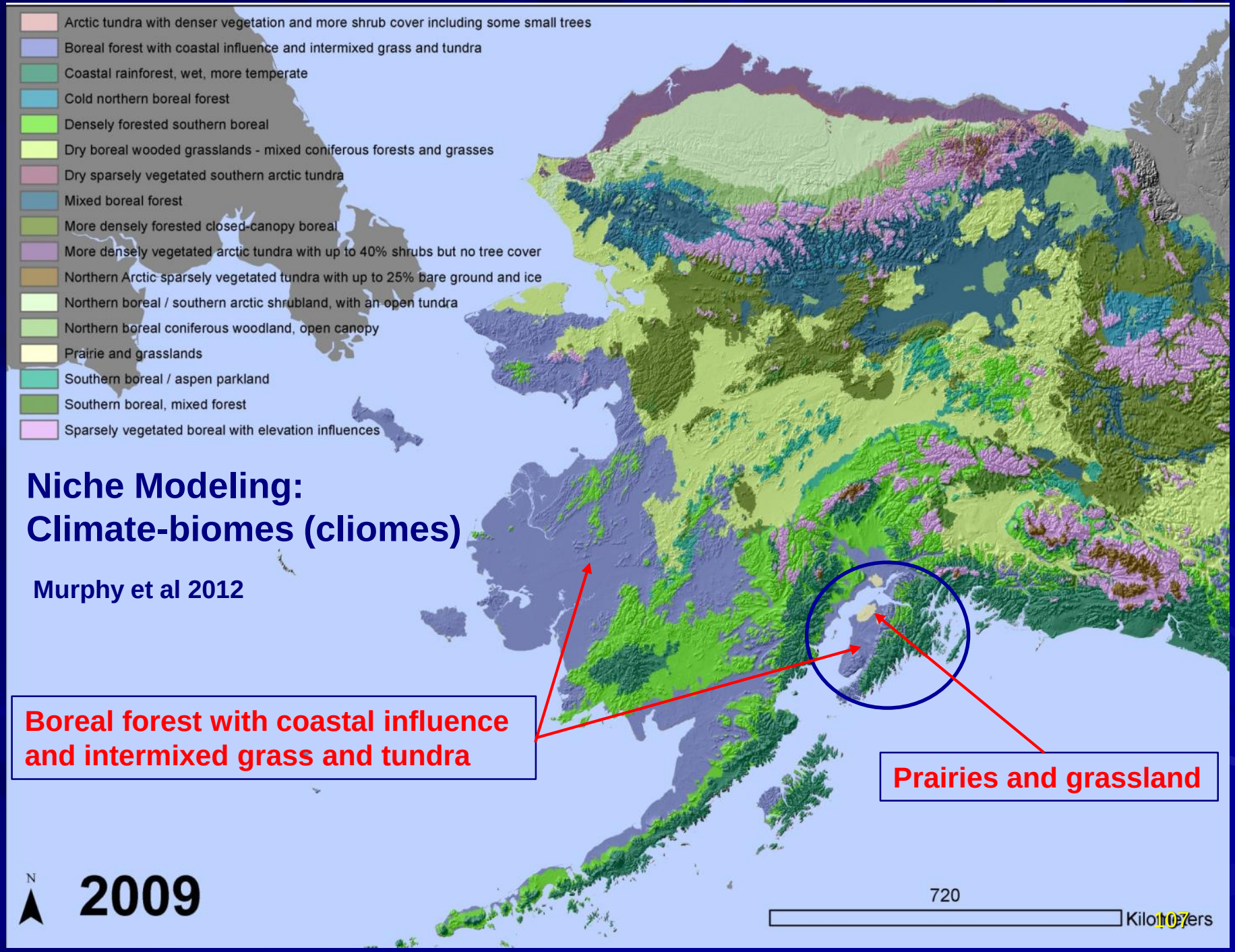
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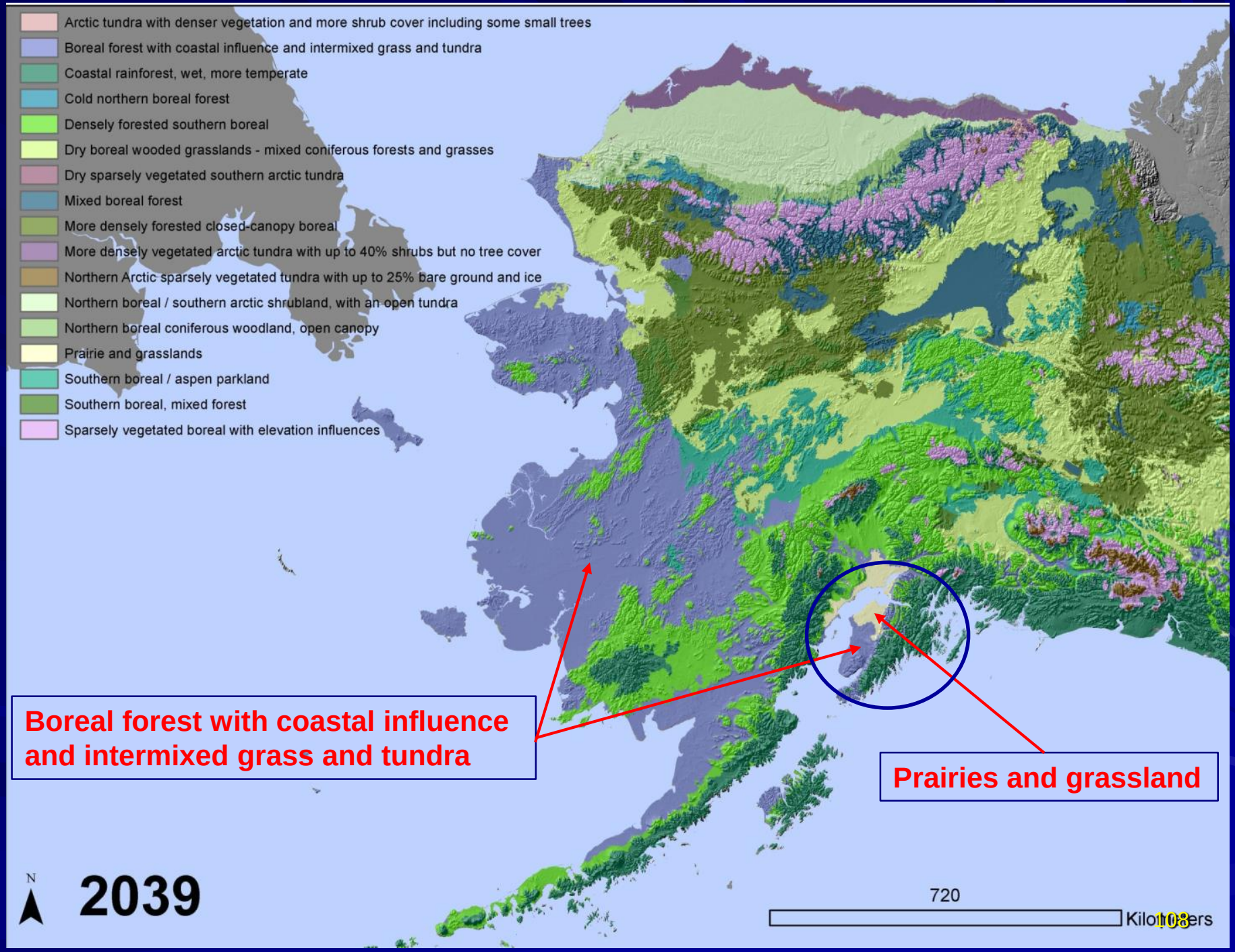
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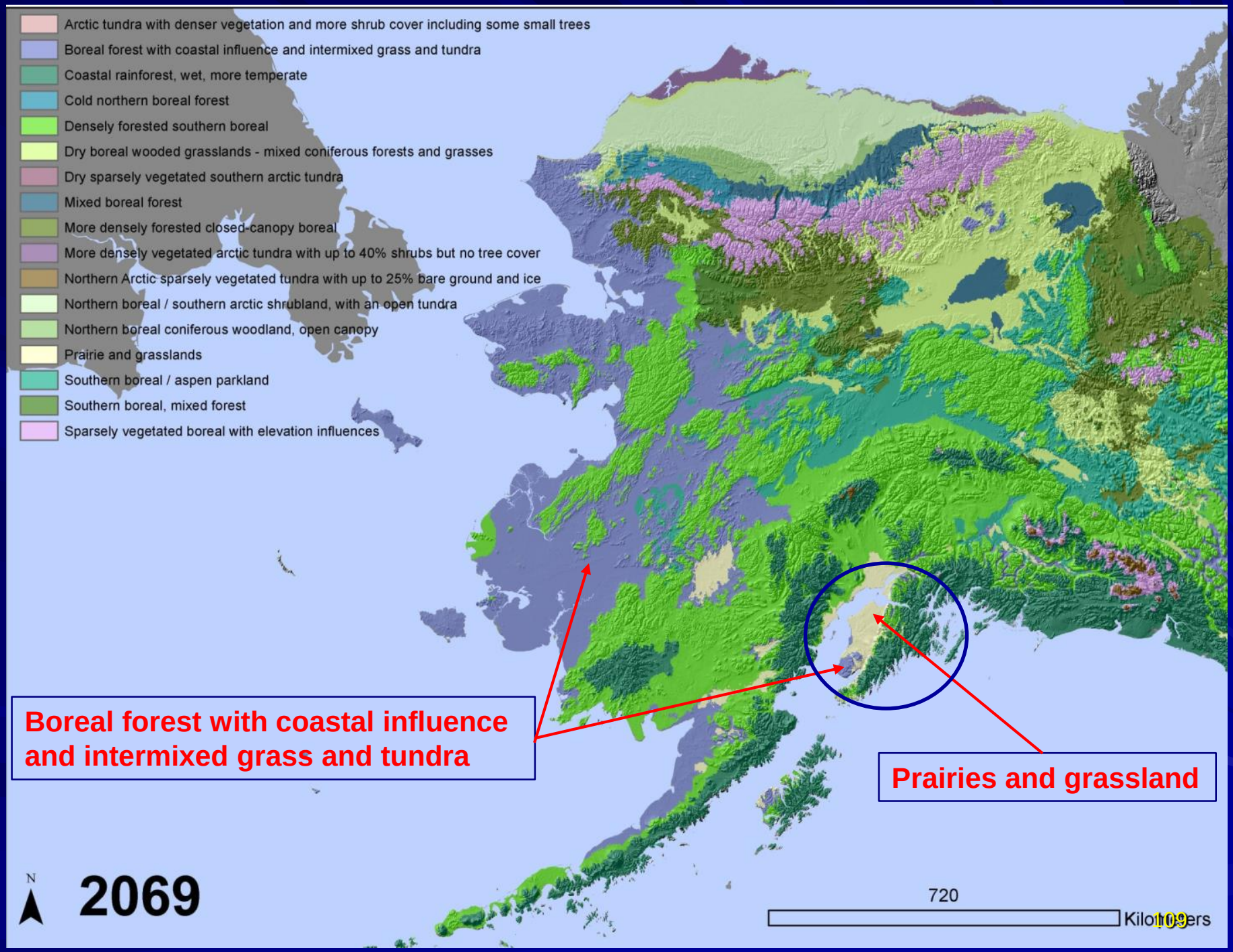
