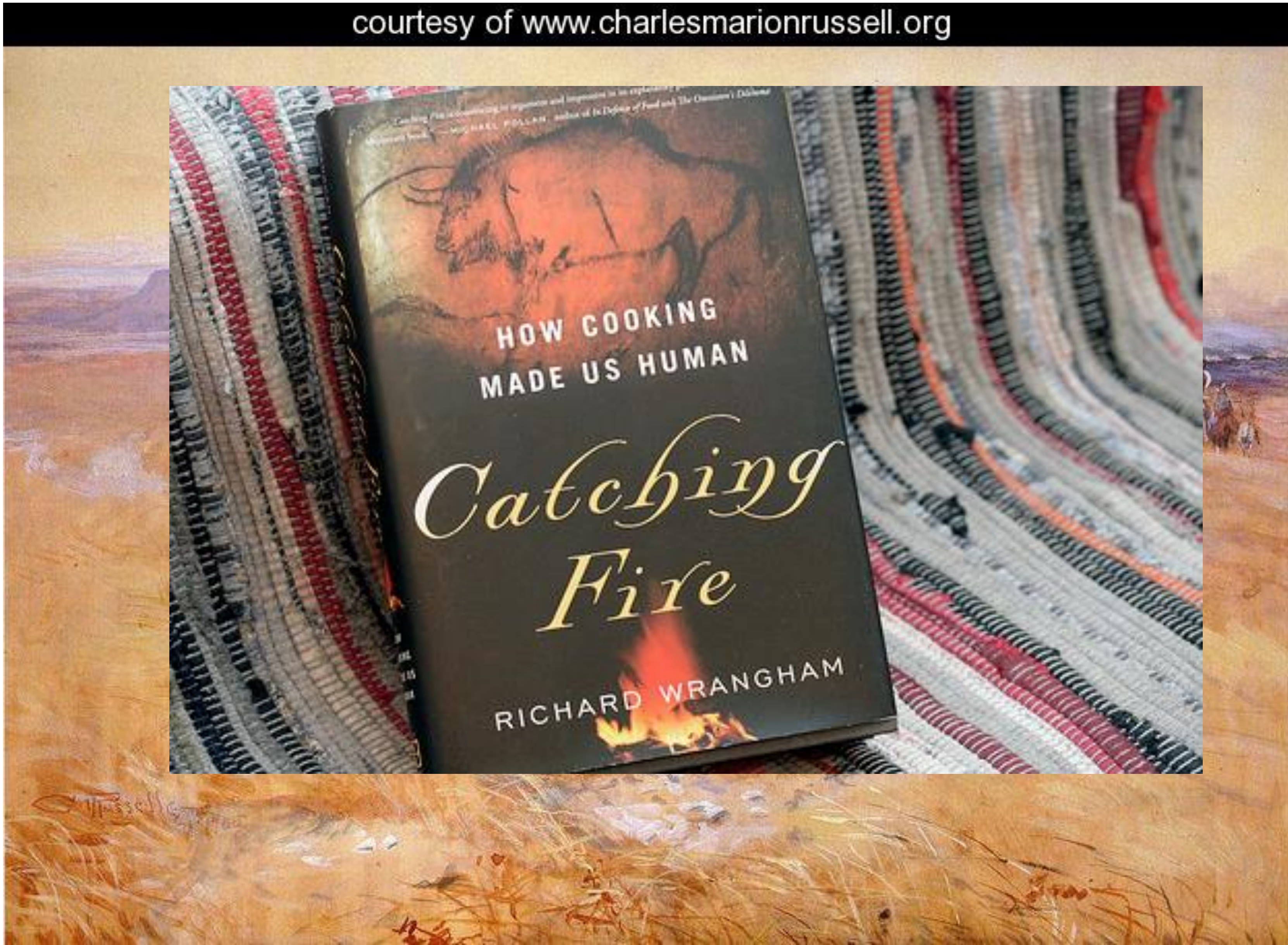
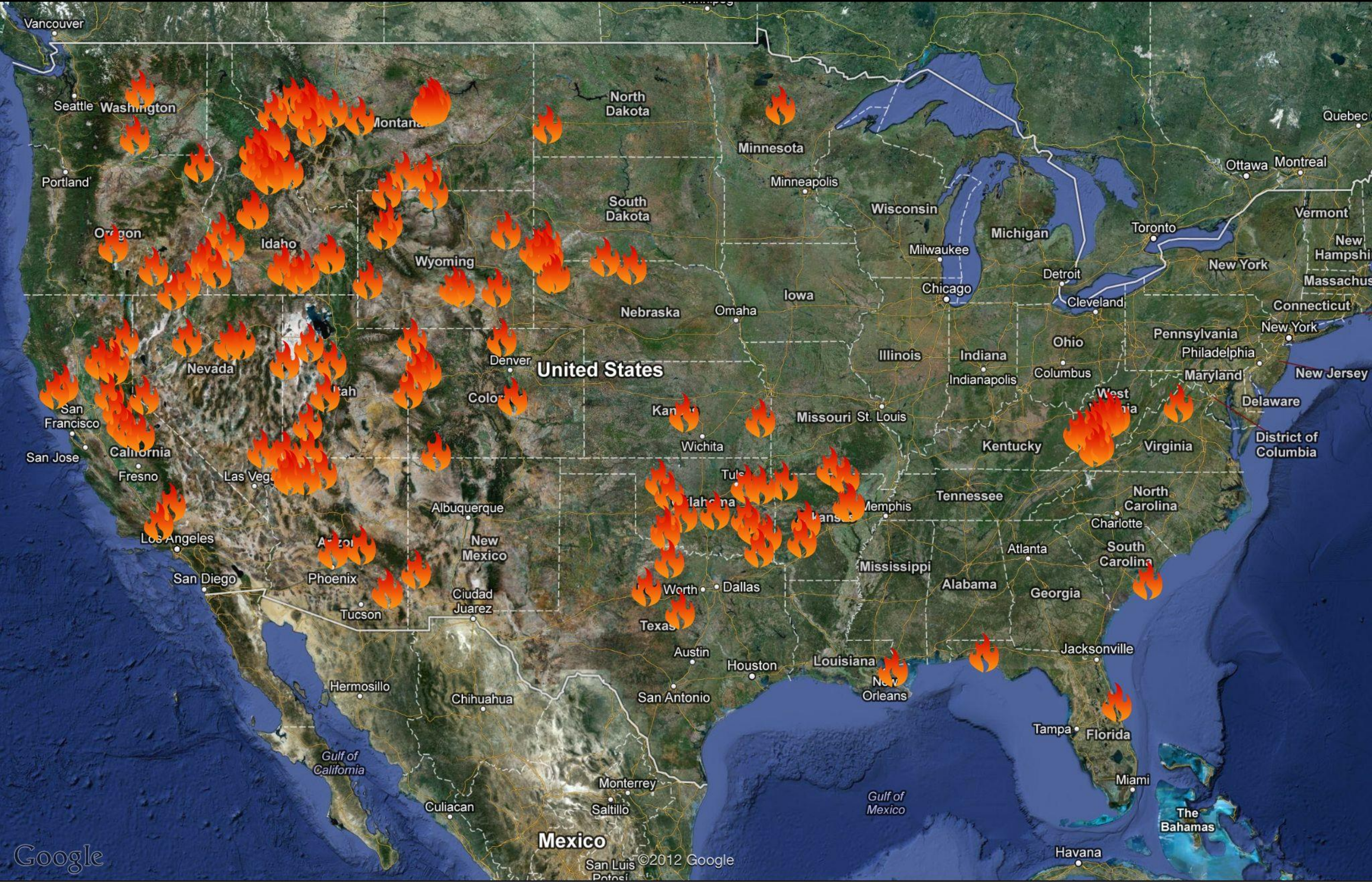
Humans and Fire



AT&T 11:26 AM 30%

Map List

Incidents



Incidents Guides Calculators

Three-fourths of US lands dominated by native vegetation show moderate or high departure from reference conditions as a result of altered fire regimes (TNC 2009).

USDA Forest Service Rocky Mountain Research Station Fire Science Lab Missoula, MT	DOI USGS Earth Resources Observation Systems (EROS) Data Center Sioux Falls, SD	The Nature Conservancy Global Fire Initiative Boulder, CO	FRCC Team Fire & Aviation Management Washington DC

Fire cycles in North American interior grasslands and their relation to prairie drought

K. J. Brown[†‡§], J. S. Clark[†¶], E. C. Grimm[‖], J. J. Donovan[††], P. G. Mueller[‖], B. C. S. Hansen[‡‡], and I. Stefanova[‡‡]

[†]Department of Biology and [¶]Nicholas School of the Environment, Duke University, P.O. Box 90338, Durham, NC 27708; [‡]Department of Quaternary Geology, Geological Survey of Denmark and Greenland, 10 Øster Voldgade, DK-1350 Copenhagen K, Denmark; [‖]Illinois State Museum, Research and Collections Center, 1011 East Ash Street, Springfield, IL 62703; [††]Department of Geology and Geography, West Virginia University, 425 White Hall, P.O. Box 6300, Morgantown, WV 26506; and [‡‡]Limnological Research Center, University of Minnesota, 220 Pillsbury Hall, 310 Pillsbury Drive Southeast, Minneapolis, MN 55455

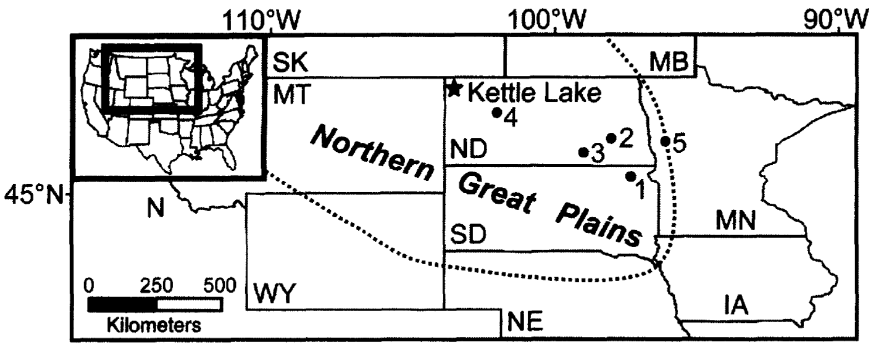


Fig. 1. Study location (*Inset*) and study site map. The dotted line defines the approximate boundary of the NGP. Kettle Lake is marked by a star. Sites numbered 1–4 correspond to other locations where aridity cycles have been detected: 1, Pickerel Lake (South Dakota) and Spring Lake; 2, Moon Lake (North Dakota); 3, Coldwater Lake; 4, Rice Lake. Location 5 is West Olaf Lake.

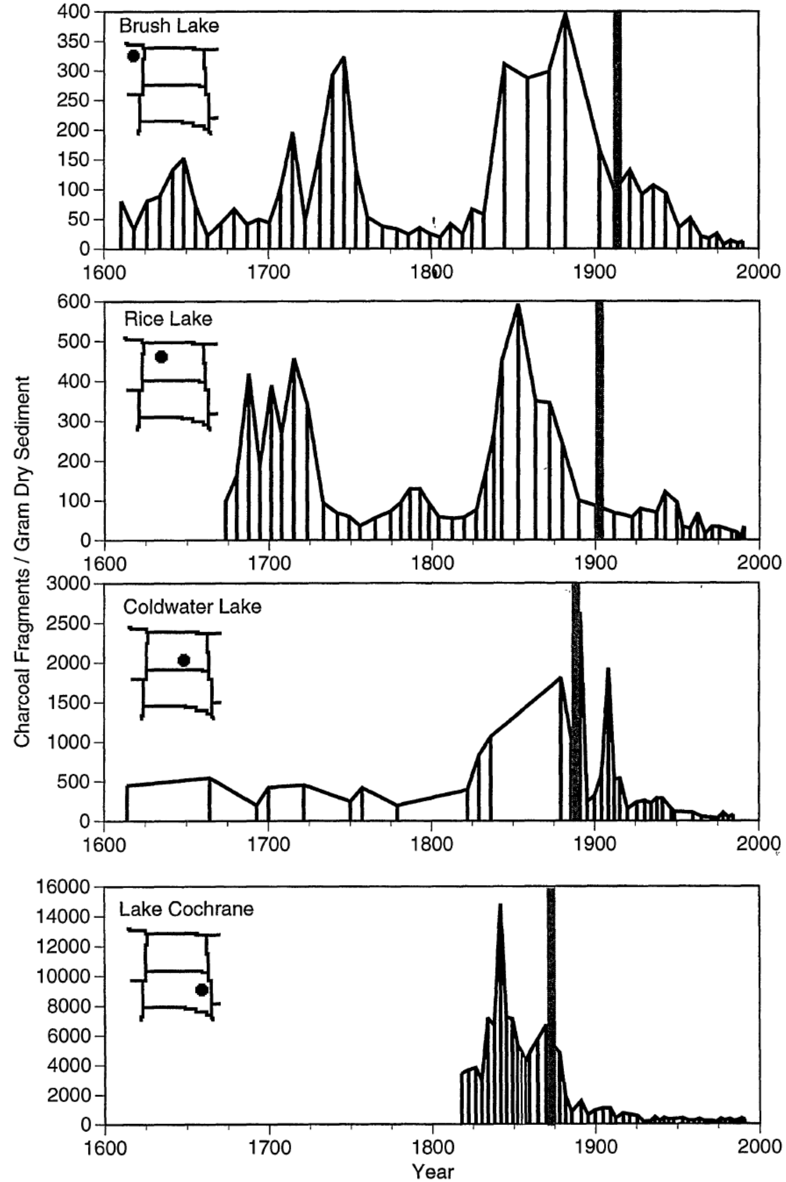


FIG. 1.—Charcoal concentration [fragments/gram (dry weight)] in sediments from four northern Great Plains lakes. Bar indicates approximate time of European settlement. Dot on map indicates location (*see* text for exact coordinates) of lakes

History of fire and Douglas-fir establishment in a savanna and sagebrush–grassland mosaic, southwestern Montana, USA

Emily K. Heyerdahl [a,*], Richard F. Miller [b,1], Russell A. Parsons [a]

Fire History at the Forest-Grassland Ecotone in Southwestern Montana

STEPHEN F. ARNO AND GEORGE E. GRUELL

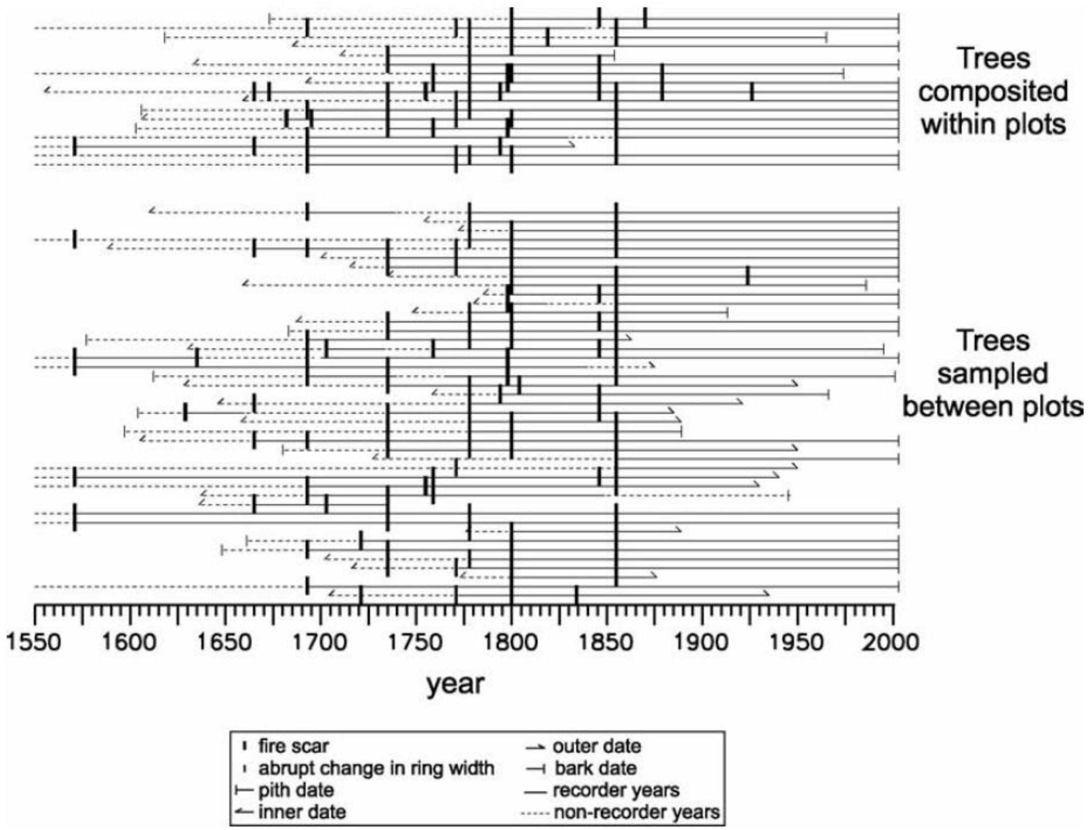


Fig. 2. Chronology of surface fire occurrence in the study area. Each horizontal line shows either the composite fire-scar record for a plot (i.e., fire-scar dates composited for all trees within a plot, specifically one to four trees sampled over approximately 2 ha), or the record from a single tree sampled opportunistically between plots. Non-recorder years precede the formation of the first scar on each tree but also occur when subsequent fires or rot consume that record. Inner and outer dates are the dates of the earliest or latest rings sampled for trees where pith or bark was not sampled.

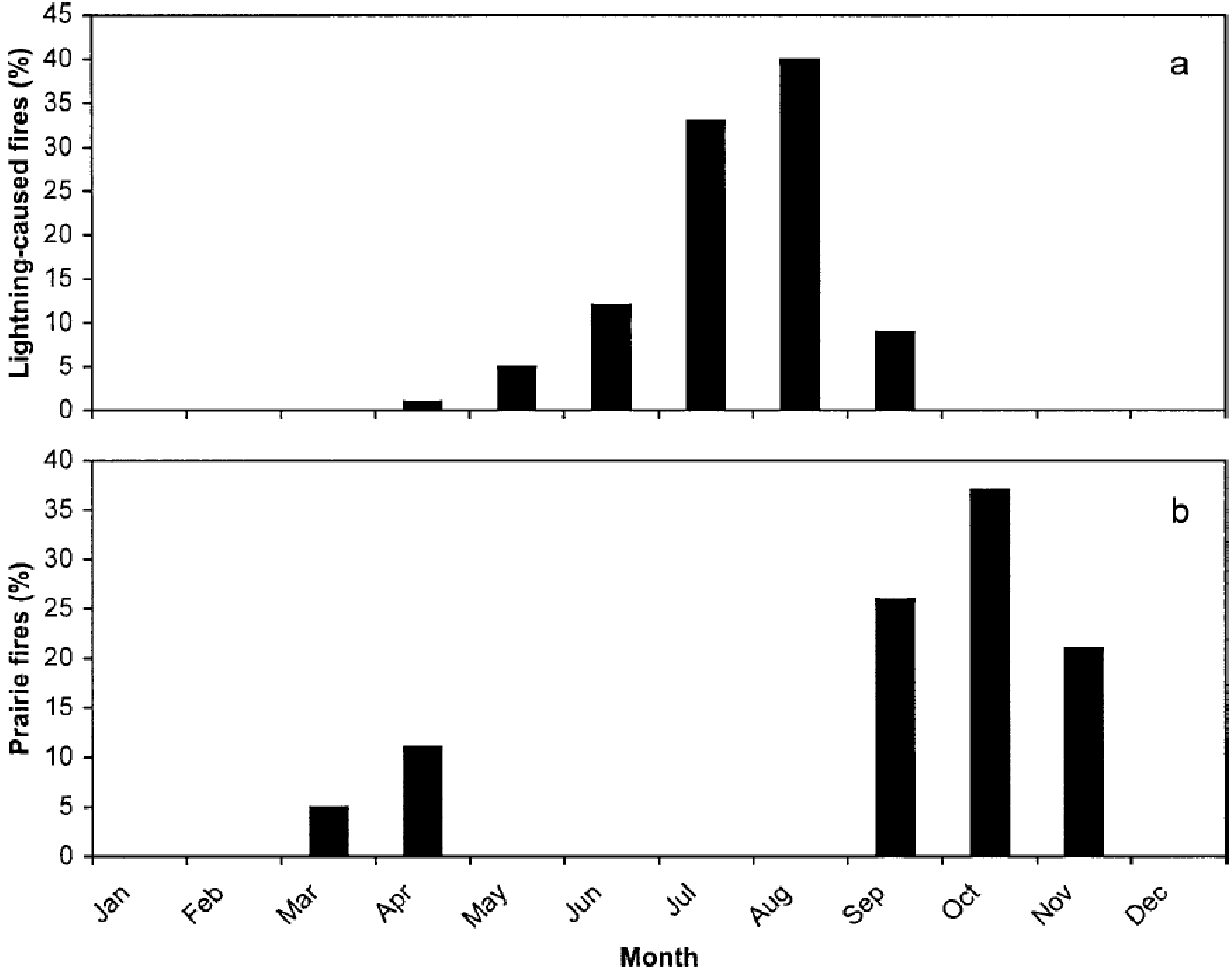
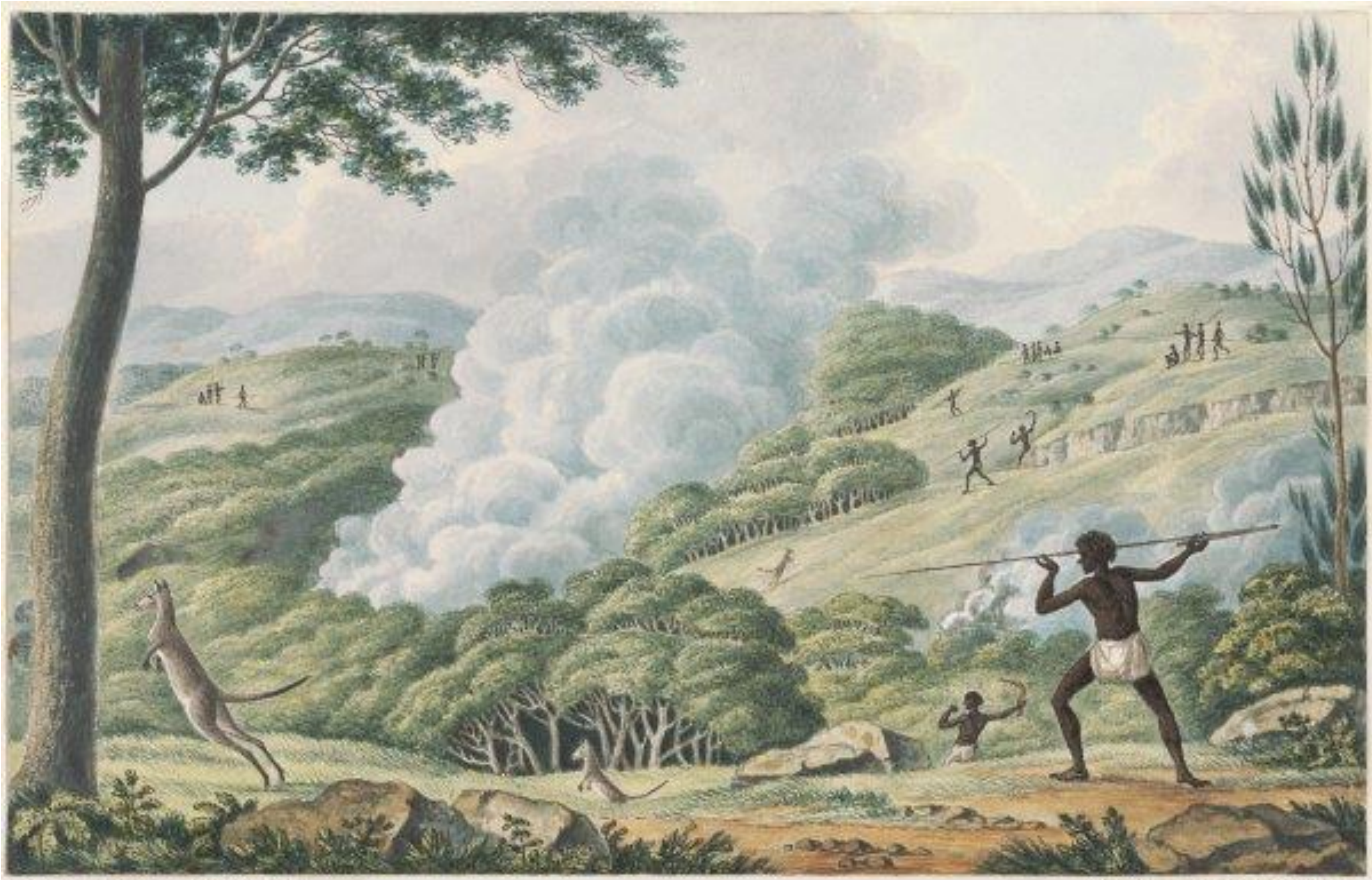


Fig. 4. The distribution of fires on the northern Great Plains. (a) The distribution of lightning fires that occurred from 1940 to 1981, as reported by Higgins (1984). There are few lightning fires during spring or fall because there are very few lightning strikes during those periods. (b) The distribution of prairie fires as reported by Alexander Henry the Younger from 1800 to 1807 when the northern Great Plains were under aboriginal control (Gough 1988).



Pyric Herbivory: What is the role of fire in grazed landscapes?

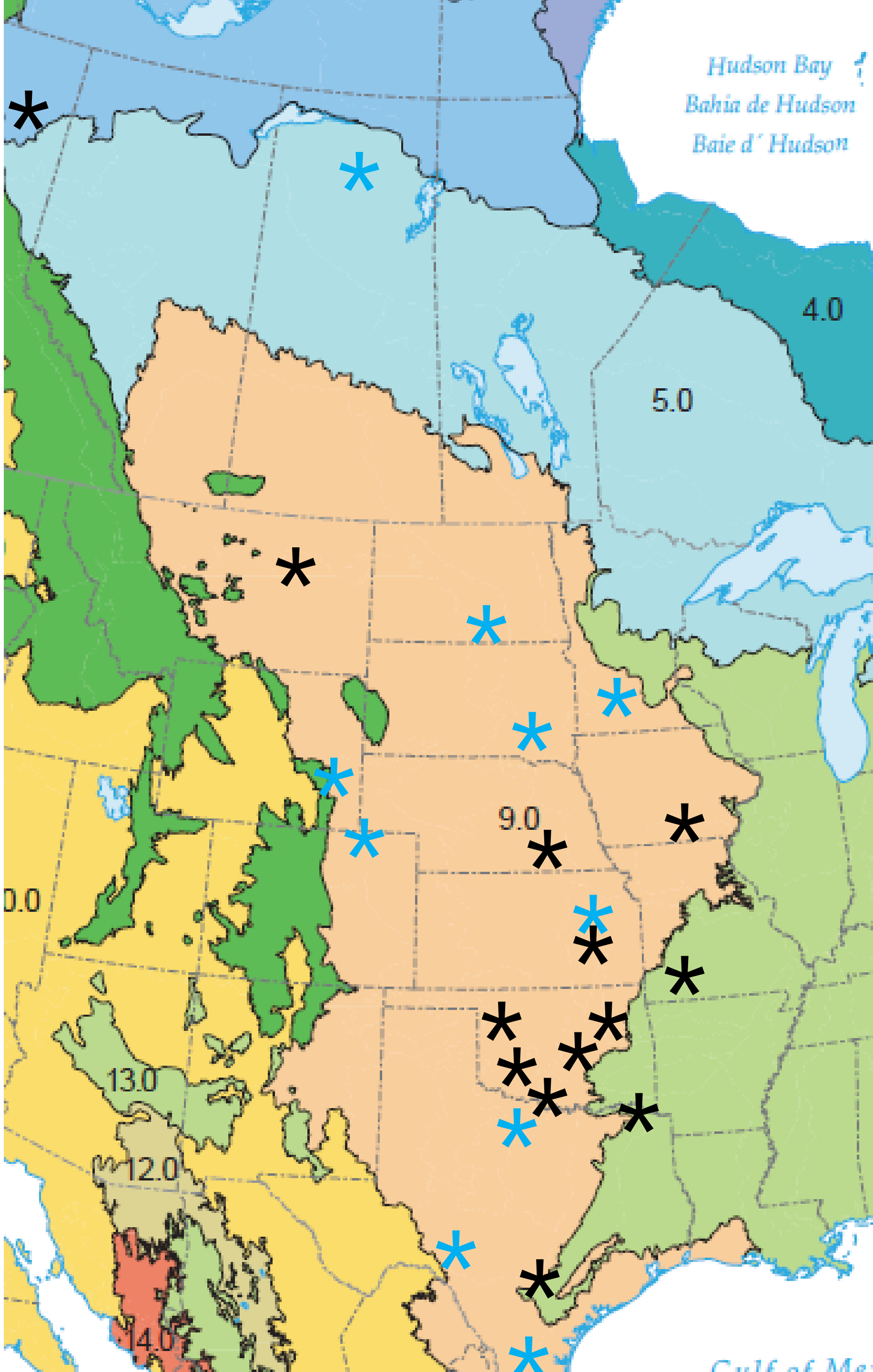
Sam Fuhlendorf
Oklahoma State University

Other important questions:

1. How do fire and grazing interact on landscapes?
2. How can we manipulate the interaction to achieve specific objectives?
3. What is “excellent rangeland condition”?
4. What if bison could carry a drip torch?

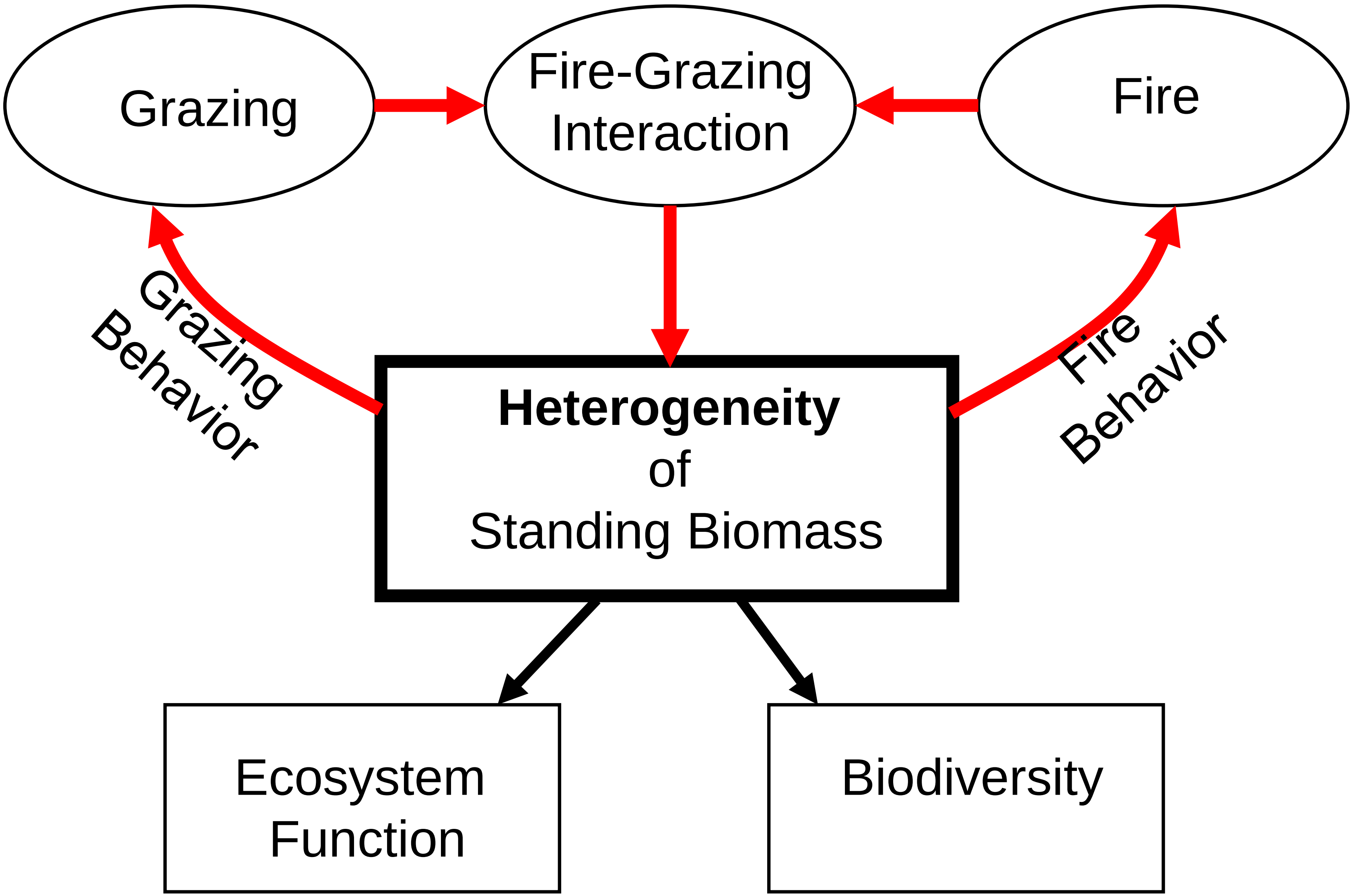
Study Locations

- * Fuhlendorf et al
- * Other studies



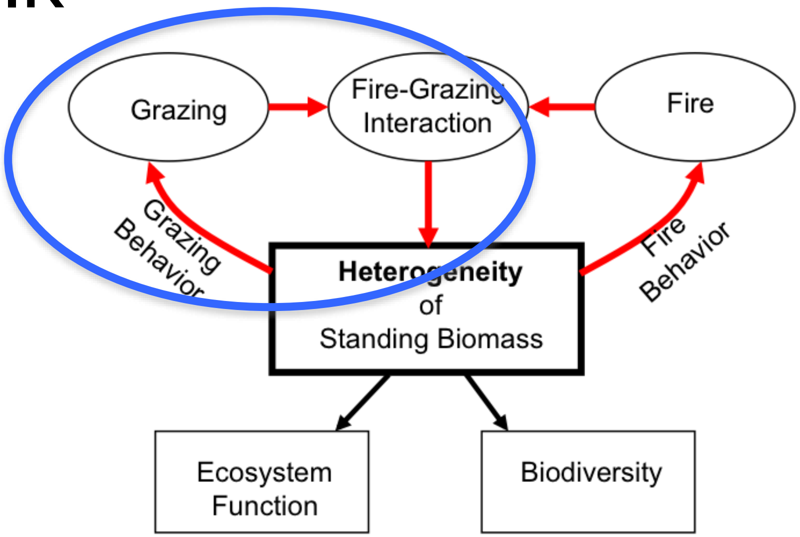
Heterogeneity Paradigm

Pyric Herbivory, Patch Burning, Patch Burn Grazing



Does fire alter grazing behavior?

- Bison, cattle, horses, elk
- Pasture size
- Patch size
- Time since fire
- Variable regions



Fire-grazing interaction (pyric herbivory) as a critical ecosystem process- Global perspective

Africa
Moe, Wegge, & Kapela 1990; Wilsey 1996; Salvatori et al. 2001; Gureja & Owen-Smith 2002; Tomor & Owen-Smith 2002; Archibald & Bond 2004; Archibald et al. 2005; Klop, van Goethem, & de Iongh 2007; Savadogo, Sawadogo, & Tiveau 2007; Archibald 2008; Hassan et al. 2008; Klop & van Goethem 2008; Waldram, Bond, & Stock 2008; Parrini & Owen-Smith 2010
Asia
Moe & Wegge 1994; Moe & Wegge 1997; Sankaran 2005
Australia
Kirkpatrick, Marsden-Smedley, & Leonard In press; Kutt & Woinarski 2007; Murphy & Bowman 2007; Leonard, Kirkpatrick, & Marsden-Smedley 2010
Europe
Kramer, Groen, & van Wieren 2003; Vandvik et al. 2005; Onodi et al. 2008; Davies et al. 2010
North America
Duvall & Whitaker 1964; Hobbs & Spowart 1984; Vinton et al. 1993; Turner et al. 1994; Pearson et al. 1995; Wallace et al. 1995; Coppedge & Shaw 1998; Biondini, Steuter, & Hamilton 1999; Smith, Hardin, & Flinders 1999; Fuhlendorf & Engle 2004; Schuler et al. 2006; Van Dyke & Darragh 2007; Bleich et al. 2008; Meek et al. 2008

Allred et al. 2011

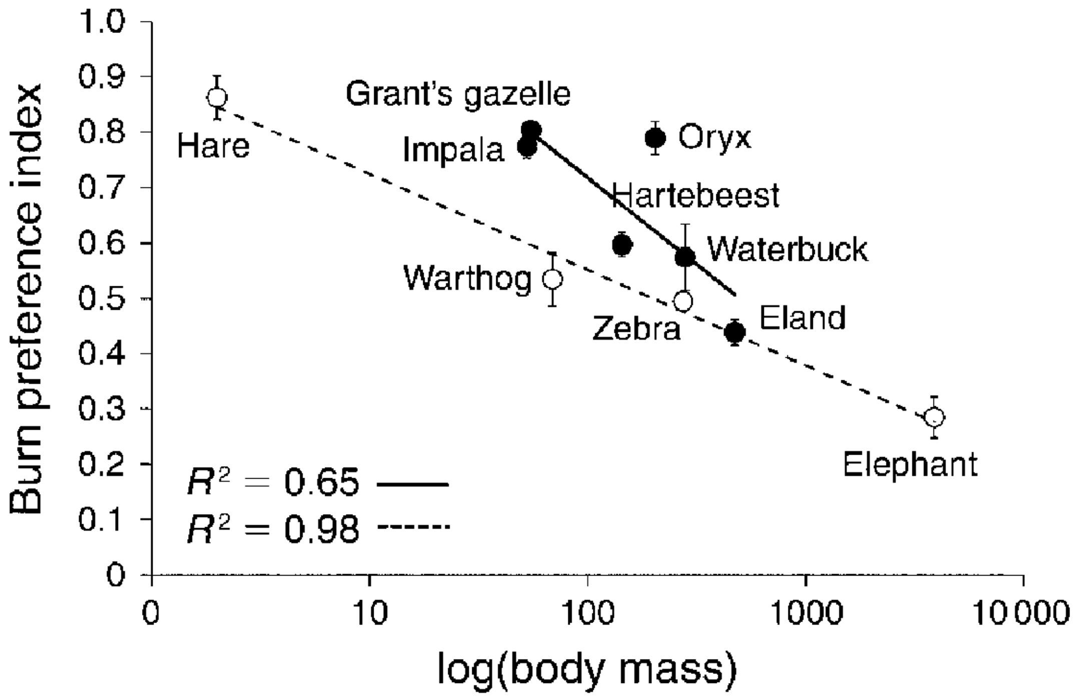
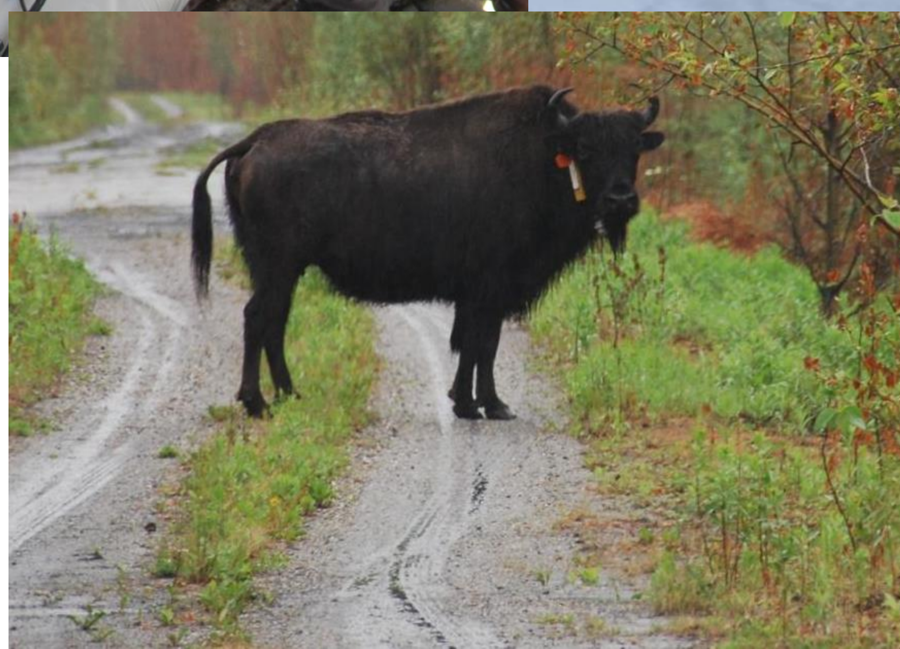


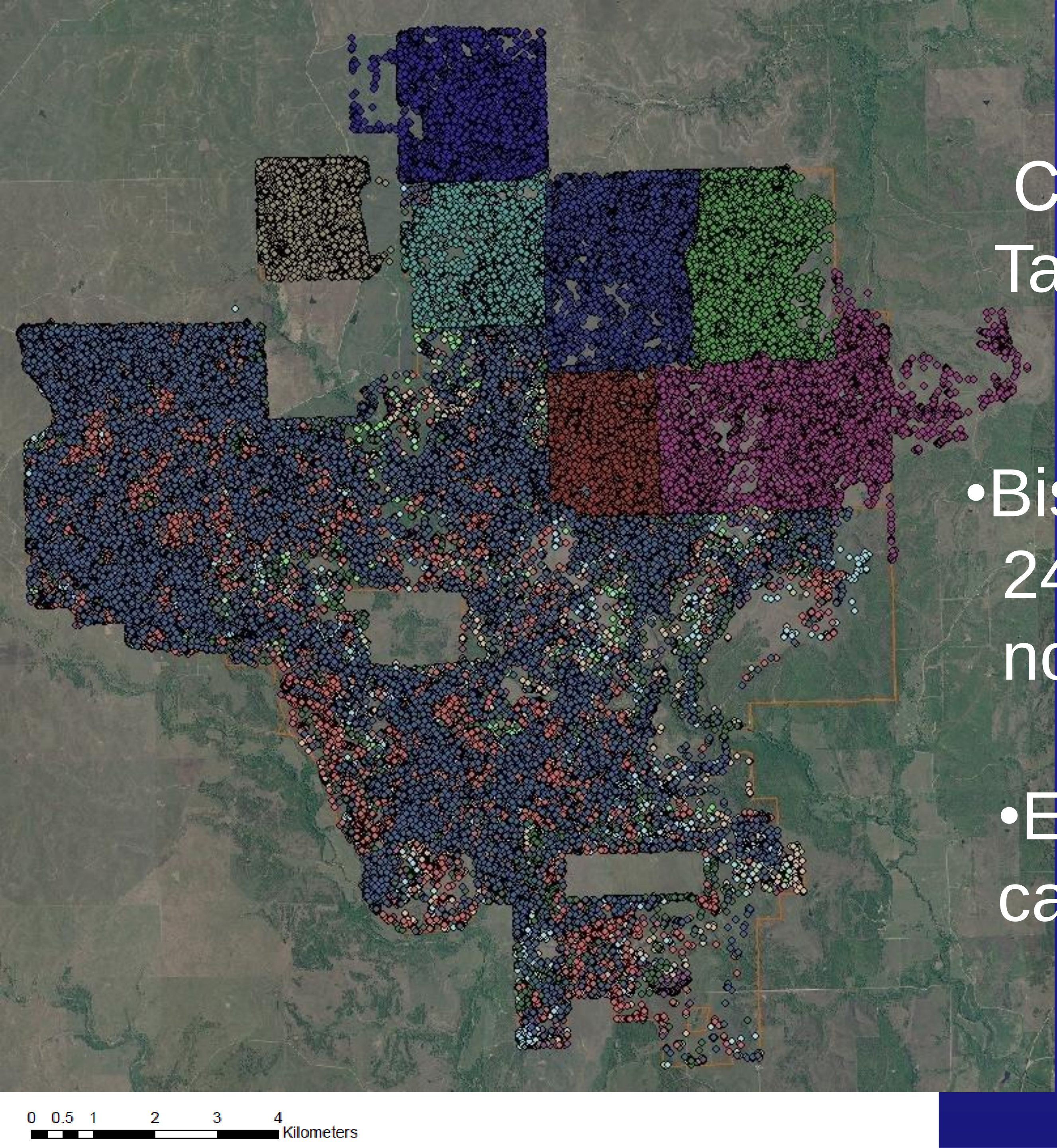
FIG. 2. Grazer preference for burned areas negatively scales to body mass (originally measured in kg) for both hindgut fermenters (open circles) and foregut fermenters (solid circles). Burn preference indices (mean 6 SE) are from 18 burned plots where "burn preference'' is dung in burned areas/(dung in burned areasþ dung in control transects). Regression equations for the full linear mixed model on a log–log scale are: y ¼ 1.24x$^{-0.12}$ and y ¼2.17$^{-0.19}$ for hindgut (dotted line) and foregut grazers (solid line), respectively. Fitted lines and R^2 values are for uncorrected means. The burn preference index ranges from 0 to 1, where 0 equals complete avoidance of burned areas and 1 indicates complete preference for burned areas.