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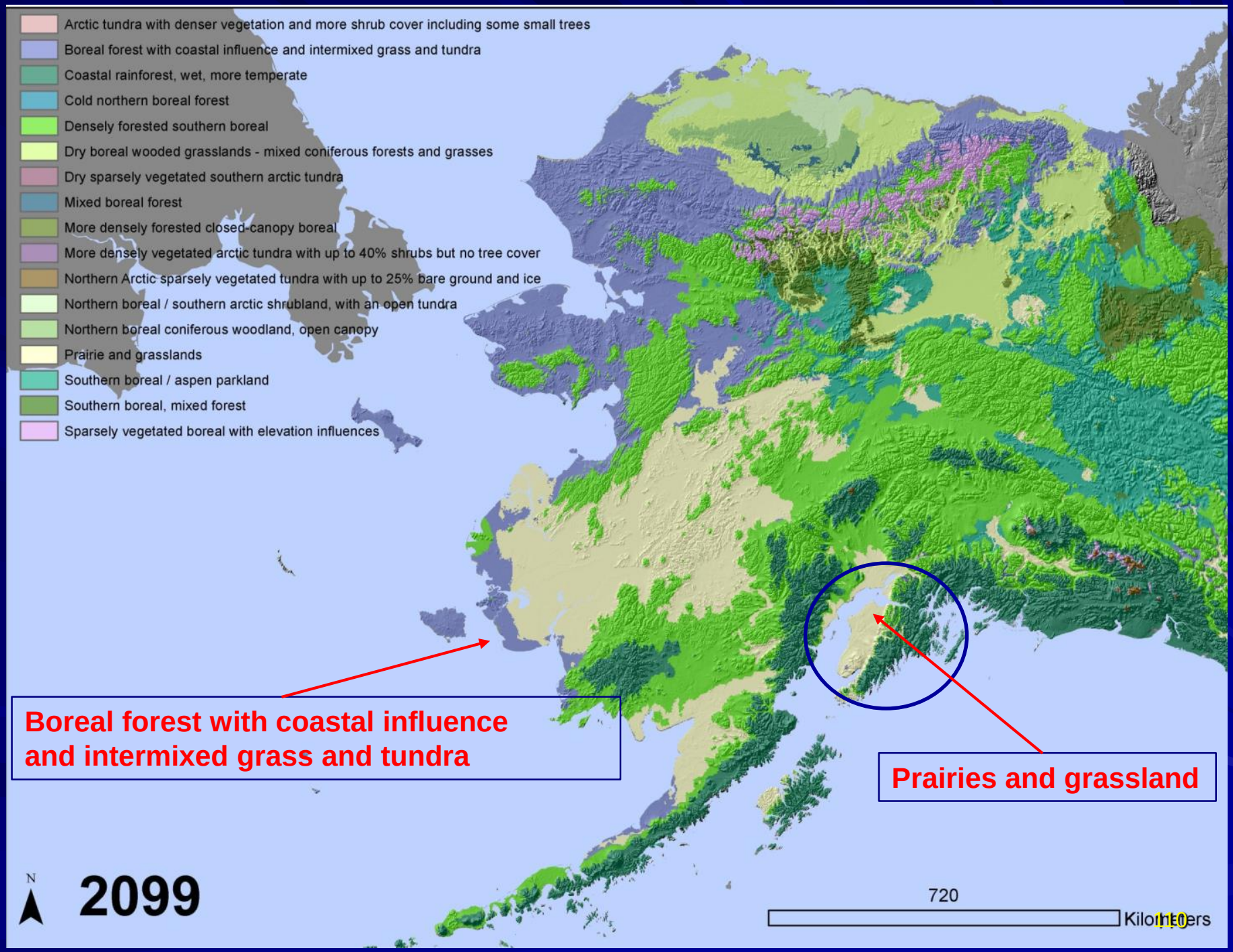
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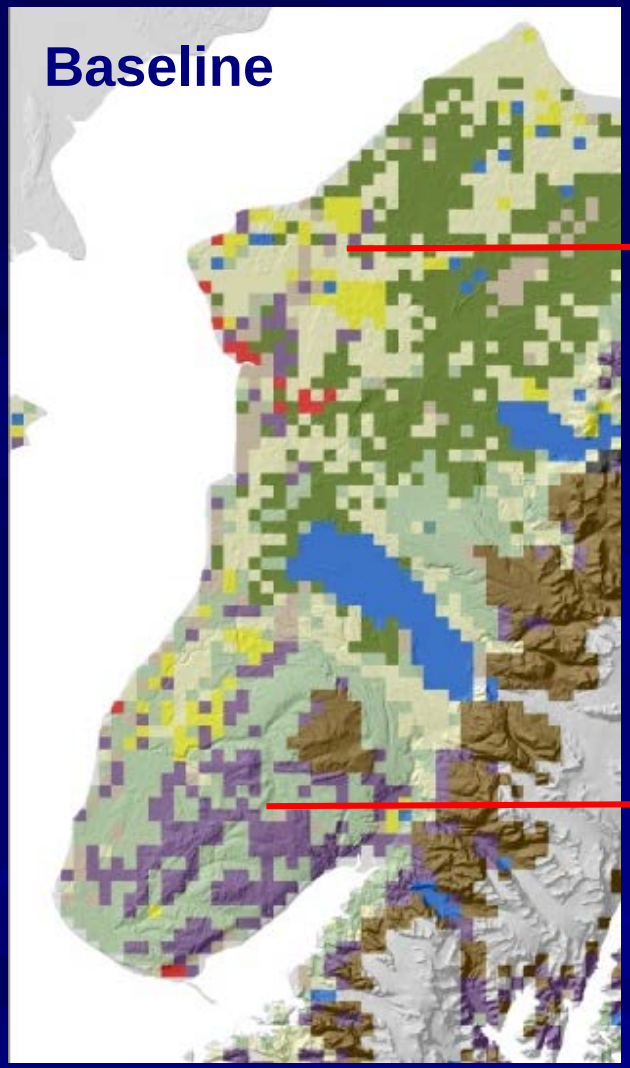
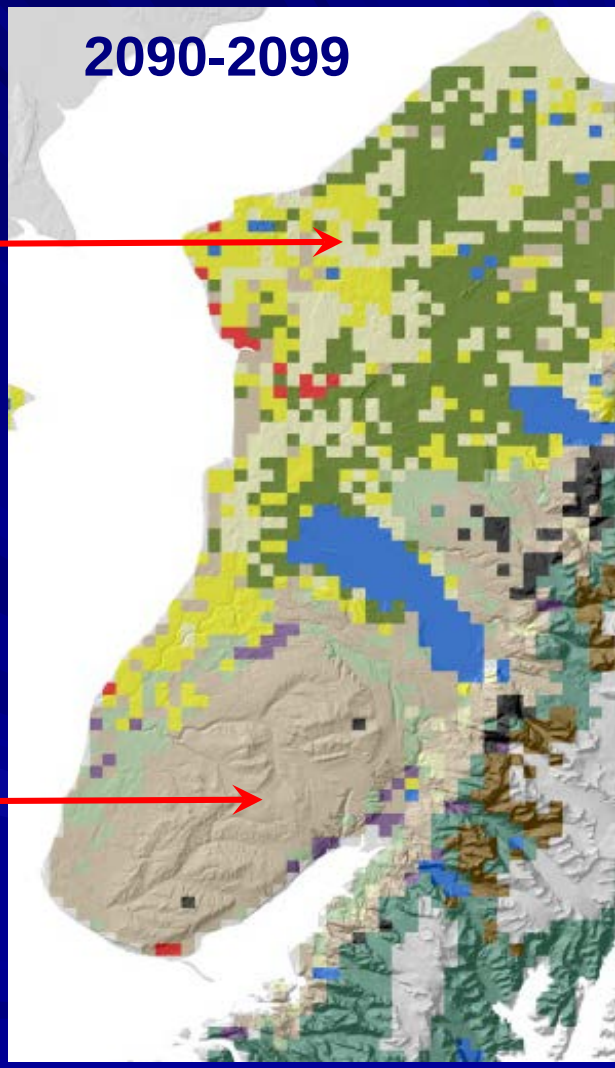
Random Forests model – 10 veg types, SNAP A1B (mid-range) scenario



Shifting from Black Spruce to more Hardwoods

Shifting from White-Sitka Spruce, Shrubs and Alpine to Herbaceous (grassland)



An Alternative, Longer-Term Hypothesis

The Kenai will become much drier, as it was 14,000 - 9,000 years ago.

Fire frequency will be much higher and burn severity will be extreme.

Fire will be supported by upland hardwoods, as it was 14,000 - 9,000 years ago, as well as by thick black spruce in the muskegs.

It is entirely possible that it will take several centuries to reach this degree of drought.

In the meanwhile grasslands may become widespread in the uplands, as the models to 2100 predict.

Two Possible Future Landscapes for the Western Kenai

Grassland

Hardwood Forest

That’s All for Today!