Sensenig et al. 2010

Gureja & Owen-Smith 2002
Archibald & Bond 2004
Archibald et al. 2005


17.02.2009 13:40





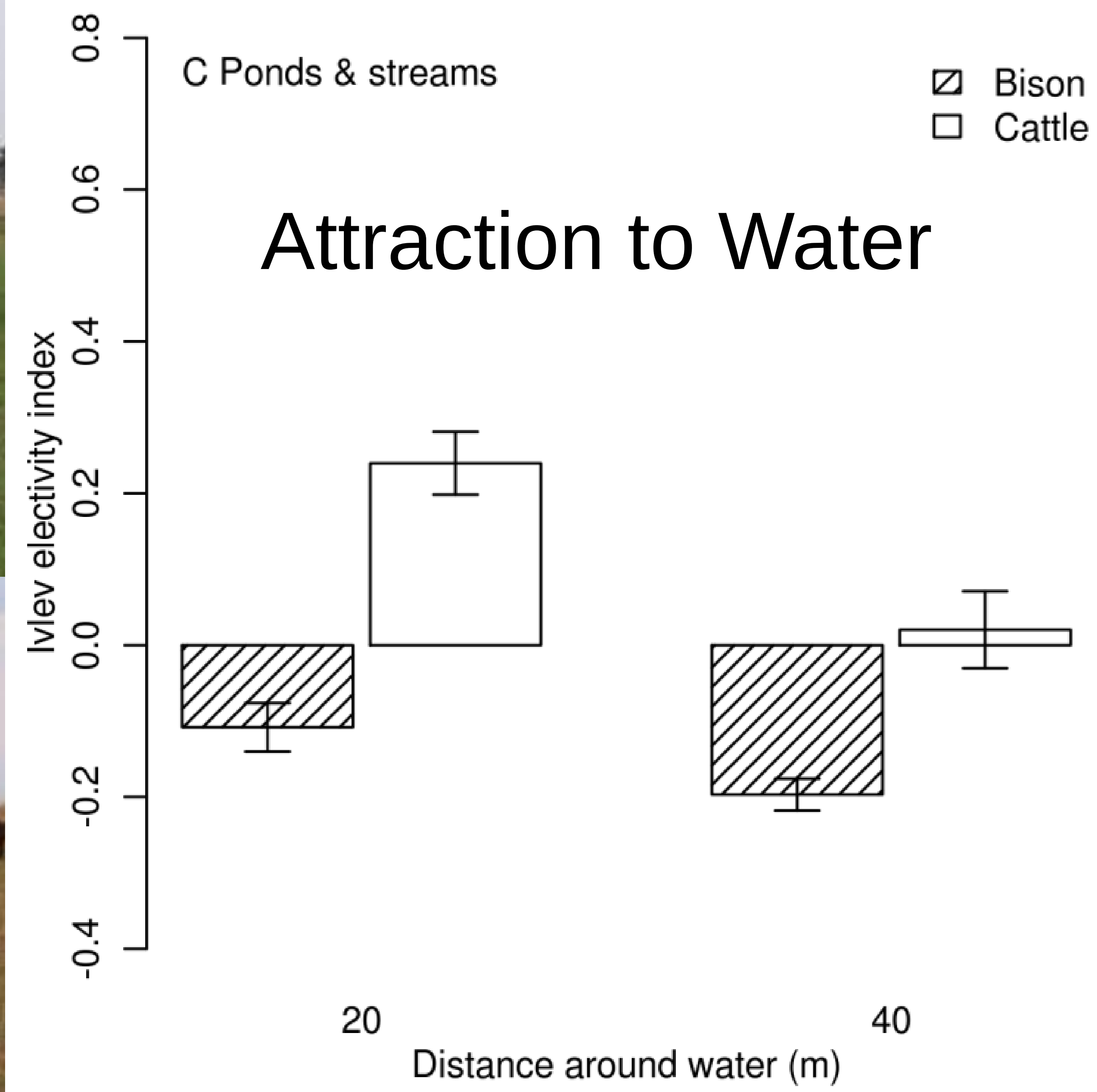
The Nature Conservancy's Tallgrass Prairie Preserve

- Bison Unit
  24,000 ac
  no cross-fences

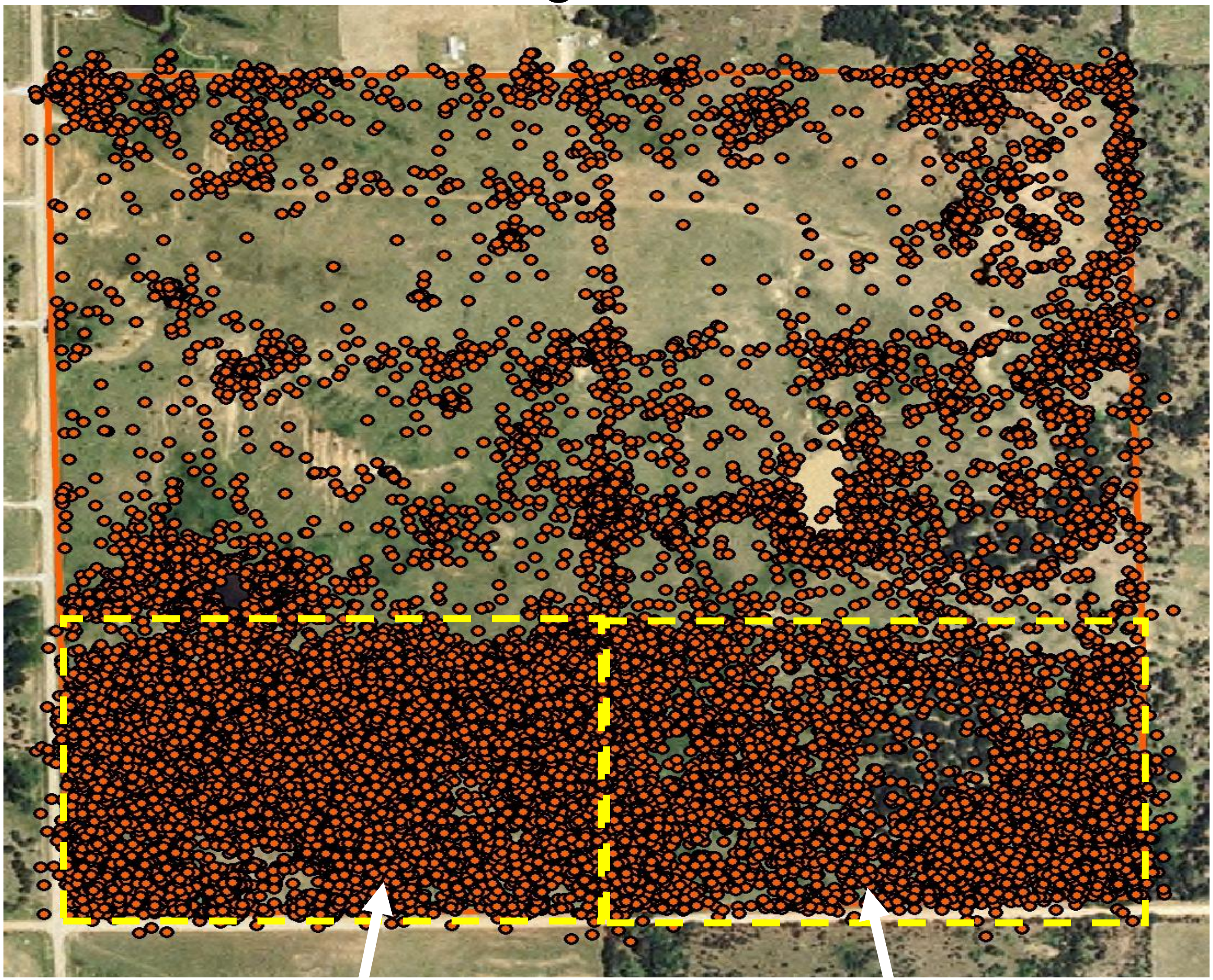
- Experimental cattle pastures

- http://www.youtube.com/watch?v=L5eTmVQxtEM

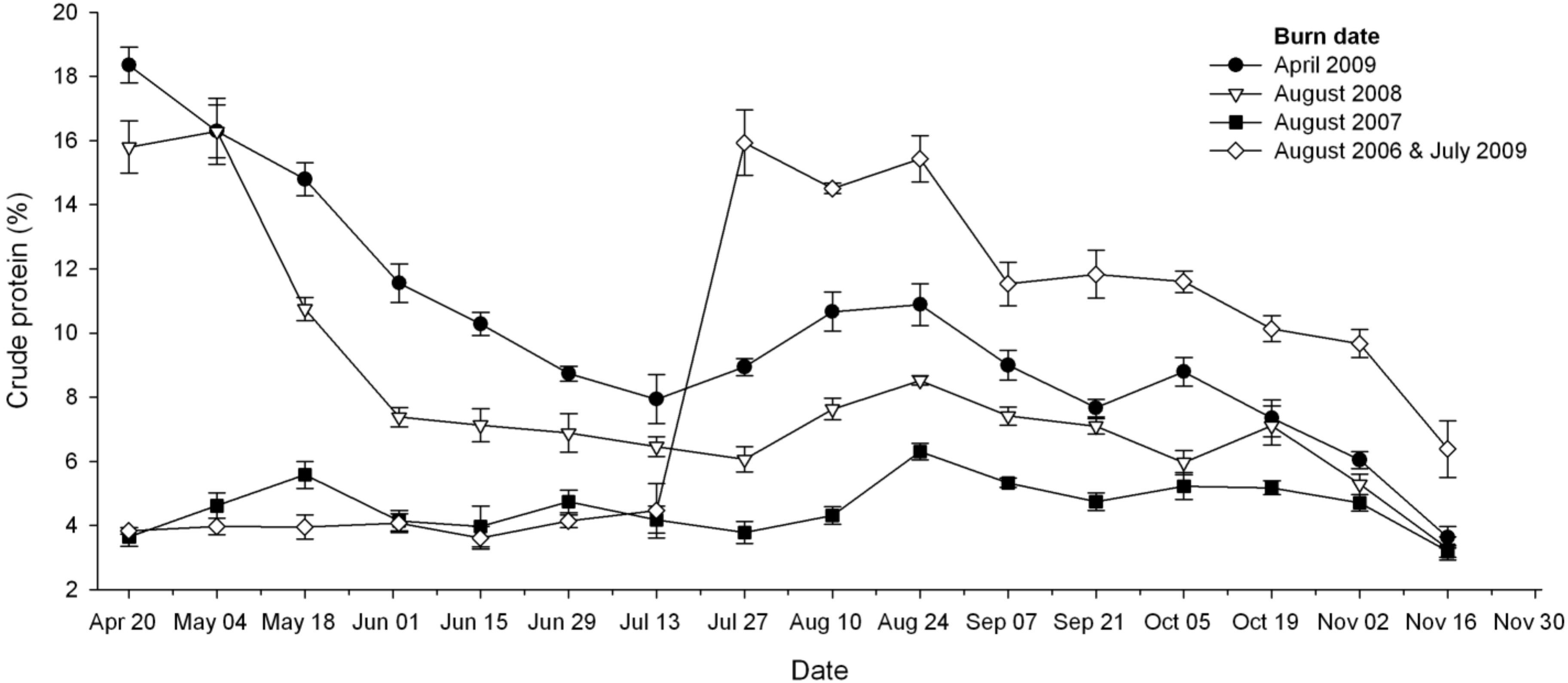
Attraction to Water



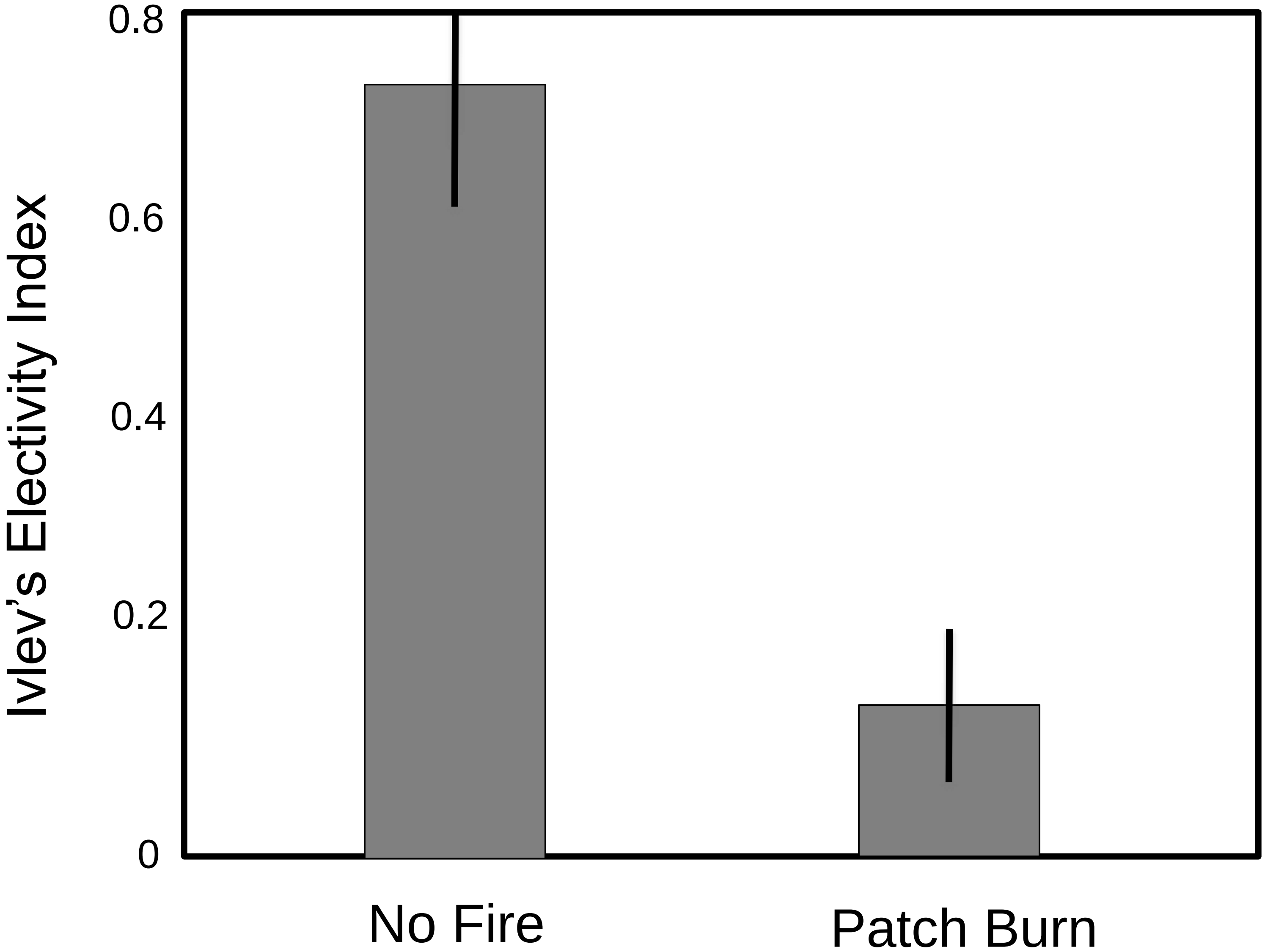
Grazing Site Selection in Heterogeneous Treatment
Growing Season 2008



Forage quality



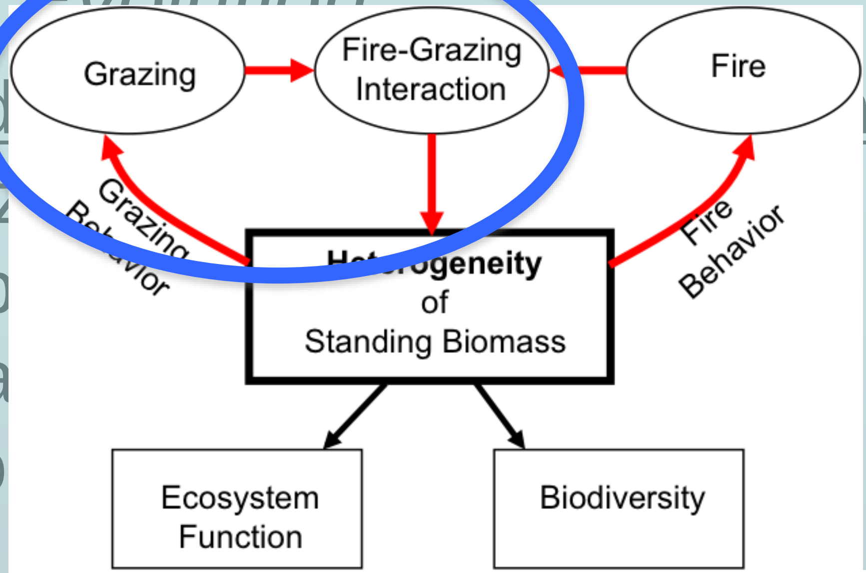
Preference by Cattle for Riparian Areas in Western OK



Allred, Fuhlendorf, Engle and Elmore (*2011*). *Ecology and Evolution*

Stud... n

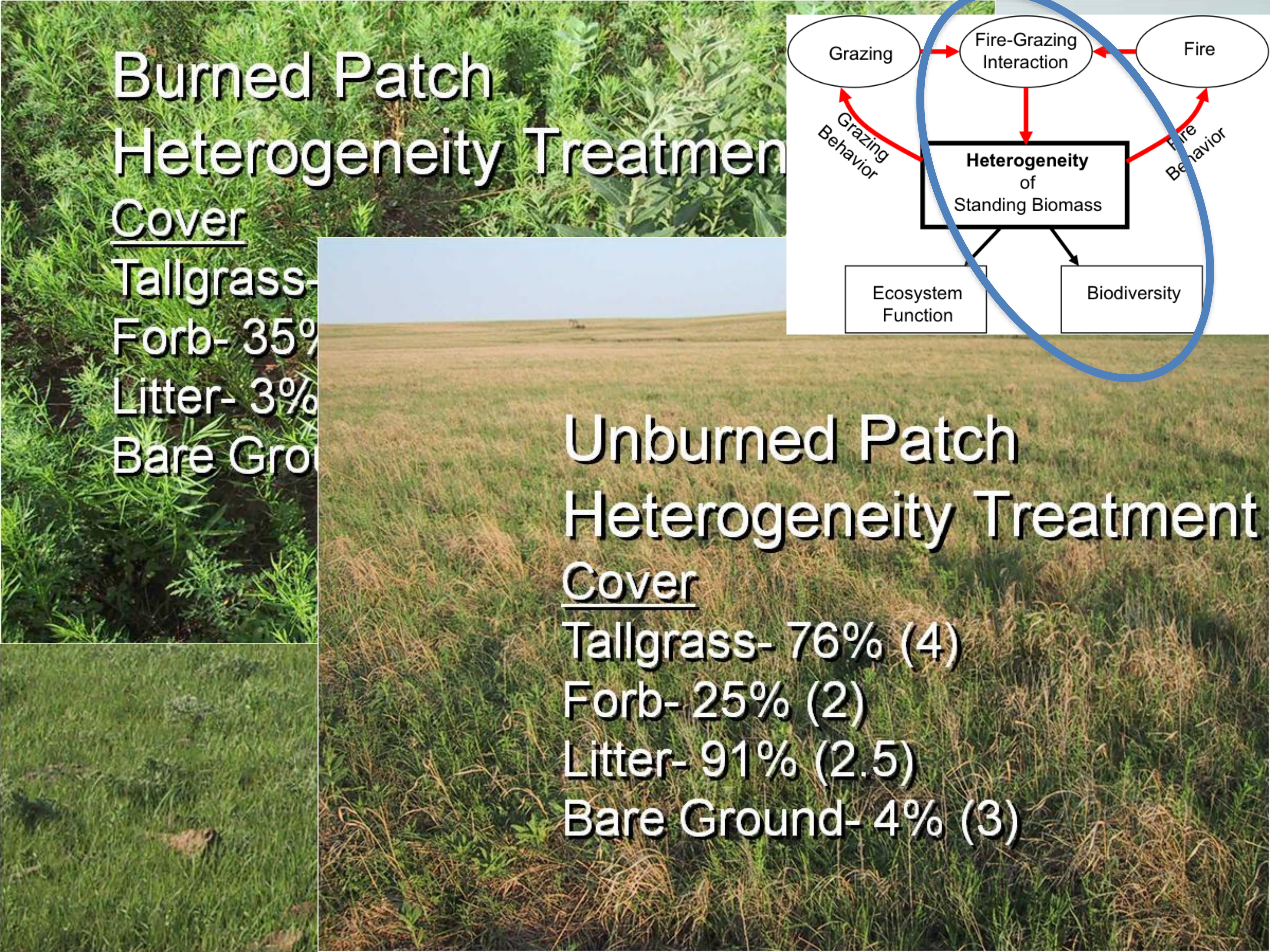
1. Siz...
2. Sp... cattle)
3. Pa...
4. Lo...



Allred et al. 2011, 2012, 2013
Fuhlendorf et al. 2010
Fuhlendorf and Engle 2004
Etc.

Conclusion:

1. Time sinc... nt in influencin...
2. The stren... significan... change across any of the variables.
3. Analysis of grazing without fire is incomplete.


Burned Patch
Heterogeneity Treatmen
Cover
Tallgrass-
Forb- 35%
Litter- 3%
Bare Gro
Grazing
Fire-Grazing Interaction
Fire
Grazing Behavior
Fire Behavior
Heterogeneity of Standing Biomass
Ecosystem Function
Biodiversity
Unburned Patch
Heterogeneity Treatment
Cover
Tallgrass- 76% (4)
Forb- 25% (2)
Litter- 91% (2.5)
Bare Ground- 4% (3)

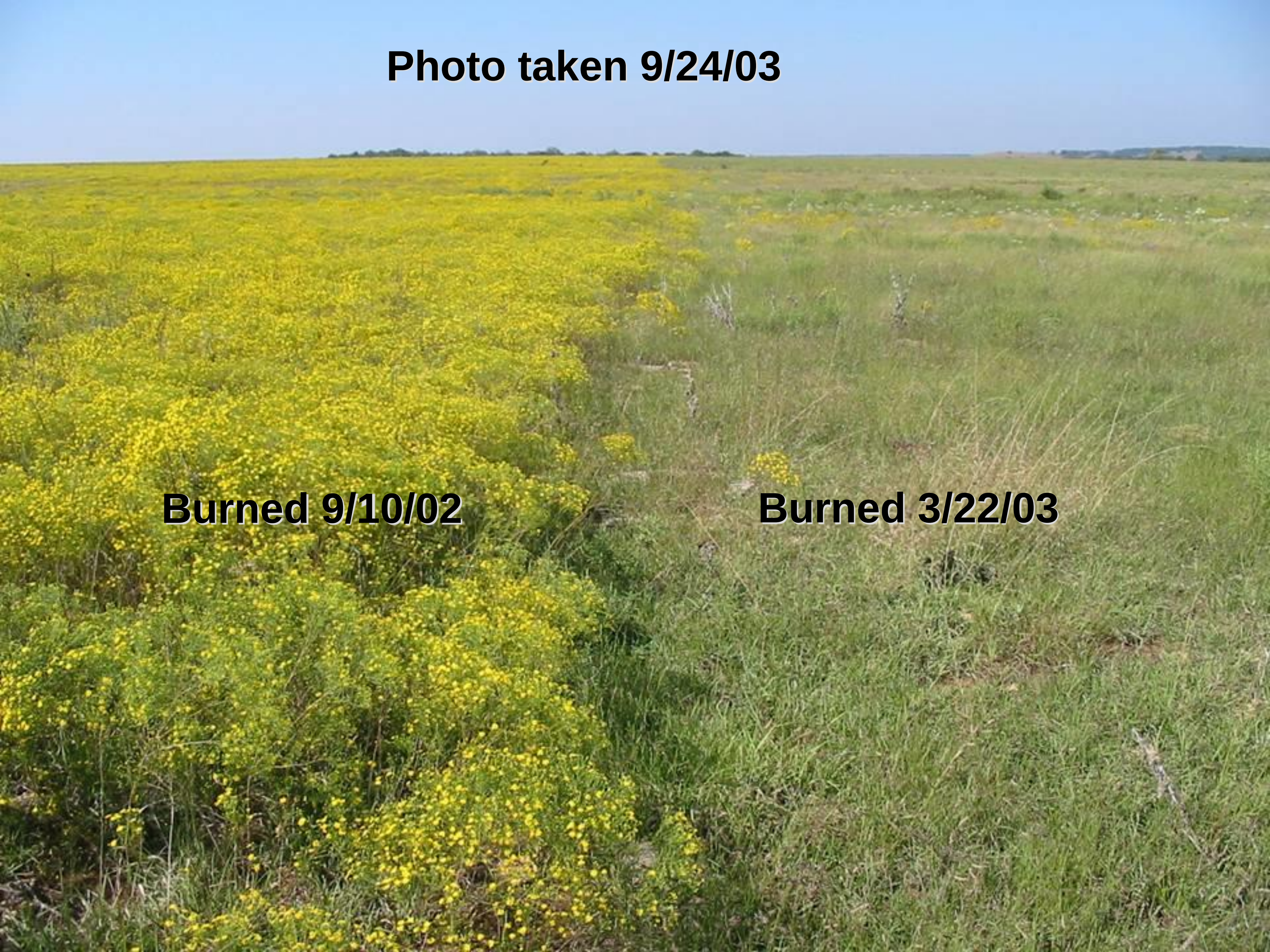
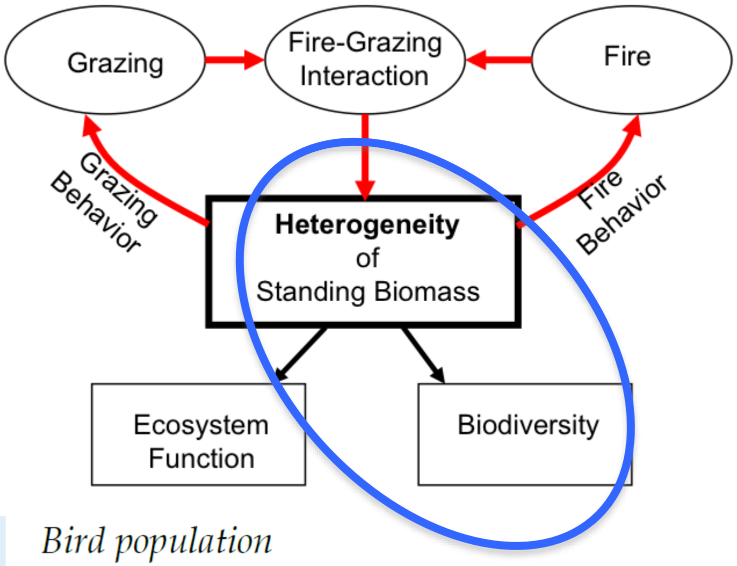
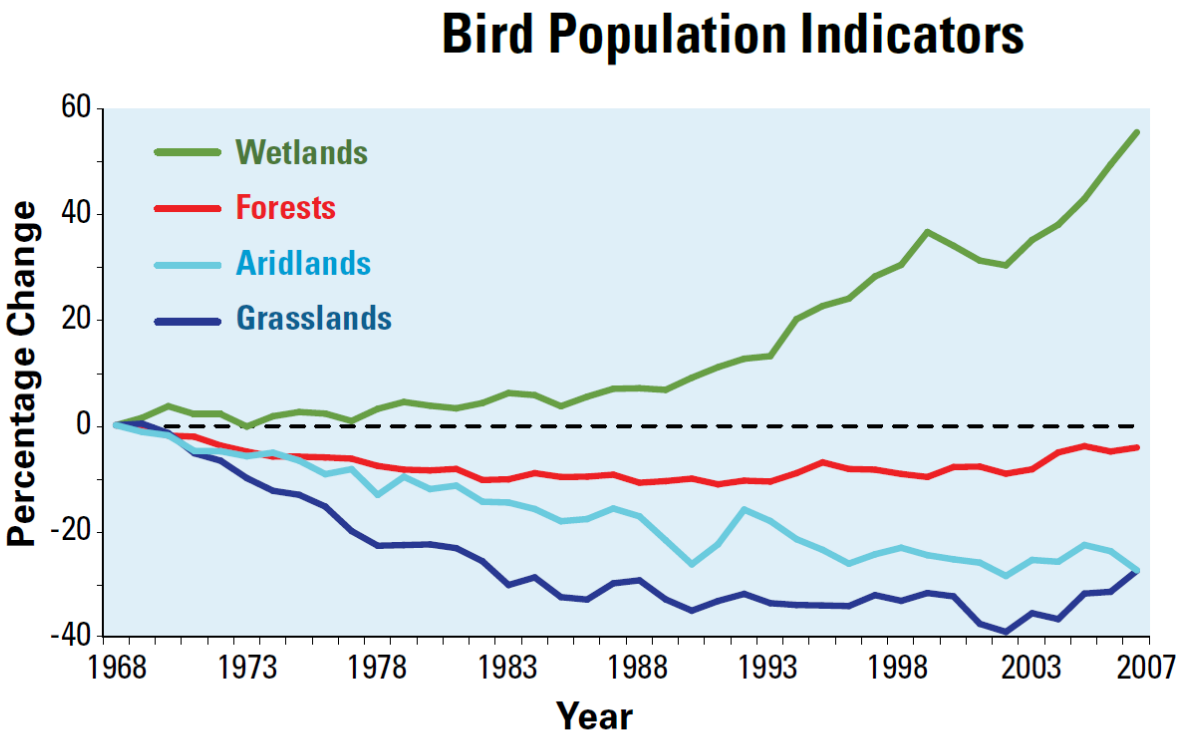


Photo taken 9/24/03
Burned 9/10/02
Burned 3/22/03

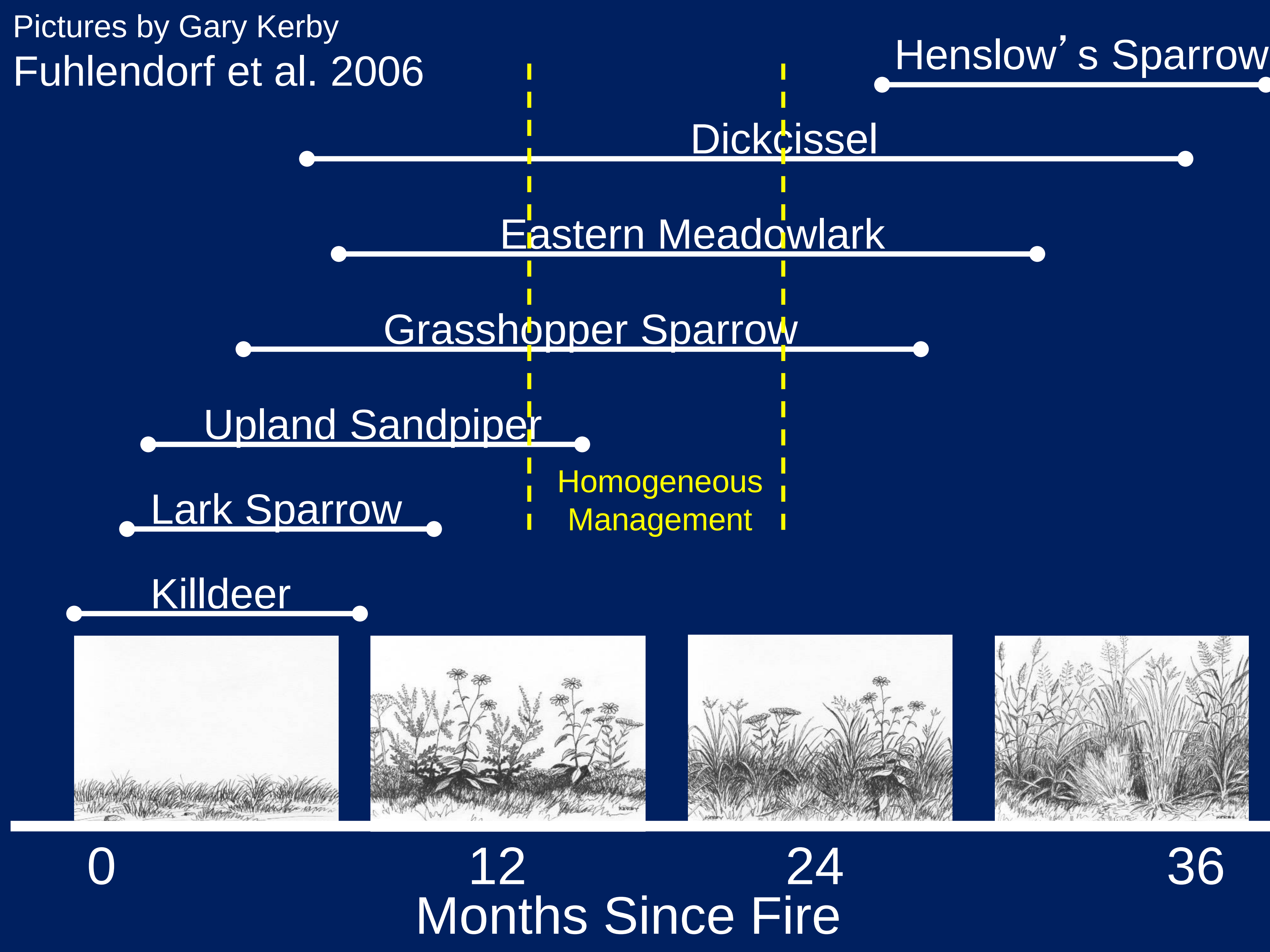
Is biodiversity dependent on heterogeneity that is driven by pyric herbivory?



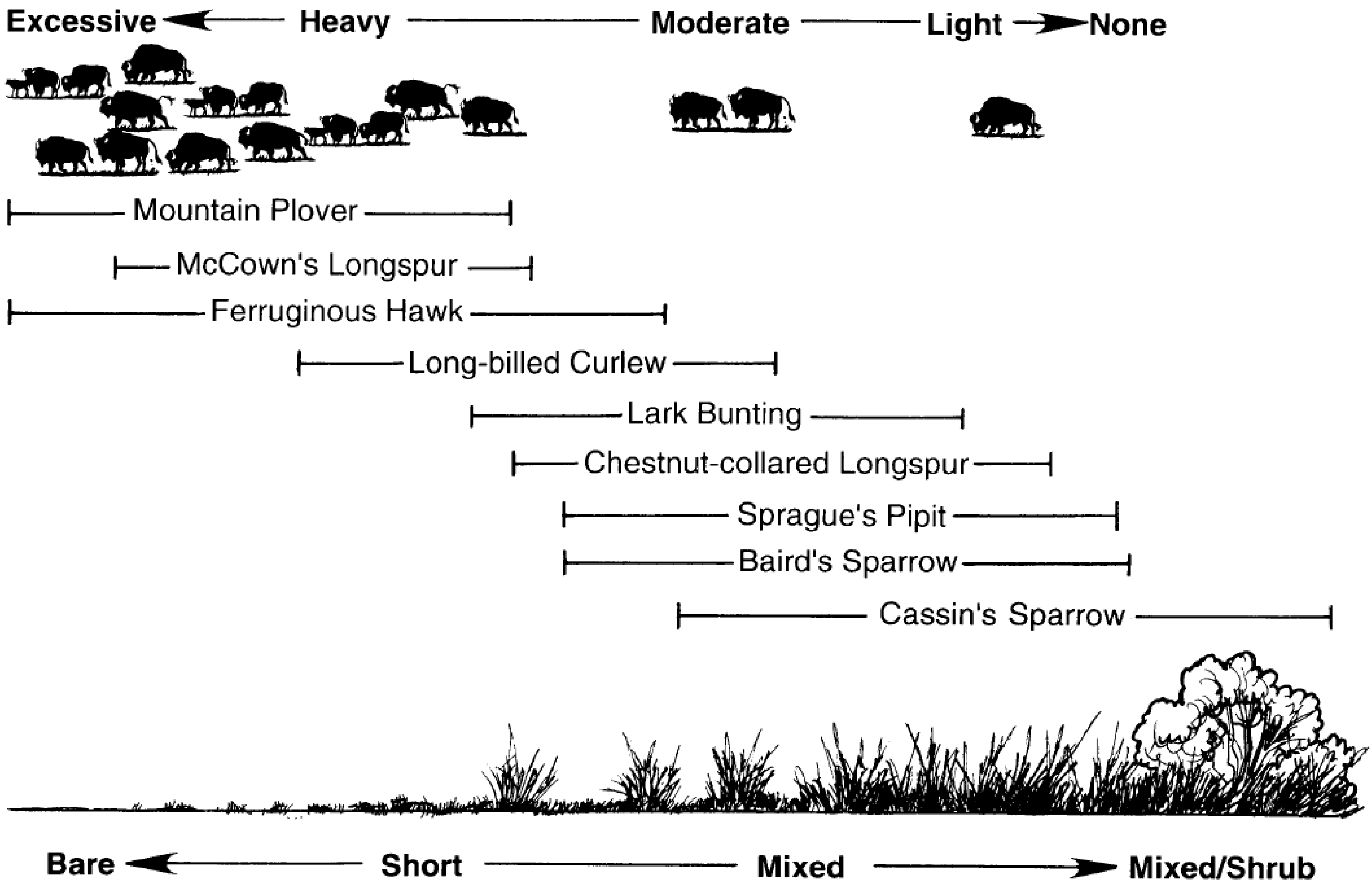


Bird population indicators based on trends for obligate species in four major habitats.

North American Bird Conservation Initiative, U.S. Committee, 2009. The State of the Birds, United States of America, 2009. U.S.Department of Interior:Washington,DC. 36 pp http://www.stateofthebirds.org/pdf_files/State_of_the_Birds_2009.pdf



Pictures by Gary Kerby
Fuhlendorf et al. 2006
Henslow's Sparrow
Dickcissel
Eastern Meadowlark
Grasshopper Sparrow
Upland Sandpiper
Lark Sparrow
Killdeer
Homogeneous
Management
0
12
24
36
Months Since Fire



Excessive
Heavy
Moderate
Light
None
Mountain Plover
McCown's Longspur
Ferruginous Hawk
Long-billed Curlew
Lark Bunting
Chestnut-collared Longspur
Sprague's Pipit
Baird's Sparrow
Cassin's Sparrow
Bare
Short
Mixed
Mixed/Shrub

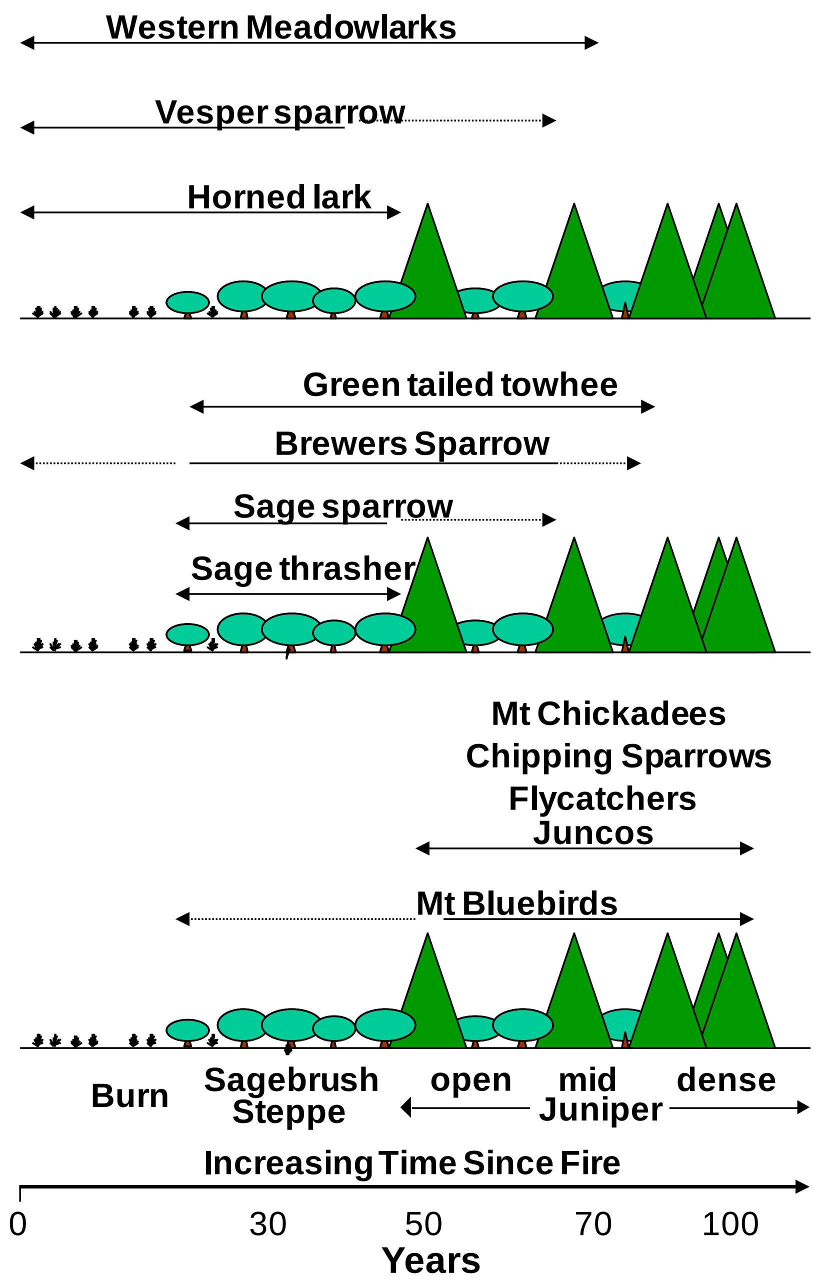
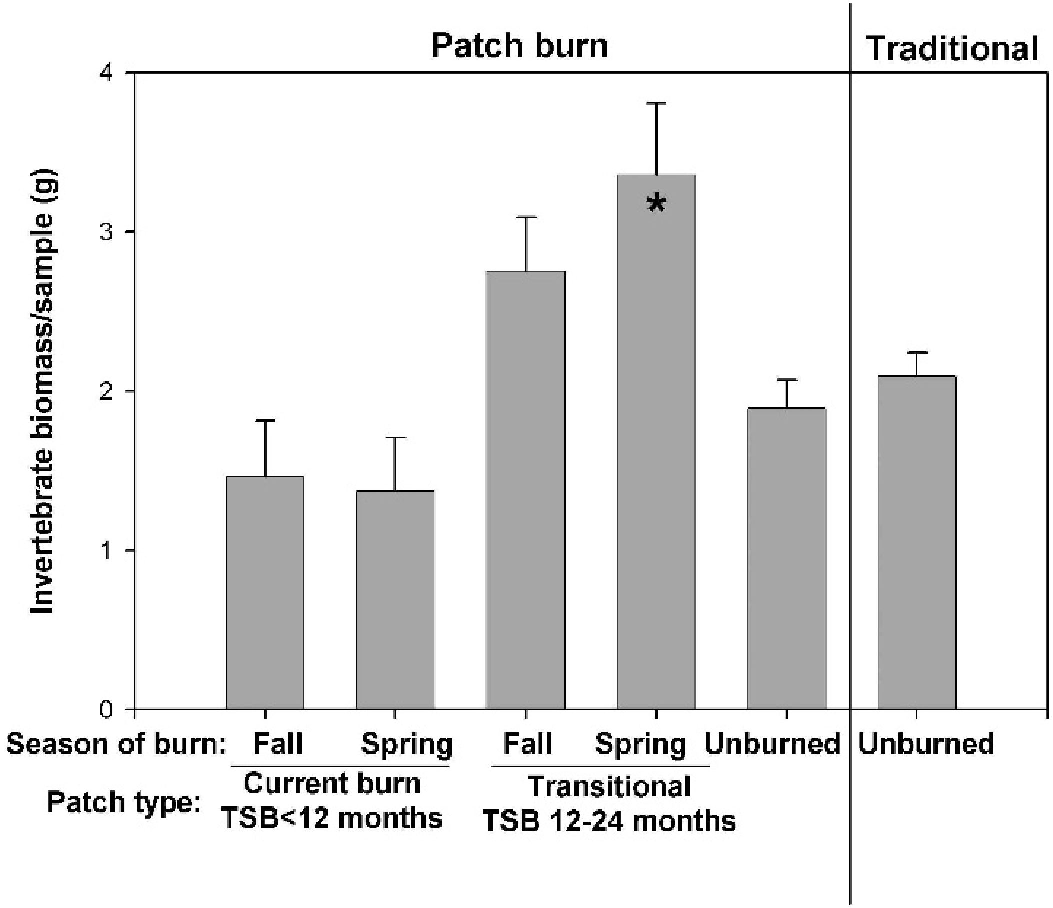


Figure 8. Response of birds to time since fire on Great Basin rangelands (Reinkensmeyer et al. 2007).

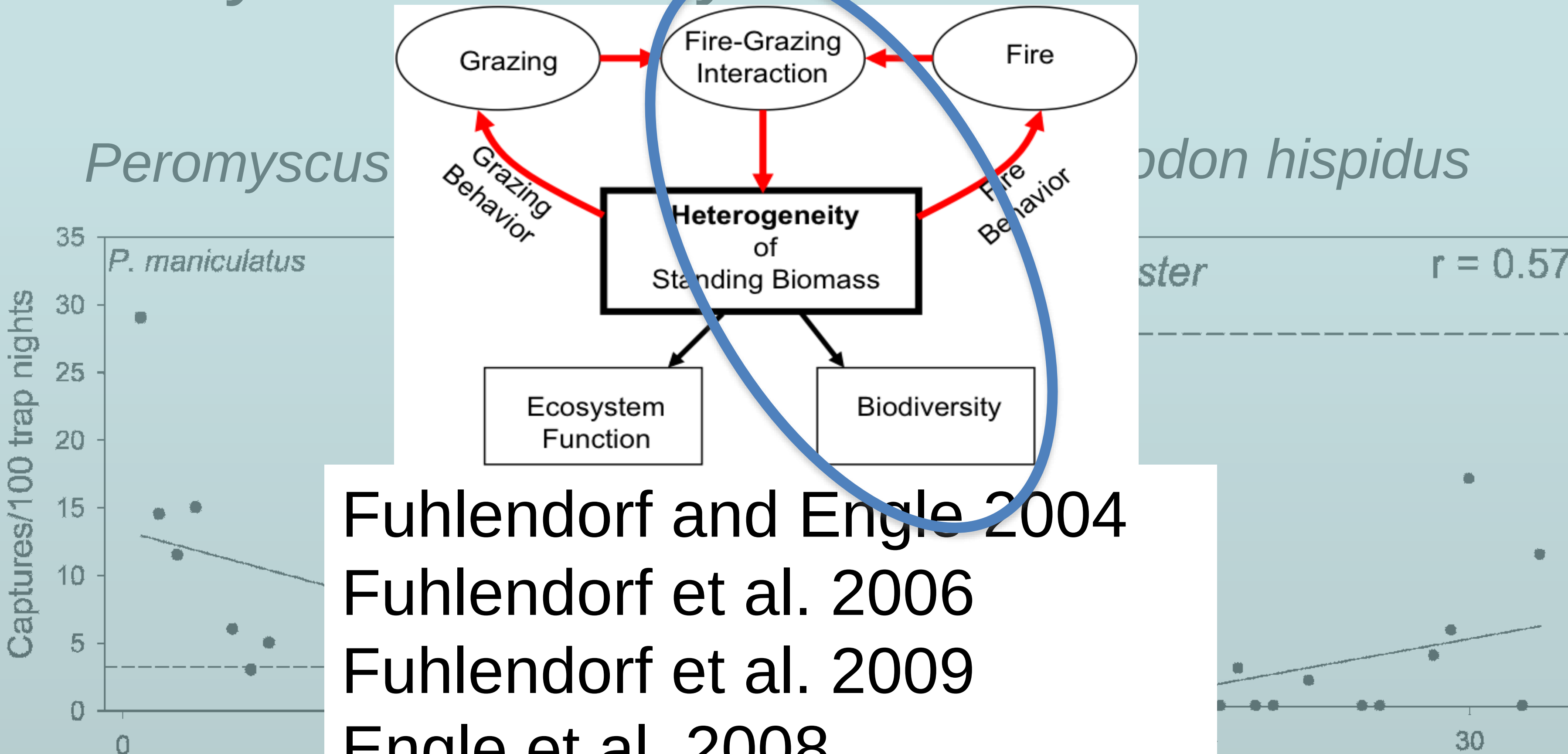
Pyric Herbivory and Insects



Engle et al. 2008
Doxon et al. 2011

Pyric Herbivory and Small Mammals

Peromyscus ... *odon hispidus*

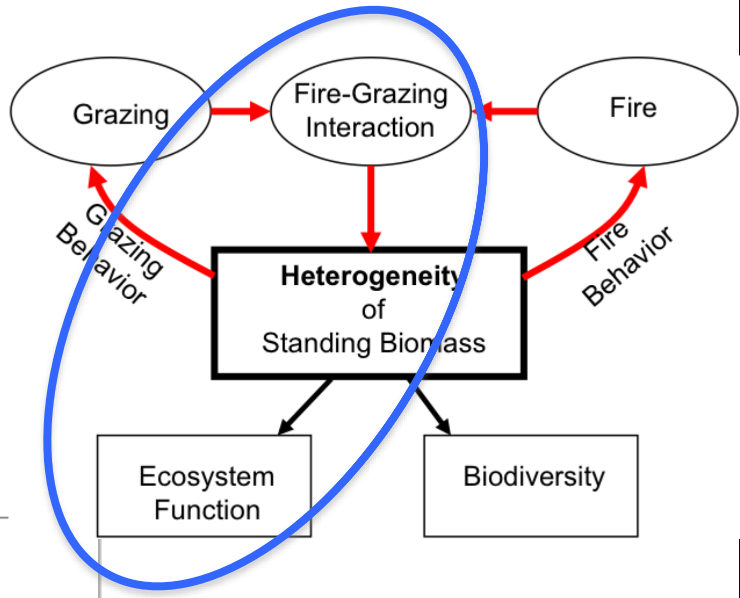


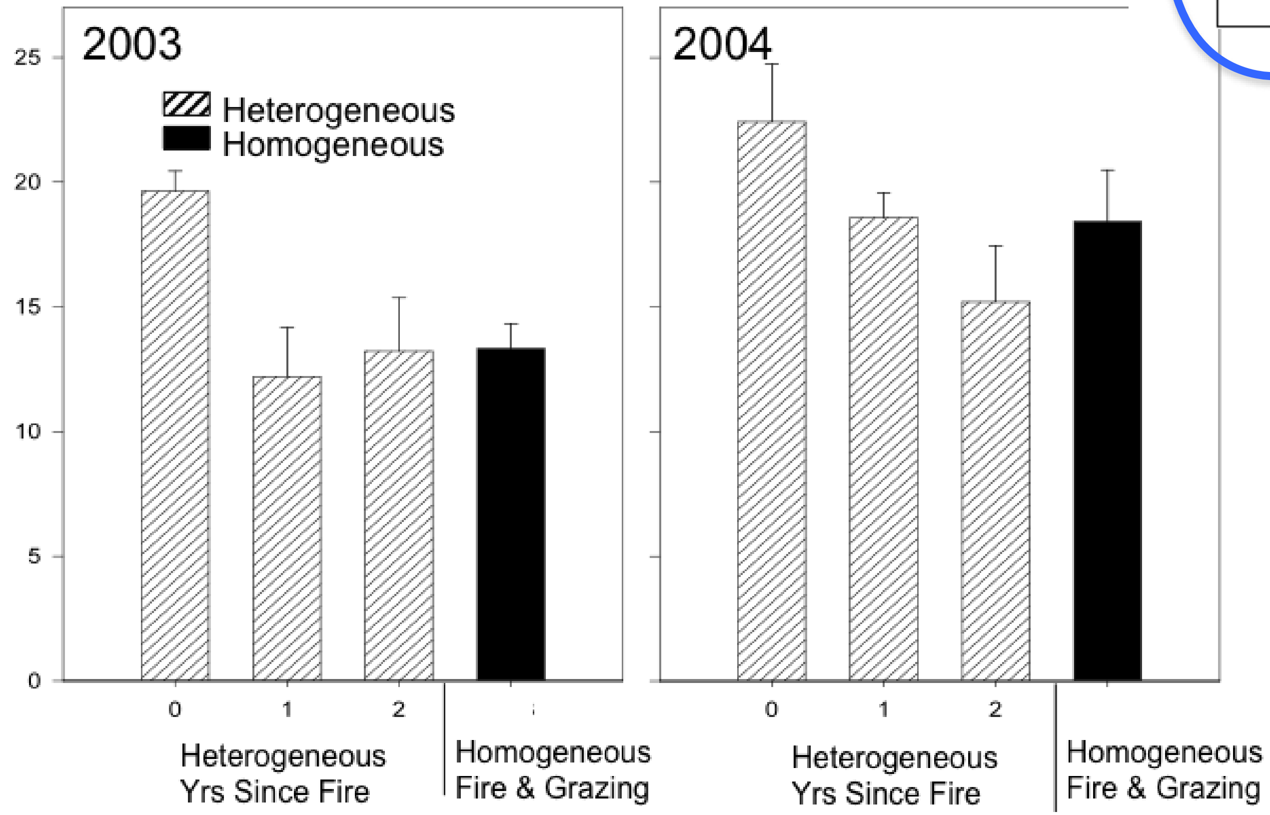
Fuhlendorf and Engle 2004
Fuhlendorf et al. 2006
Fuhlendorf et al. 2009
Engle et al. 2008
Fuhlendorf et al. 2010
Doxon et al. 2011
Etc.

Mon... Since Fire

Fuhlendorf et al. 2010

Greater nitrogen available on recently burned patches that attract greater densities of grazers

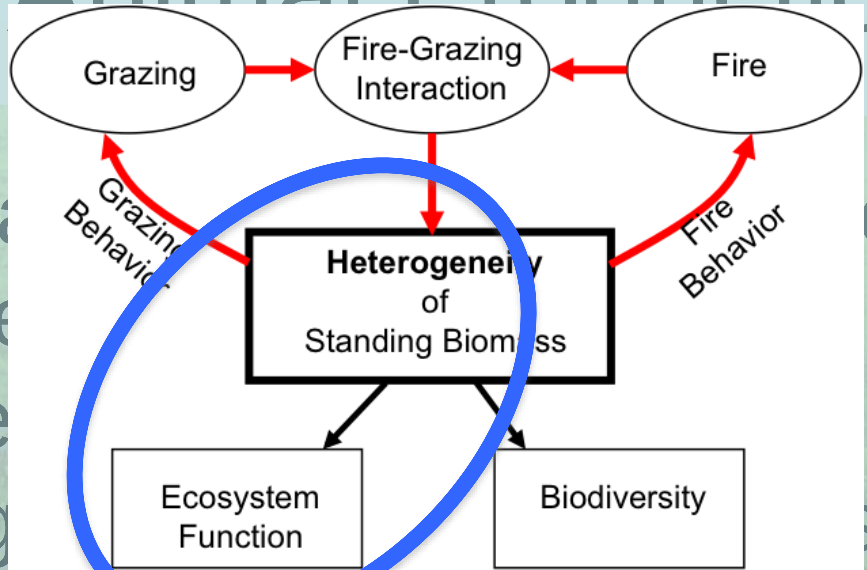




Anderson, Fuhlendorf & Engle 2006

Animal Production

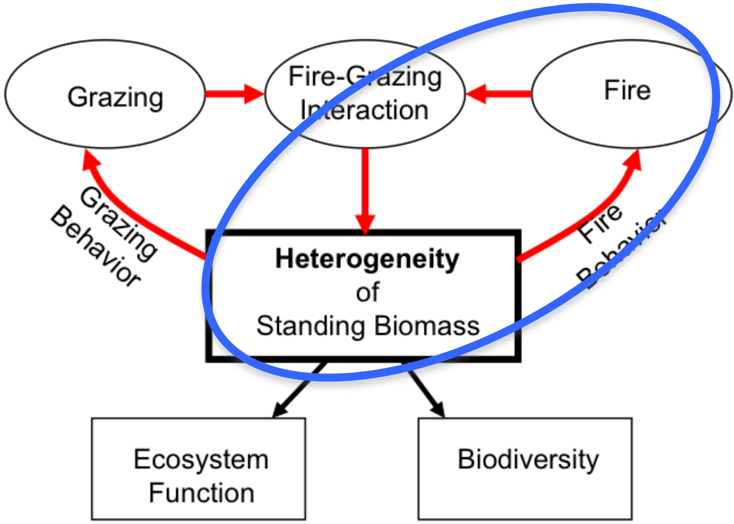
1. Bison a … es
   a. Site … burned are
   b. Hig … s when allo … e
   c. Foo … n behavior tha … ogen ava
2. Cattle- … f over 10 years- no negative effects and some positive effects

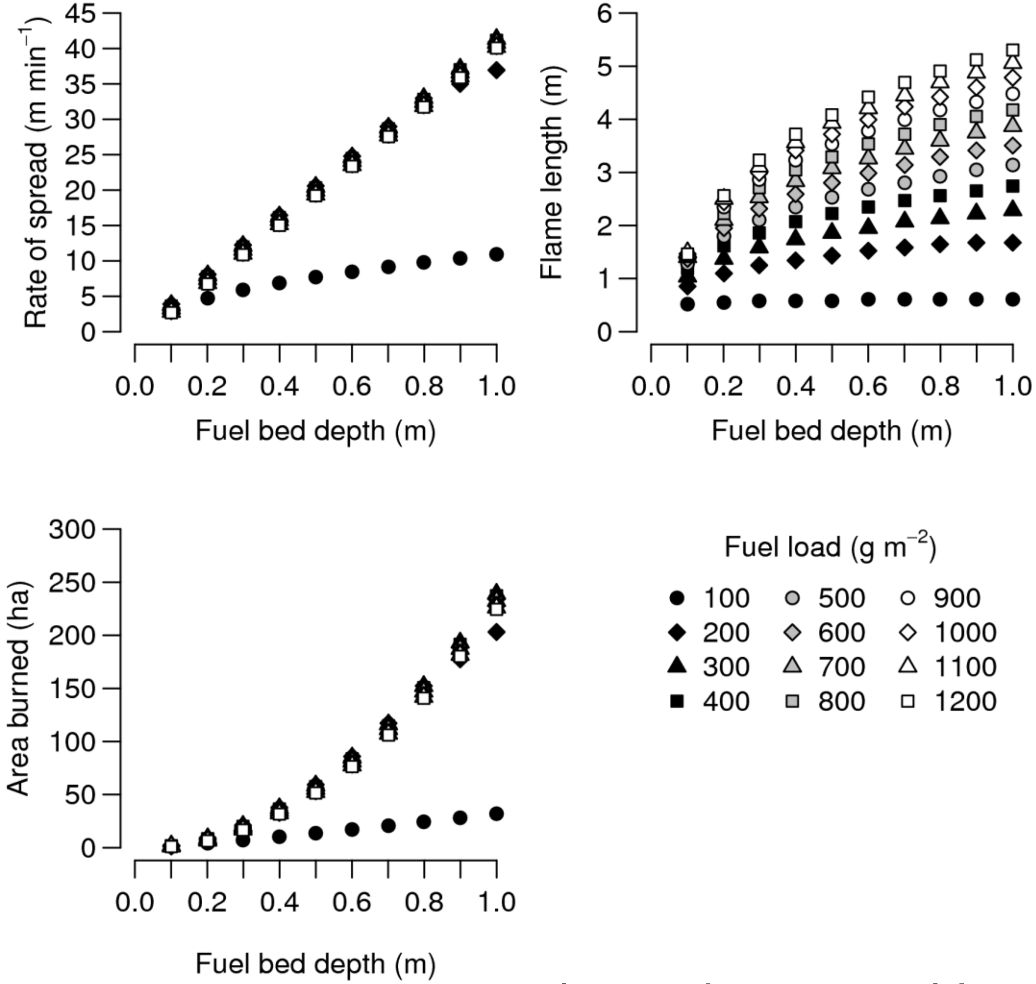


Anderson et al. 2006
Fuhlendorf et al. 2009
Cummings et al. 2006
Vermeire et al. 2005
Limb et al. 2011
Etc.

fireecology.okstate.edu

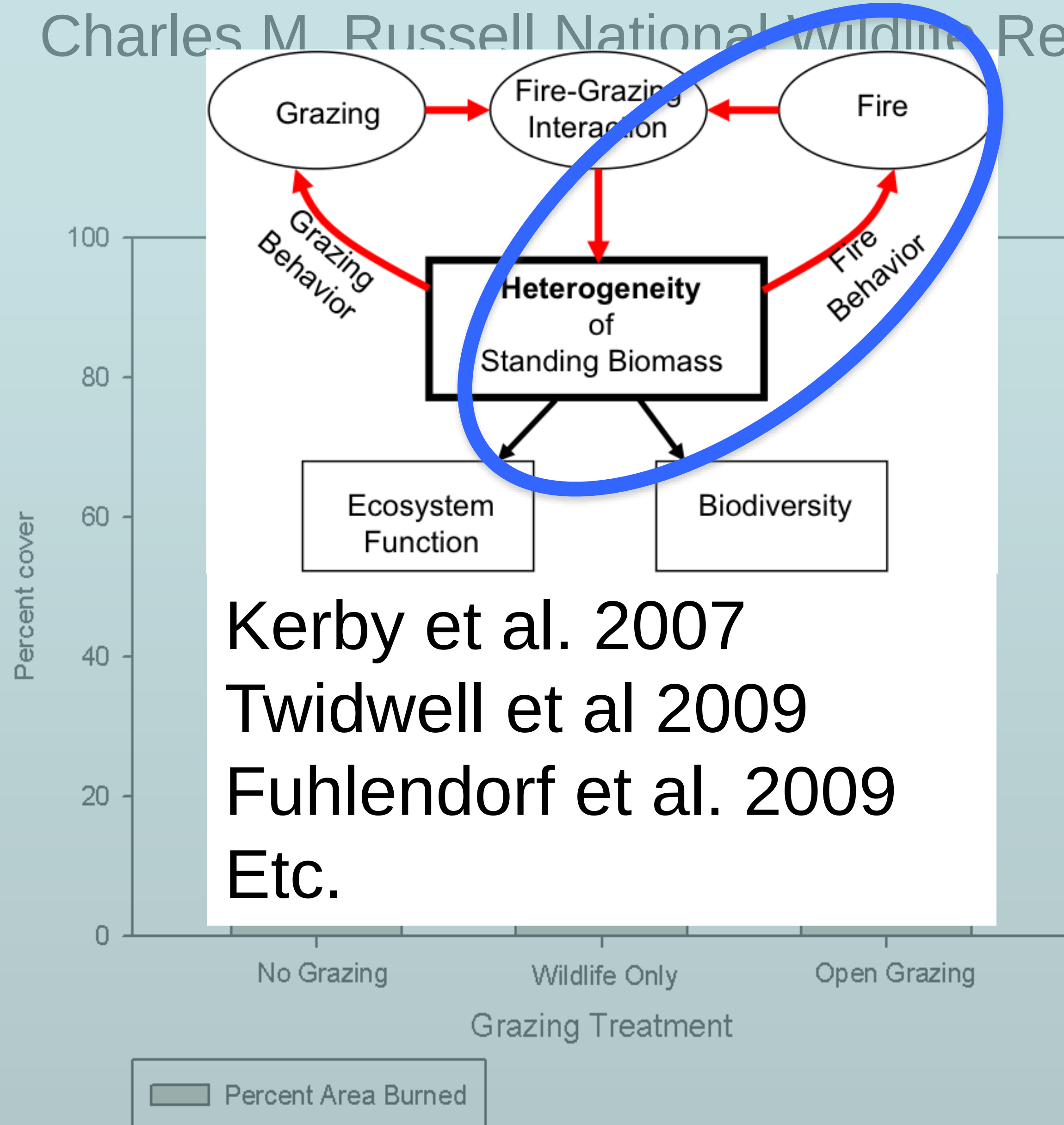
Does grazing effect fire behavior?





Kerby et al. 2007, Fuhlendorf et al. 2009

Charles M. Russell National Wildlife Refuge



Kerby et al. 2007
Twidwell et al 2009
Fuhlendorf et al. 2009
Etc.

Fire in Bambi

George Catlin on his 1832 Missouri River voyage:
“Every acre of these vast prairies burns over during the fall or early in the spring, . . . the fire slowly creeps with a feeble flame… **where the wild animals often rest in their lairs until the flames almost burn their noses, when they will reluctantly rise, and leap over it**, and trot off amongst the cinders, where the fire has passed and left the ground as black as jet.”
(Catlin, *Letters and Notes*, vol. 2, no. 33, 1841; reprint 1973)


Fire in Stillwater OK

Conclusions

1. All ecosystems are heterogeneous
2. Fire and herbivory are critically linked
3. Biodiversity requires heterogeneity- in grasslands that means highly variable fire and grazing distribution in space and time
4. Most management is single objective and reduces heterogeneity
5. Considering grasslands as shifting mosaics can simultaneously
   - Enhance biodiversity
   - Sustain ecosystem services
6. This interaction operated anywhere with fire and herbivory
7. The strength is dependent on the relationships among grazing site selection, fire intensity, herbaceous biomass and forage quality- How much heterogeneity is possible?

Fuhlendorf and colleagues . *30 peer-reviewed publications in 8 different journals.* Many other publications from other authors.

Pyric Herbivory in Action on Boreal Rangelands?

The Fire-Grazing Interaction of Wood Bison in NE BC, Canada

S. Leverkus,[1,2] S. Fuhlendorf,[1] M. Gregory,[1] and N. Elliot[2]

[1] Oklahoma State University [2] Range Program, BC Provincial Government

Boreal rangelands and fire

- Most intact terrestrial ecosystem in the world
- Natural and anthropogenic fire dominant driver
- Boreal fire creates mosaics (landscape) = heterogeneity
- Evidence of fire in the Boreal : charcoal and pollen, oral

Johnson, 1992; Larsen and MacDonald,1998; Lewis, 1977,1980, 1982, 1988; Rowe and Scotter, 1973; Suffling, 1998

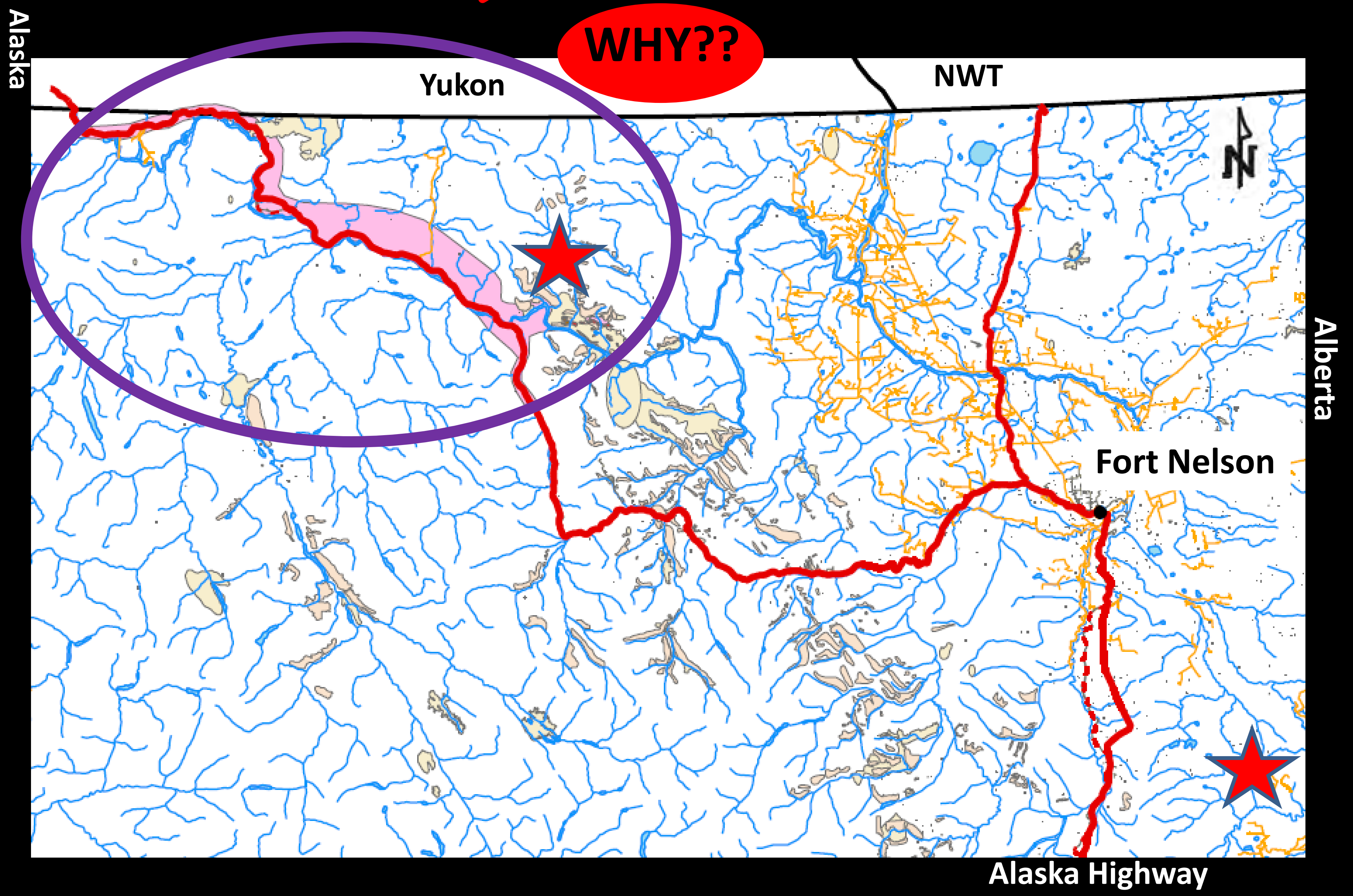

09.07.2008 10:05

Boreal Forest

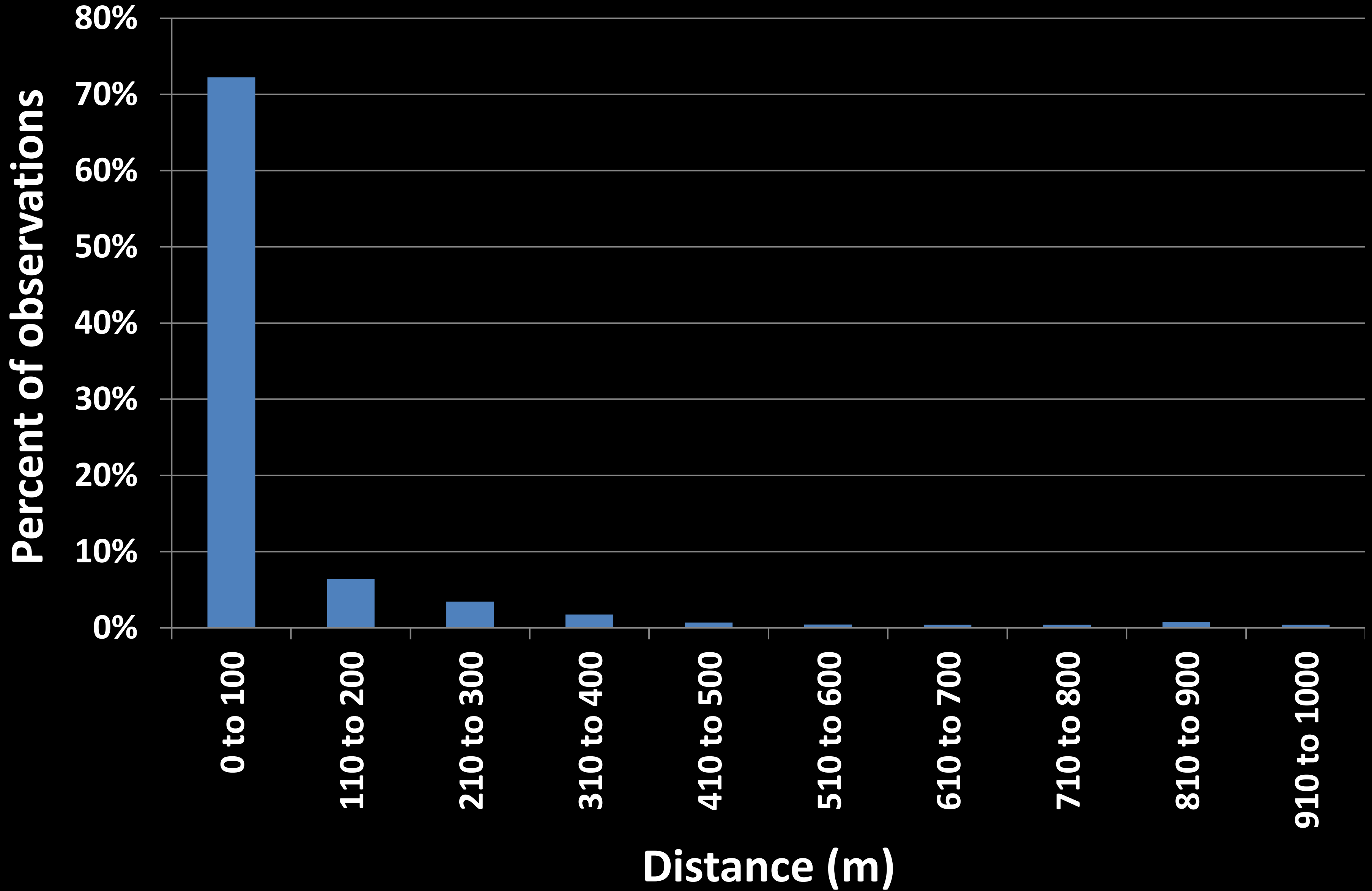
Reintroduced 49 head @ Nordquist (1995) on Liard River and 40 head @ Etthithun (1999) on the Fontas River

Herd size has remained low since reintroduction

WHY??

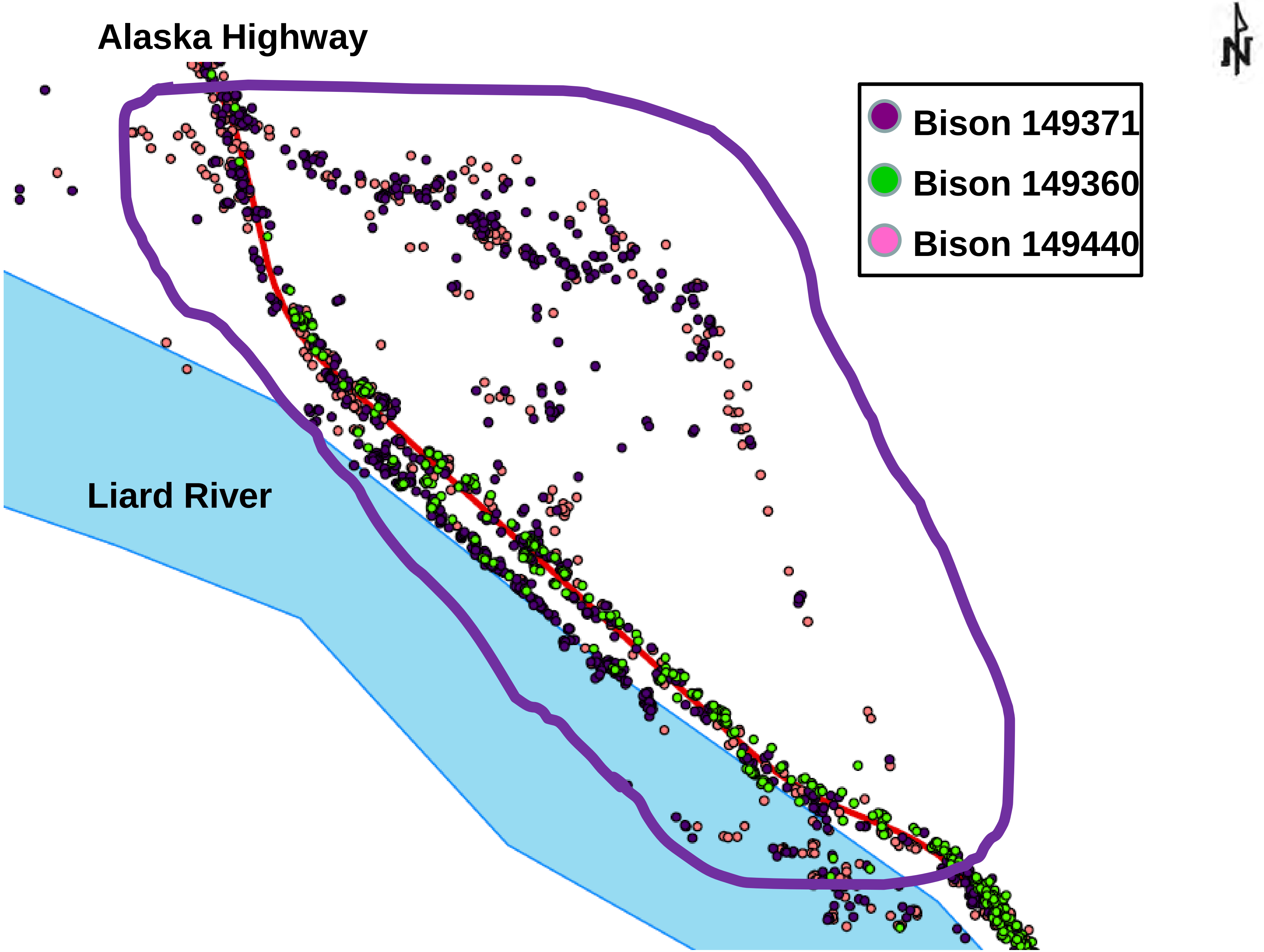


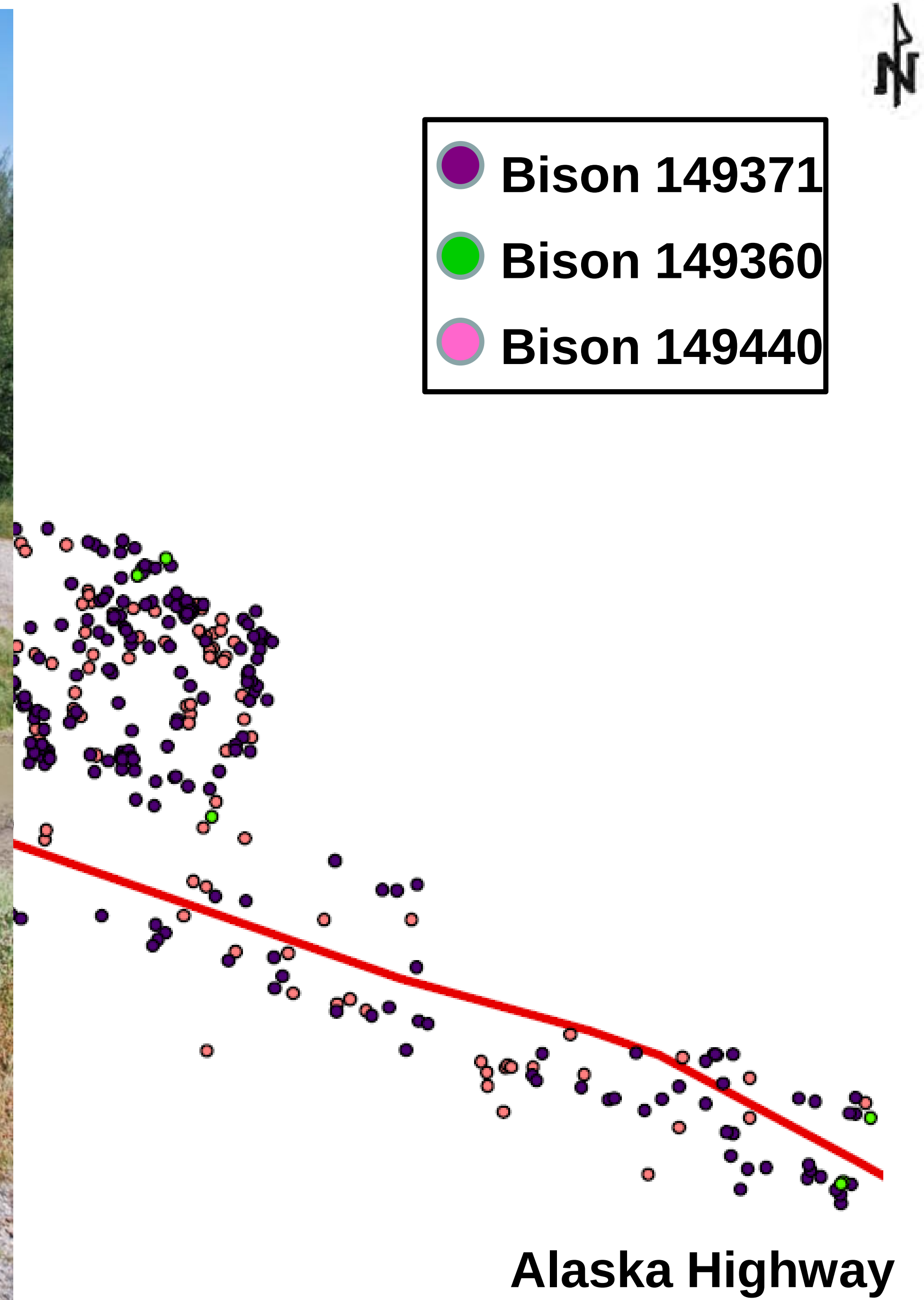
Actual percent observations by distance from highway (1km)

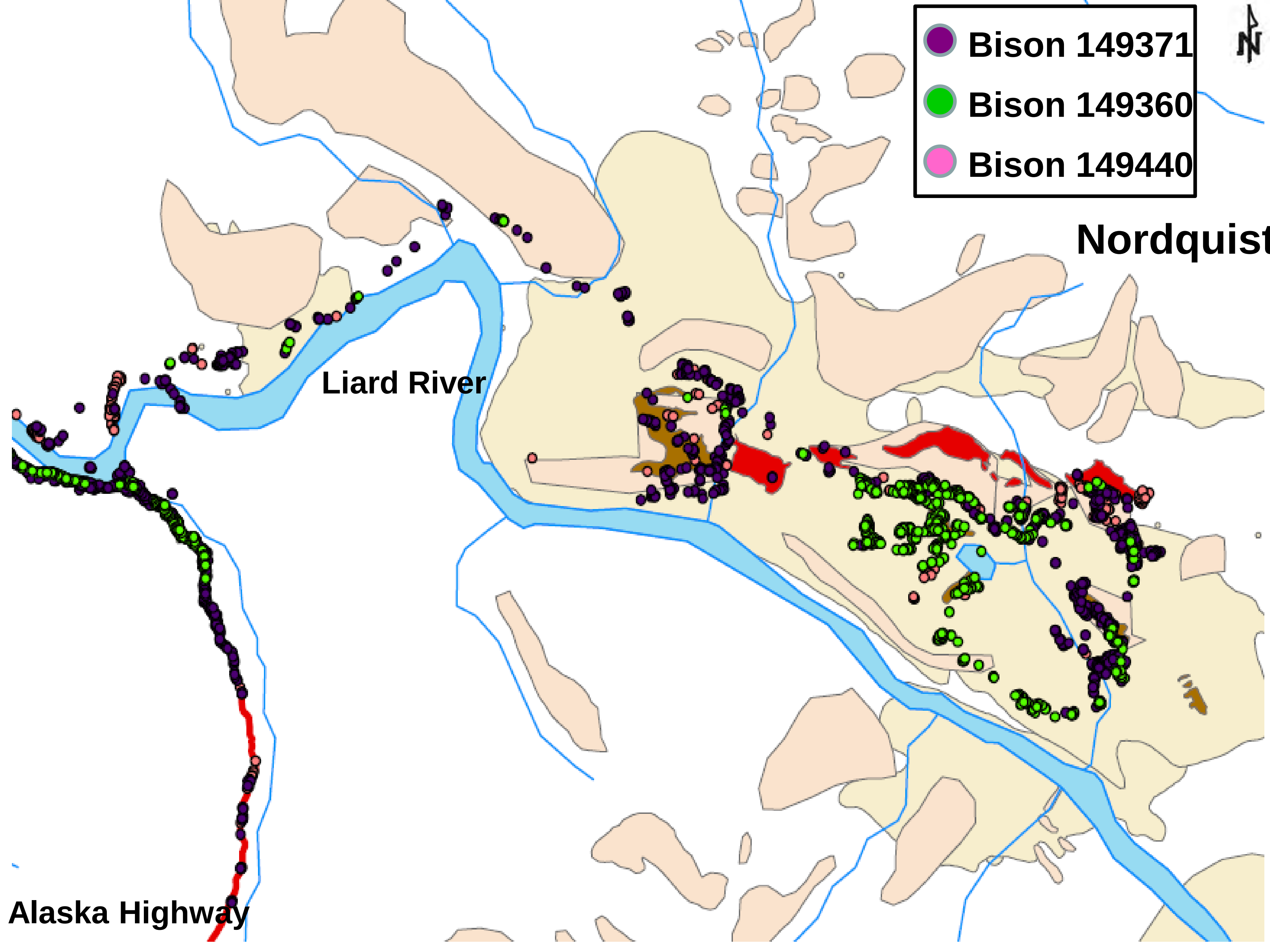


Actual bison distribution of 3 collared animals





Alaska Highway
Bison 149371
Bison 149360
Bison 149440
Liard River
N


N
Bison 149371
Bison 149360
Bison 149440
Alaska Highway


Bison 149371
Bison 149360
Bison 149440
Nordquist
Liard River
Alaska Highway
N


21.05.2009 17:14

Lana Lowe, Lands Director, Fort Nelson First Nation


So, is IT a silver bullet?

- Pyric herbivory vs. Patch burning vs. need for heterogeneity
- Scale dependence or landscape context
- What about other herbivores?
- Regional/site differences
- Are there negative effects on some species?
- Interactions with climate and other disturbances (e.g. prairie dogs)

The Prairie Butterfly Paradox

The Regal Fritillary,
For example


07/20/2009

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SCIENCE @ DIRECT®
ELSEVIER
Palaeogeography, Palaeoclimatology, Palaeoecology 208 (2004) 141–152
PALAEO
www.elsevier.com/locate/palaeo

Interactions of climate and fire at two sites in the northern Great Plains, USA

Charles E. Umbanhowar Jr.

Department of Biology, St. Olaf College, 1520 St. Olaf Avenue, Northfield, MN 55057, USA

Received 10 April 2003; received in revised form 12 December 2003; accepted 5 March 2004

Abstract

The relationship of fire and climate in explaining the origin and maintenance of the grassland
has long been of interest. I examined the hypothesis that burning was more frequent during
reconstruct fire histories near Coldwater Lake in southcentral ND, and Rice Lake in northcentral
ostracod Mg/Ca ratios as a proxy for climate at these same two sites. Over the past 10 000 y
Coldwater (0.04–5.68 mm^2 cm^{-2} $year^{-1}$) greatly exceeded influx rates for Rice (< 0.01–1.91 n
showed strong, significant periodicities of ~ 1500–1800, ~ 800–900 and ~ 130–140 yea
minima were only similar at ~ 4200 cal years BP. Charcoal influx during the past 2000 years als
of between 310–400 and 140 years at both sites. Comparison of smoothed charcoal influxe
suggests that both proxies are responding to changes in climate. When smoothed with a 320–4
charcoal influx typically preceded rises in ostracod Mg/Ca ratio by ~ 50–100 years, and further
of the residuals suggested a variable relationship between Mg/Ca ratios and charcoal influx. These
or reject the fuel limitation hypothesis, and this lack of clear support may result from (a) climate
and C_4 grasses resulting in maximum productivity at intermediate moisture levels, (b) possibly c
and Mg/Ca ratios to summer vs. winter precipitation, or (c) ground-water driven lags in the respon
climate. Comparison of the results from this study with other studies suggests that links betwe
scales (0–100 years) may be broadly constrained by longer term (~ 500–2000 years) patterns o
Plains.

Keywords: charcoal; grasslands; fire; C_3/C_4 productivity; northern Great Plains; paleoenvironment

Fire cycles in North American interior grasslands and their relation to prairie drought

K. J. Brown[†‡§], J. S. Clark[†¶], E. C. Grimm[‖], J. J. Donovan[††], P. G. Mueller[‖], B. C. S. Hansen[‡‡], and I. Stefanova[‡‡]

[†]Department of Biology and [¶]Nicholas School of the Environment, Duke University, P.O. Box 90338, Durham, NC 27708; [‡]Department of Quaternary Geology, Geological Survey of Denmark and Greenland, 10 Øster Voldgade, DK-1350 Copenhagen K, Denmark; [‖]Illinois State Museum, Research and Collections Center, 1011 East Ash Street, Springfield, IL 62703; [††]Department of Geology and Geography, West Virginia University, 425 White Hall, P.O. Box 6300, Morgantown, WV 26506; and [‡‡]Limnological Research Center, University of Minnesota, 220 Pillsbury Hall, 310 Pillsbury Drive Southeast, Minneapolis, MN 55455

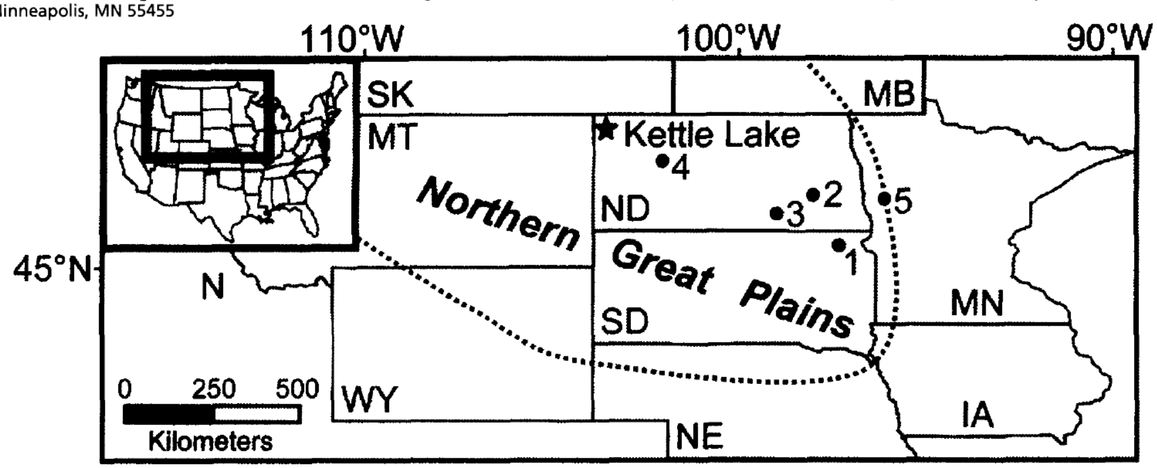


Fig. 1. Study location (*Inset*) and study site map. The dotted line defines the approximate boundary of the NGP. Kettle Lake is marked by a star. Sites numbered 1–4 correspond to other locations where aridity cycles have been detected: 1, Pickerel Lake (South Dakota) and Spring Lake; 2, Moon Lake (North Dakota); 3, Coldwater Lake; 4, Rice Lake. Location 5 is West Olaf Lake.

So, is IT a silver bullet?

- Patch burning vs. need for heterogeneity
- Scale dependence or landscape context
- What about other herbivores?
- Regional/site differences
- Are there negative effects on some species?
- Interactions with climate and other disturbances (e.g. prairie dogs)

Name: Amber Breland Date of Degree: December 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: BLACK-TAILED PRAIRIE DOG AND LARGE UNGULATE RESPONSE TO FIRE ON MIXED-GRASS PRAIRIE

Pages in Study: 118 Candidate for the Degree of Master of Science

Major Field: Natural Resource Ecology and Management

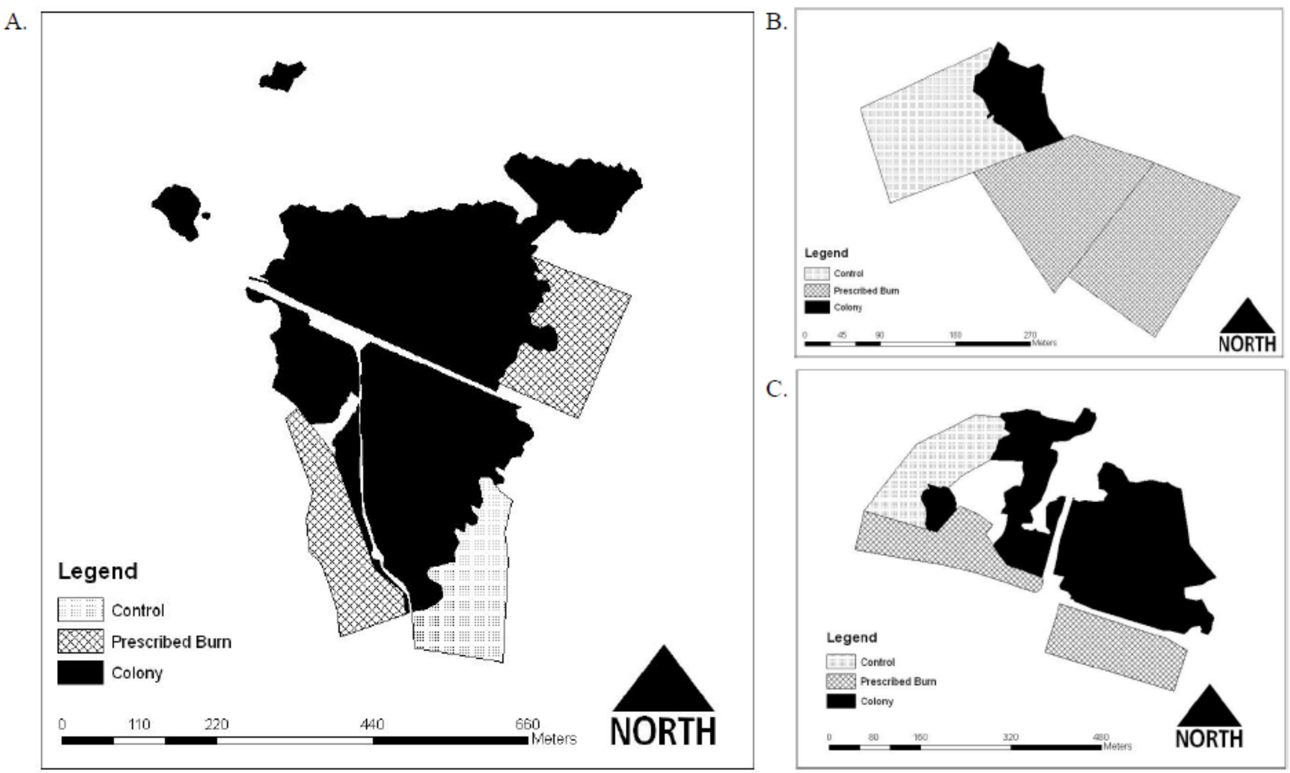
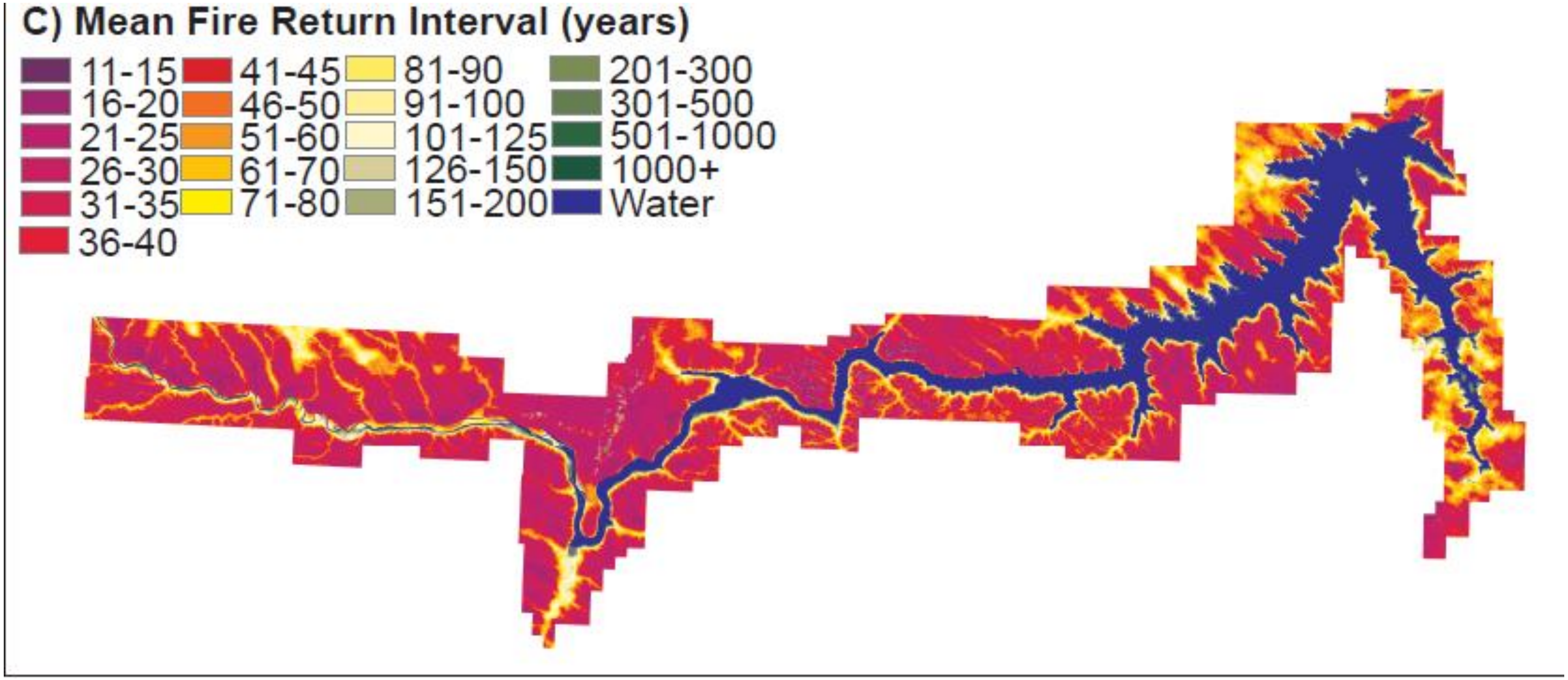


Figure 1.3. (A) Turkey Creek, (B) Quanah Parker, and (C) Holy City colony treatment locations at Wichita Mountains Wildlife Refuge, Oklahoma in 2009 and 2010.

Do we know IT works?

1. We do know that heterogeneity is important for multiple objectives.
2. In grasslands we do know that the fire-grazing interaction was a dominant disturbance.
   - Fire influences grazing
   - Grazing influences fire
   - Biodiversity and ecological processes respond
3. We do know that some species increase while others decrease with disturbance.
4. Should pyric herbivory be used for management of grazed ecosystems?
   - Depends on objectives
   - There is no silver bullet
   - Most important decisions are fire and stocking rate

Part II: HISTORICAL FIRE REGIME



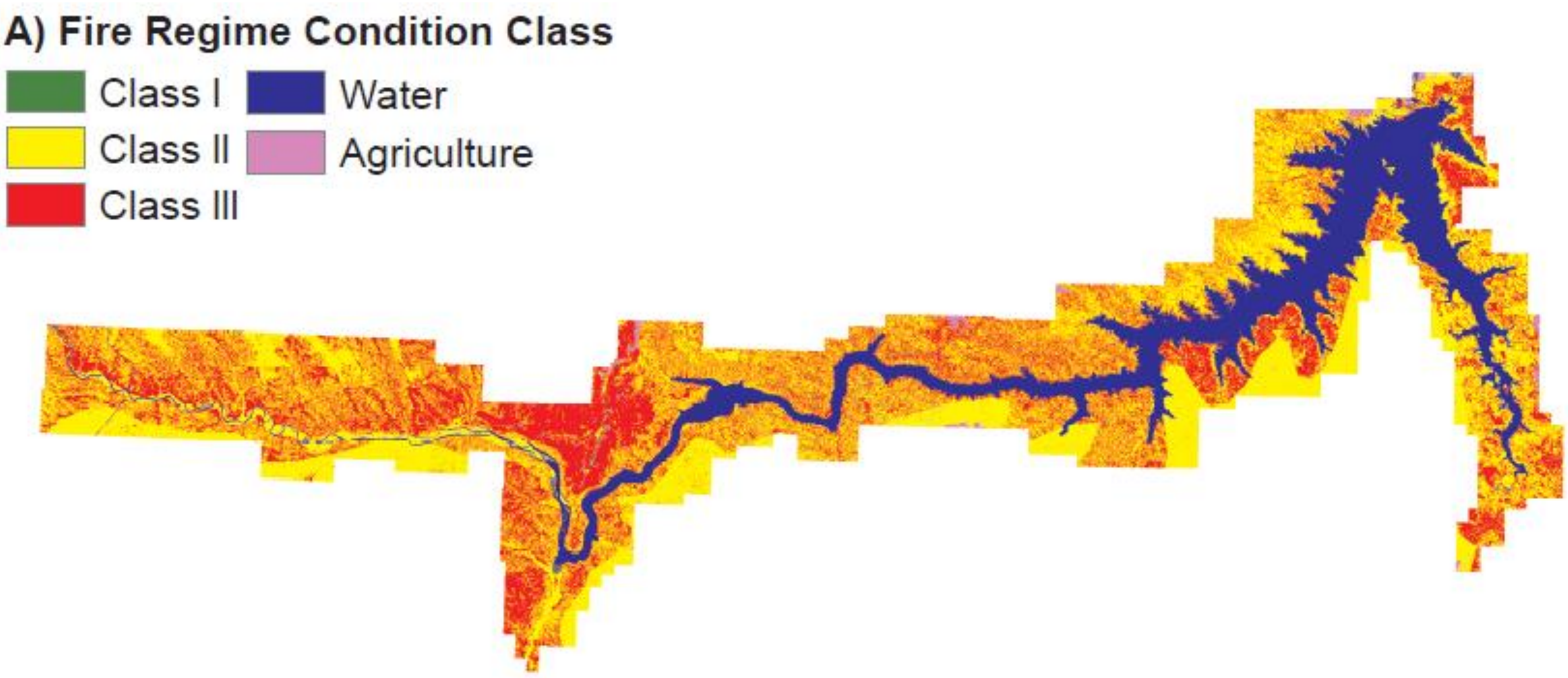
- MFRI is the number of years between successive fire events
- Most of CMR has MFRI of < 45 years and much < 20

Part II: CURRENT FIRE REGIME

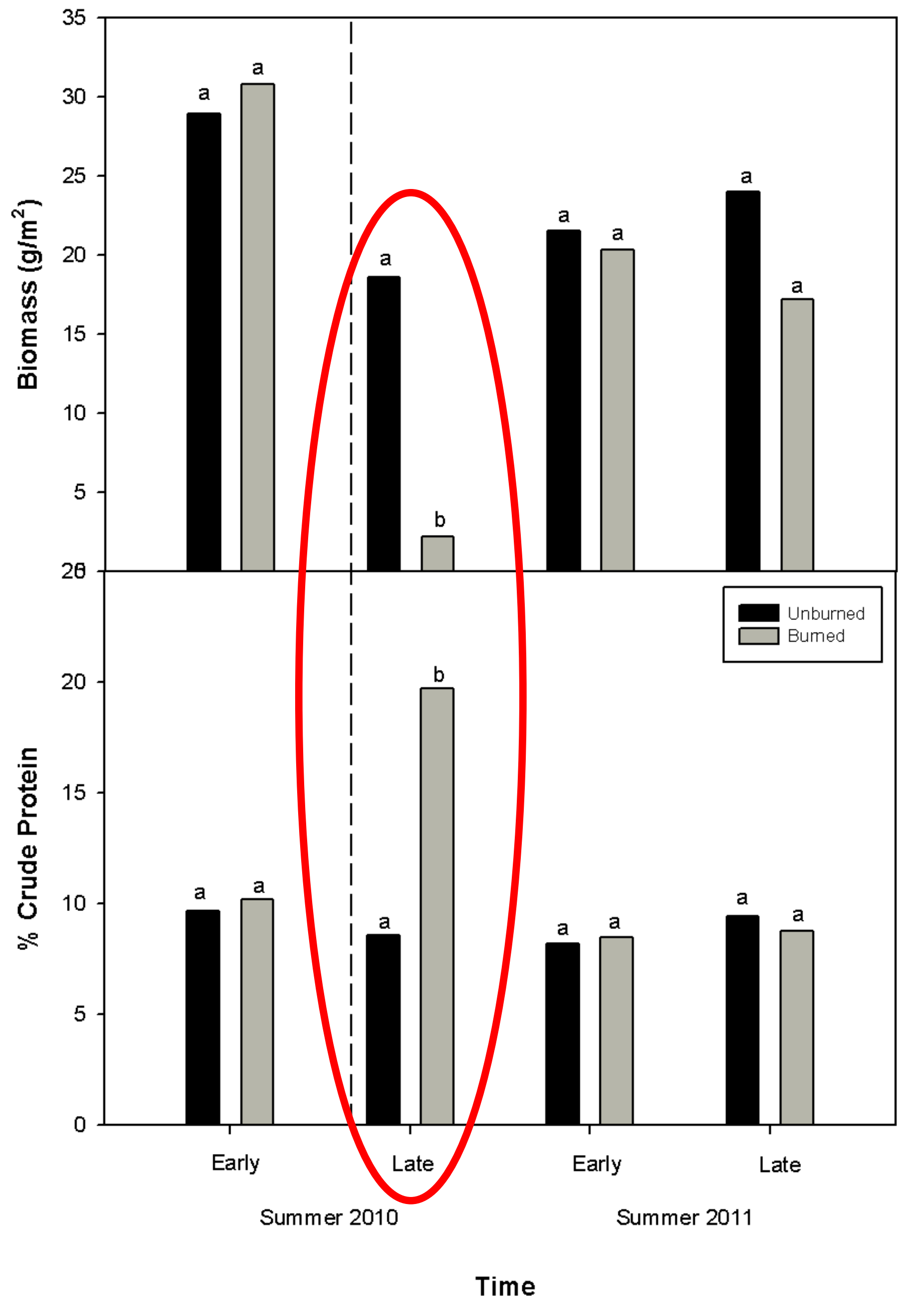
Years	Area burned (ha)	% of Total Refuge Area[1]	No. of fires	Min. Fire Size (ha)	Max. Fire Size (ha)	Ignition Source (% of total): Lightning	Human-caused	Prescribed Fire	Other[2]
1980-1984	4163.0	1.3	49	3.81E-03	4007.1	93.9	4.1	0.0	2.0
1985-1989	2829.5	0.9	75	1.64E-05	1214.0	92.0	4.0	1.3	2.7
1990-1994	5823.0	1.8	49	0.07	4478.7	63.3	30.6	4.1	2.0
1995-1999	7751.1	2.3	29	5.71E-04	4061.5	93.1	3.5	0.0	3.5
2000-2004	10509.9	3.2	36	0.04	26918.5	83.3	13.9	0.0	2.8
2005-2008	40579.9	12.3	38	0.03	13345.2	79.0	5.3	13.2	2.6
1980-2008	71656.4	21.6	276	1.64E-05	26918.5	84.4	10.1	2.9	2.5

- Trend of increasing area burned
- Only 21.6 % of refuge burned in 29 years
- Recently, there are fewer but larger fires
- Most fires are ignited by lightning
- Fire rotation of 134 years

Part II: HISTORICAL FIRE REGIME



- FRCC represents departure from the natural fire regime
- Medium to high departure is dominant on CMR



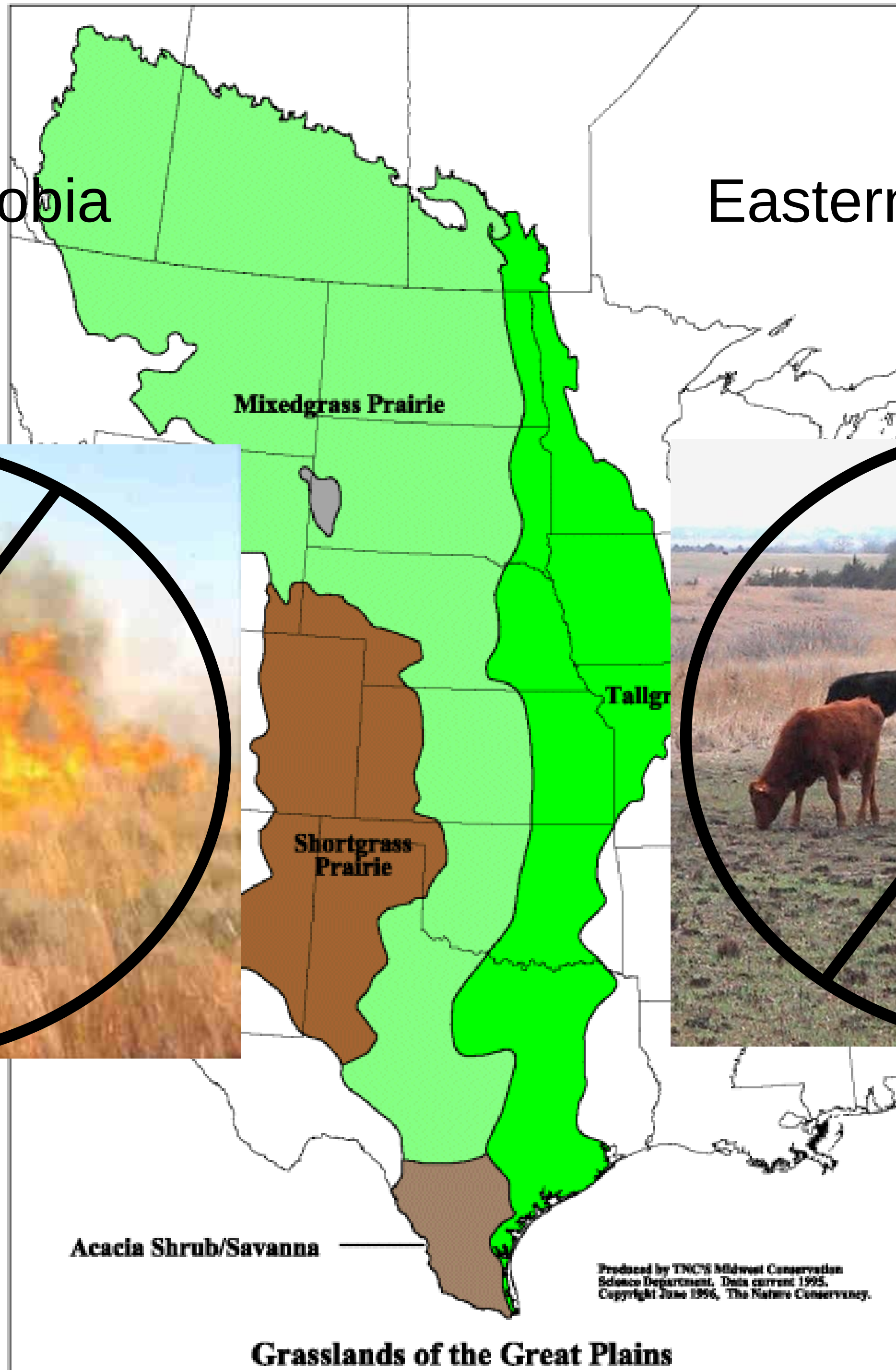
Biomass (g/m2)
35
30
25
20
15
10
5
20
a
a
a
b
a
a
a
a
% Crude Protein
Unburned
Burned
a
a
a
b
a
a
a
a
0
Early
Late
Early
Late
Summer 2010
Summer 2011
Time

Post-Burn Vegetation Cover

		2011					
		No Grazing		Wildlife Only		Open Grazing	
Group	**Species**	**Unburned**	**Burned**	**Unburned**	**Burned**	**Unburned**	**Burned**
GRASS	*Bouteloua gracilis*	1.76 ± 0.38	3.13 ± 0.49	3.41 ± 0.57	4.03 ± 0.59	7.64 ± 0.91	6.37 ± 0.73
	Bromus japonicus	18.53 ± 1.39	8.01 ± 0.93	9.58 ± 0.93	3.66 ± 0.53	10.38 ± 1.20	9.42 ± 1.05
	Pascopyrum smithii	13.15 ± 0.79	12.71 ± 0.94	11.34 ± 0.89	11.26 ± 0.90	12.08 ± 0.92	9.38 ± 0.71
	Stipa viridula	2.00 ± 0.36	1.67 ± 0.38	5.65 ± 0.72	3.86 ± 0.68	3.12 ± 0.61	2.81 ± 0.48
FORB	*Melilotus officinalis*	2.97 ± 0.66	5.75 ± 1.13	2.28 ± 0.46	2.92 ± 0.56	2.15 ± 0.61	0.99 ± 0.26
SHRUB	*Artemisia frigida*	1.66 ± 0.33	0.47 ± 0.20	2.13 ± 0.37	1.04 ± 0.27	4.51 ± 0.63	2.22 ± 0.51
	Artemisia tridentata	9.02 ± 1.35	0.65 ± 0.42	7.02 ± 1.06	2.81 ± 0.63	10.42 ± 1.32	4.18 ± 0.92
	Opuntia polyacantha	1.51 ± 0.36	0.96 ± 0.31	0.95 ± 0.26	0.64 ± 0.23	1.28 ± 0.32	1.26 ± 0.36

Western Fire Phobia

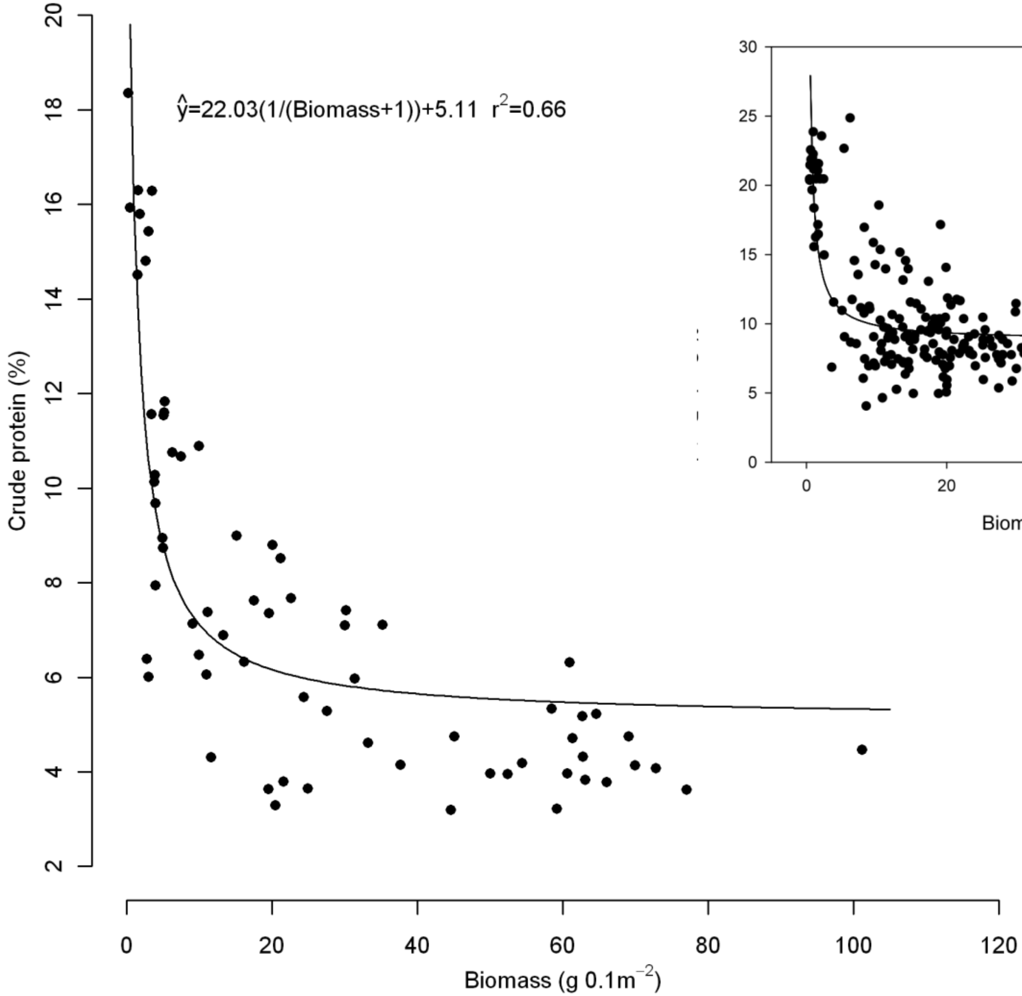
Eastern Grazing Phobia

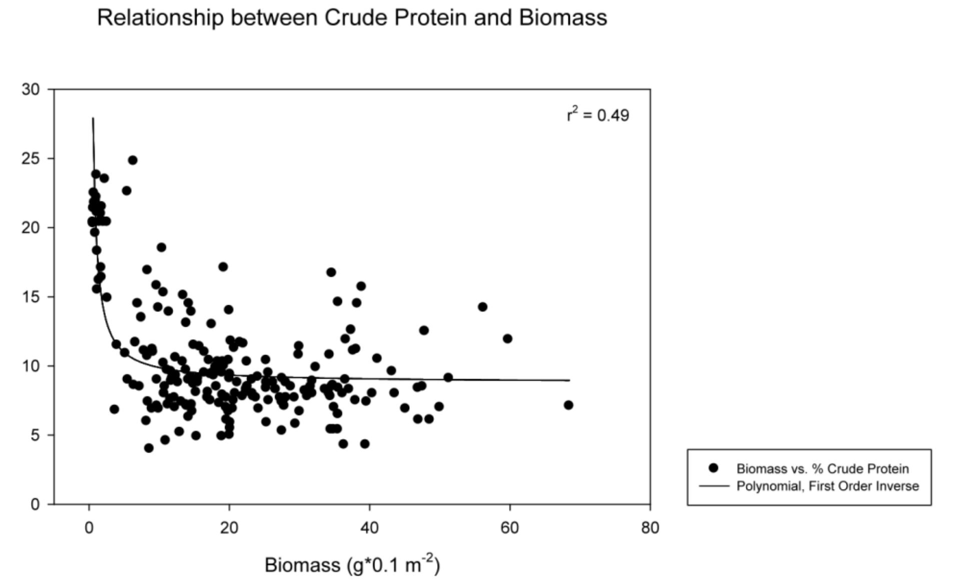


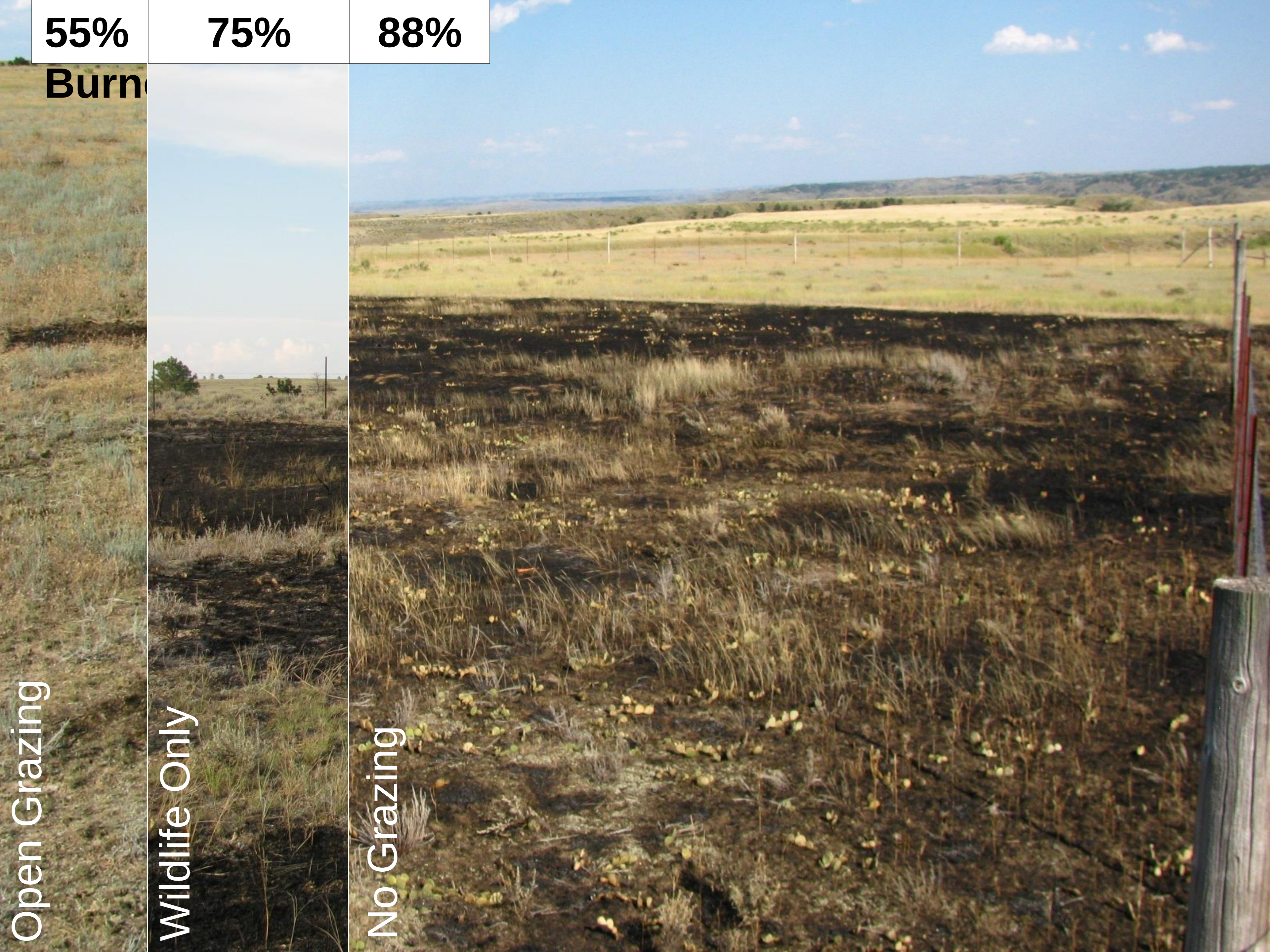
"… the most important resources of Indian hunter-gatherers are the early succession species commonly found in recently burned areas: bison, moose, deer, elk, rabbits, grouse, grass seeds, legumes, berries, bulbs. However, natural fires are too irregular in occurrence and distribution to be completely relied upon."

Henry Lewis, ethnohistorian
As quoted by Alston Chase,
Playing God in Yellowstone [pp. 93-94]

Forage quality and quantity paradox






55%
75%
88%
Burn
Open Grazing
Wildlife Only
No Grazing

J. Range Manage.
53:660–665 November 2000

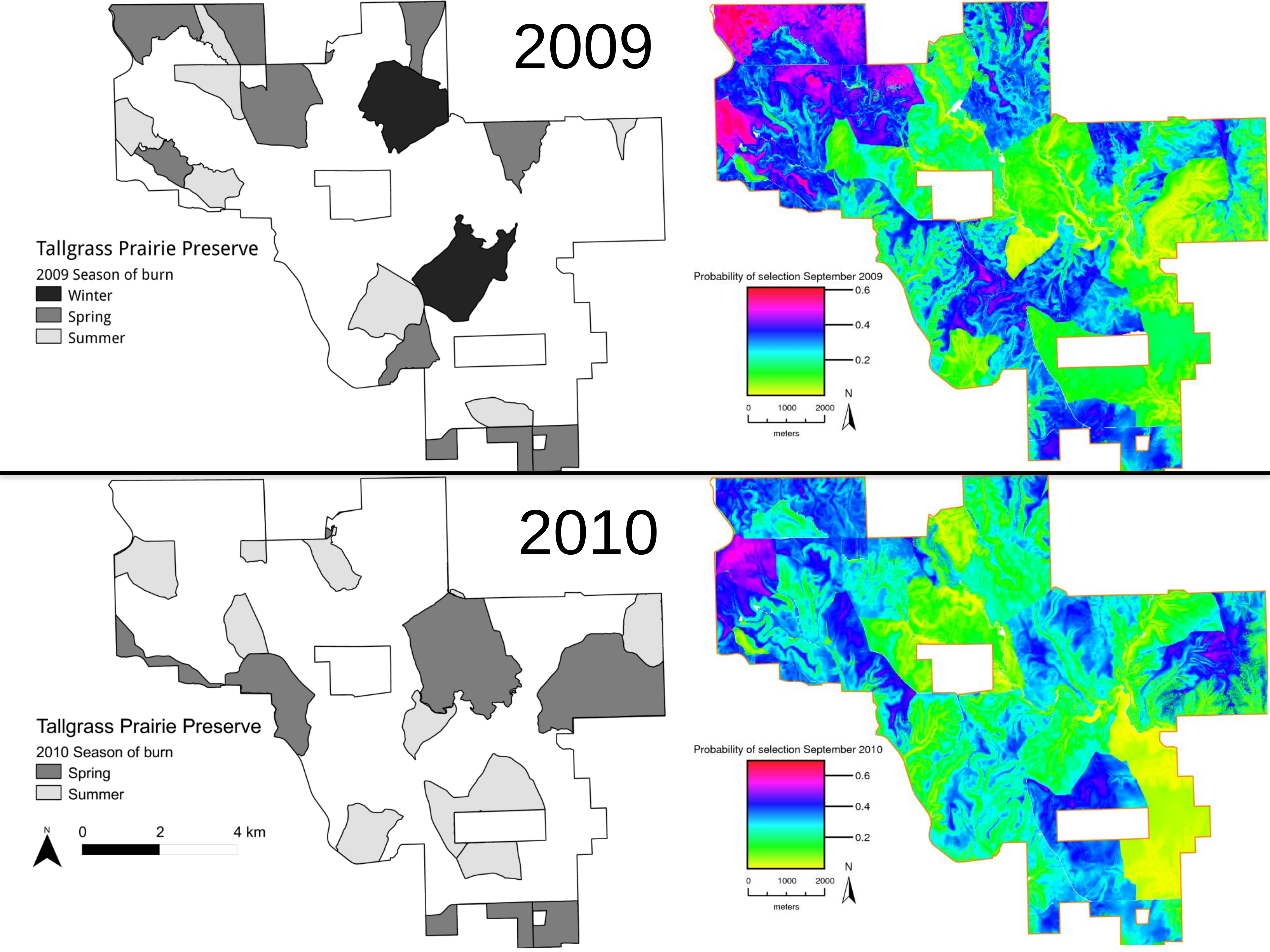
Fire history of the Rochelle Hills Thunder Basin National Grasslands

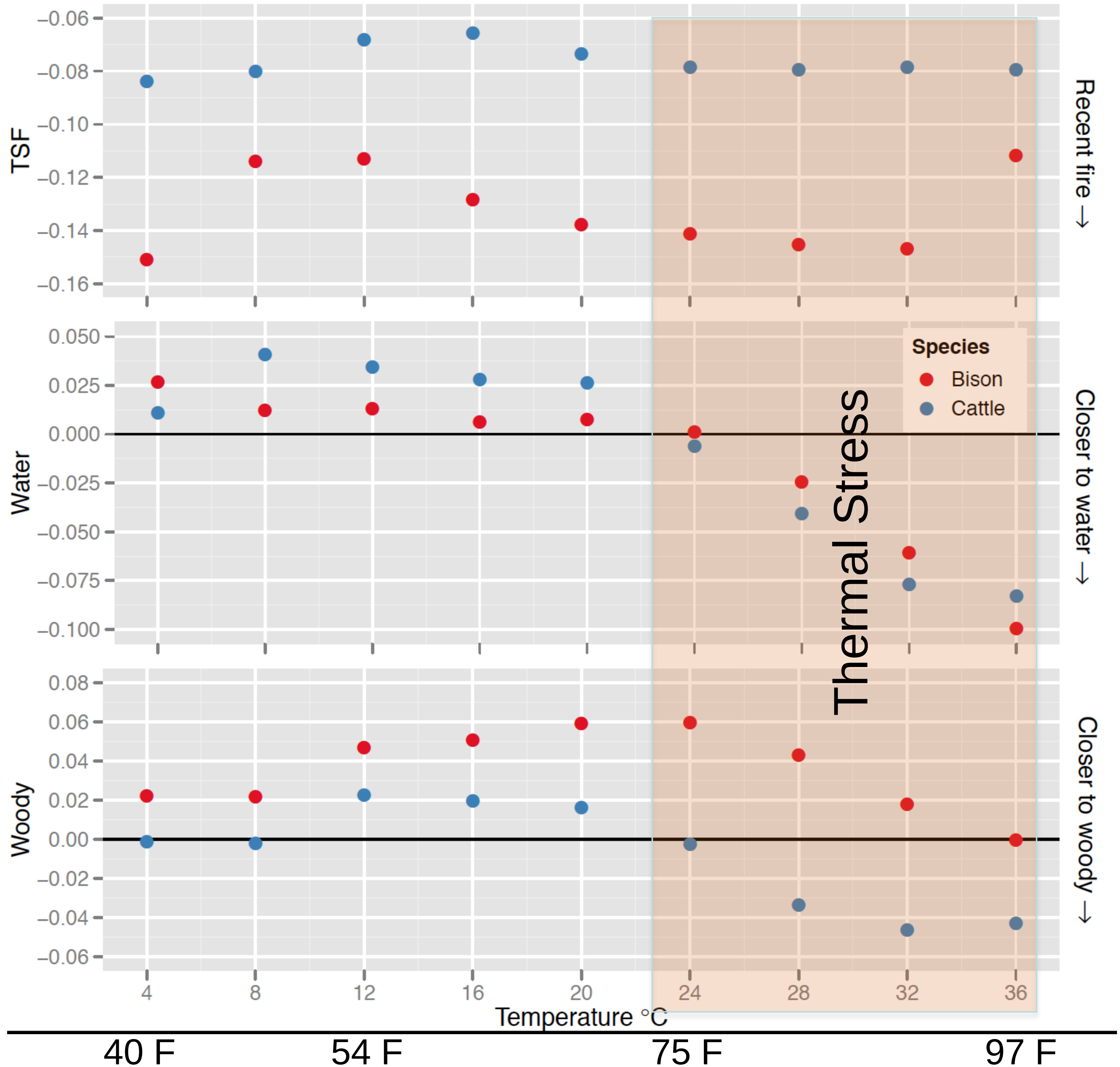
BARRY L. PERRYMAN AND W.A. LAYCOCK

Authors are assistant professor, School of Veterinary Medicine, University of Nevada, Reno, Nev. 89557, and professor emeritus, Department of Renewable Resources, University of Wyoming, Laramie, Wyo. 82071. *Research was funded by the McIntire-Stennis Ecosystem Management Program and the Department of Rangeland Ecology and Watershed Management, University of Wyoming, Laramie, Wyo.*

A fire scar chronology was constructed from ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) trees within the 70 km^2 Rochelle Hills Area of the Thunder Basin National Grasslands, in north-east Wyoming. A total of 65 fire scars occurred in 48 crossdated samples, and a master fire chronology was constructed for the period 1565 to 1988. No trees recorded more than 3 fires and most (26 of 42) recorded only one. For this reason, fire frequency intervals were considered as fire-free intervals in the Rochelle Hills Area. The Weibull Median Probability Interval (WMPI) for the entire period of record was 7.4; 7.9 for the non suppression period (1565 to 1939); and 6.7 for the suppression period (1940 to 1988). Infrequent occurrence of multiple scars, rough topography, and low potential substrates suggest that understory fuel loads were limited in amount and spatial consistency during most fire years. Position of scars within annual growth rings suggests that most fires (80%) occurred during the latter stages of the growing season or during the dormant period.

What about more arid, more complex and different herbivores?


2009
Tallgrass Prairie Preserve
2009 Season of burn
Winter
Spring
Summer
Probability of selection September 2009
0.6
0.4
0.2
0
1000
2000
meters
N
2010
Tallgrass Prairie Preserve
2010 Season of burn
Spring
Summer
N
0
2
4 km
Probability of selection September 2010
0.6
0.4
0.2
0
1000
2000
meters
N



TSF
−0.06
−0.08
−0.10
−0.12
−0.14
−0.16
Recent fire →
Water
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100
Closer to water →
Species
Bison
Cattle
Thermal Stress
Woody
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
Closer to woody →
4
8
12
16
20
24
28
32
36
Temperature °C
40 F
54 F
75 F
97 F

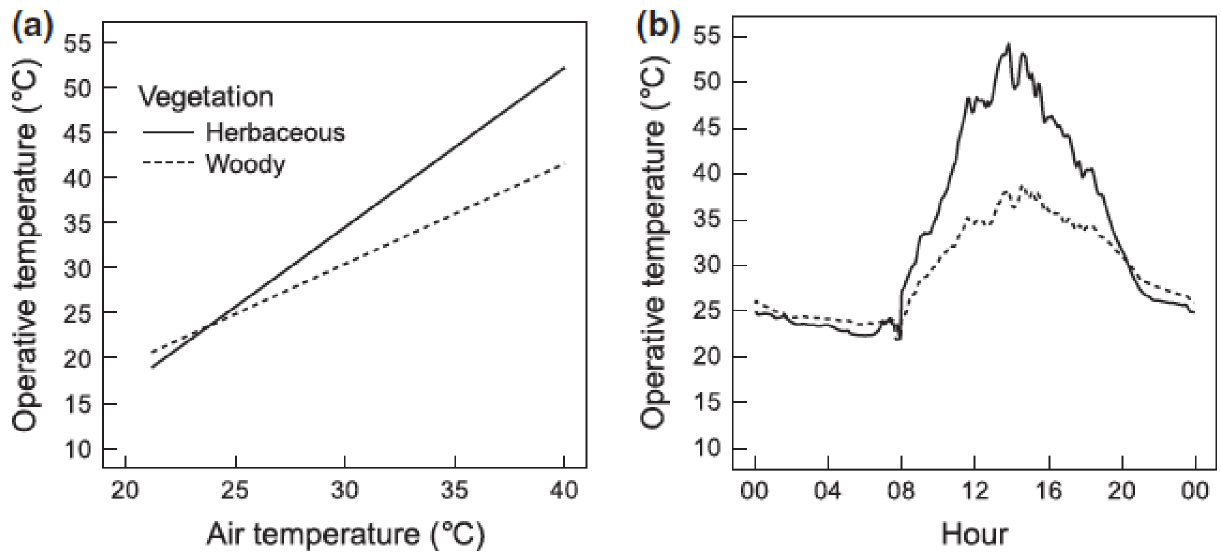
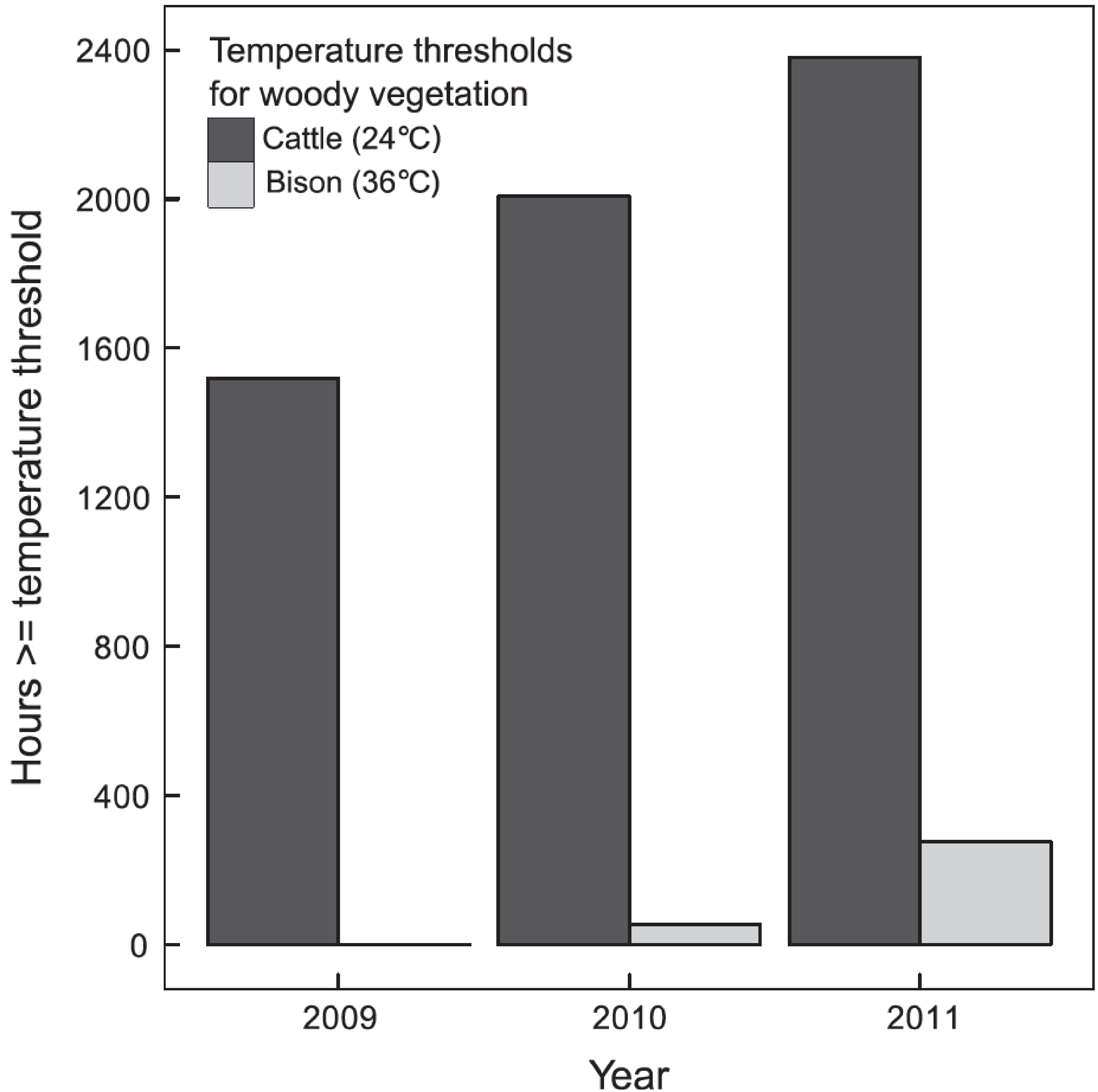


Fig. 1 Thermal representation of a tallgrass prairie ecosystem. Operative temperature as a function of (a), air temperature (*Tair*) separated by vegetation type, herbaceous ($\hat{y} = 1.91Tair - 22.33$; $r^2 = 0.72$, $P < 0.05$) and woody ($\hat{y} = 1.13Tair - 3.45$; $r^2 = 0.84$, $P < 0.05$) and (b), hour of day (values are averaged over summer sampling periods). Operative temperature is relatively more stable in woody than herbaceous vegetation. Woody vegetation is also significantly cooler at warmer air temperatures and during the heat of the day.



Temperature thresholds
for woody vegetation
Cattle (24°C)
Bison (36°C)
2400
2000
1600
1200
800
400
0
Hours >= temperature threshold
2009
2010
2011
Year