Modeling bat activity across the fire-managed landscape of Mammoth Cave Nat'l Park using remotely-sensed forest canopy data

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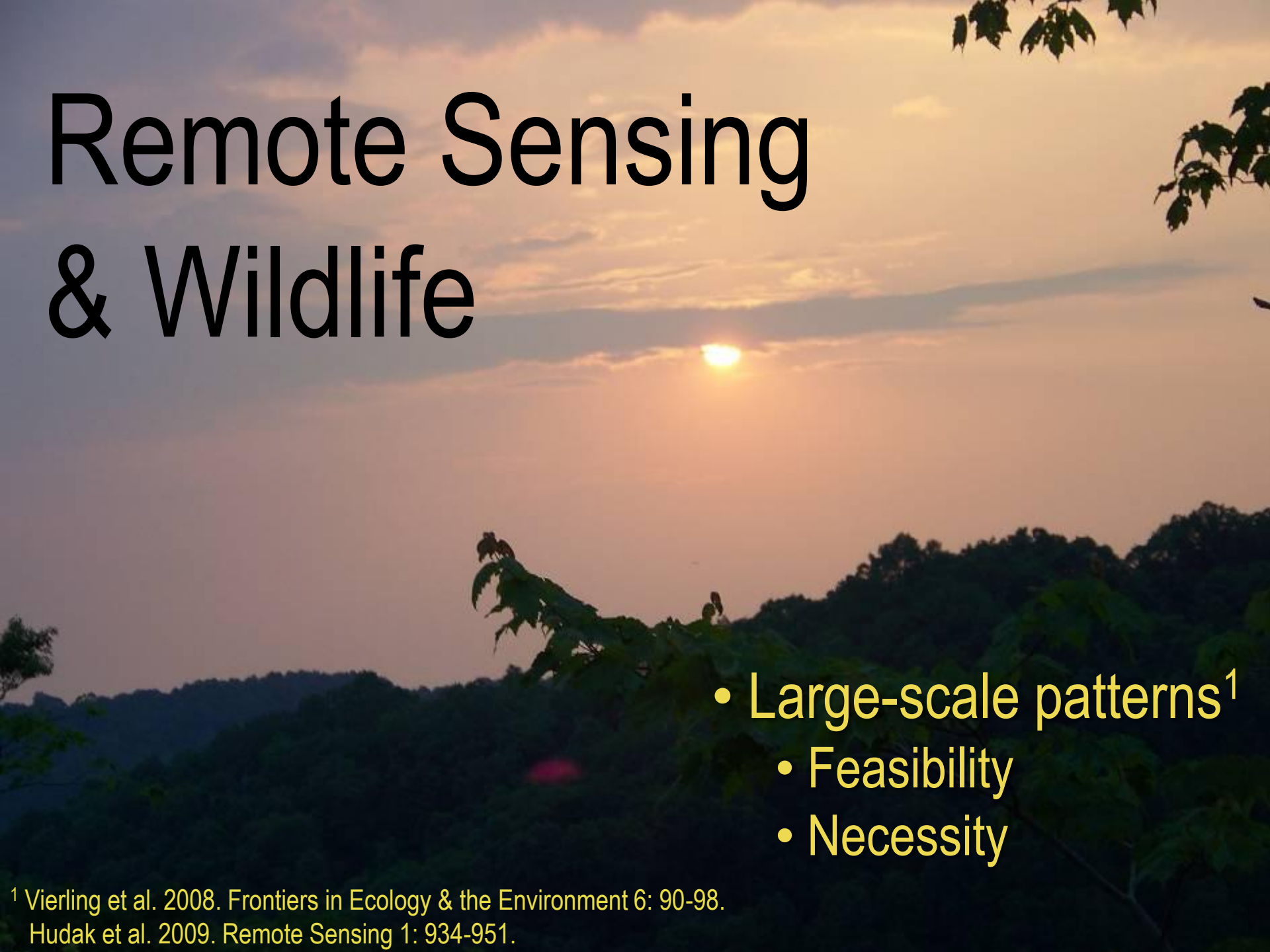
[3]Entomology Department, University of Kentucky

Remote Sensing & Wildlife



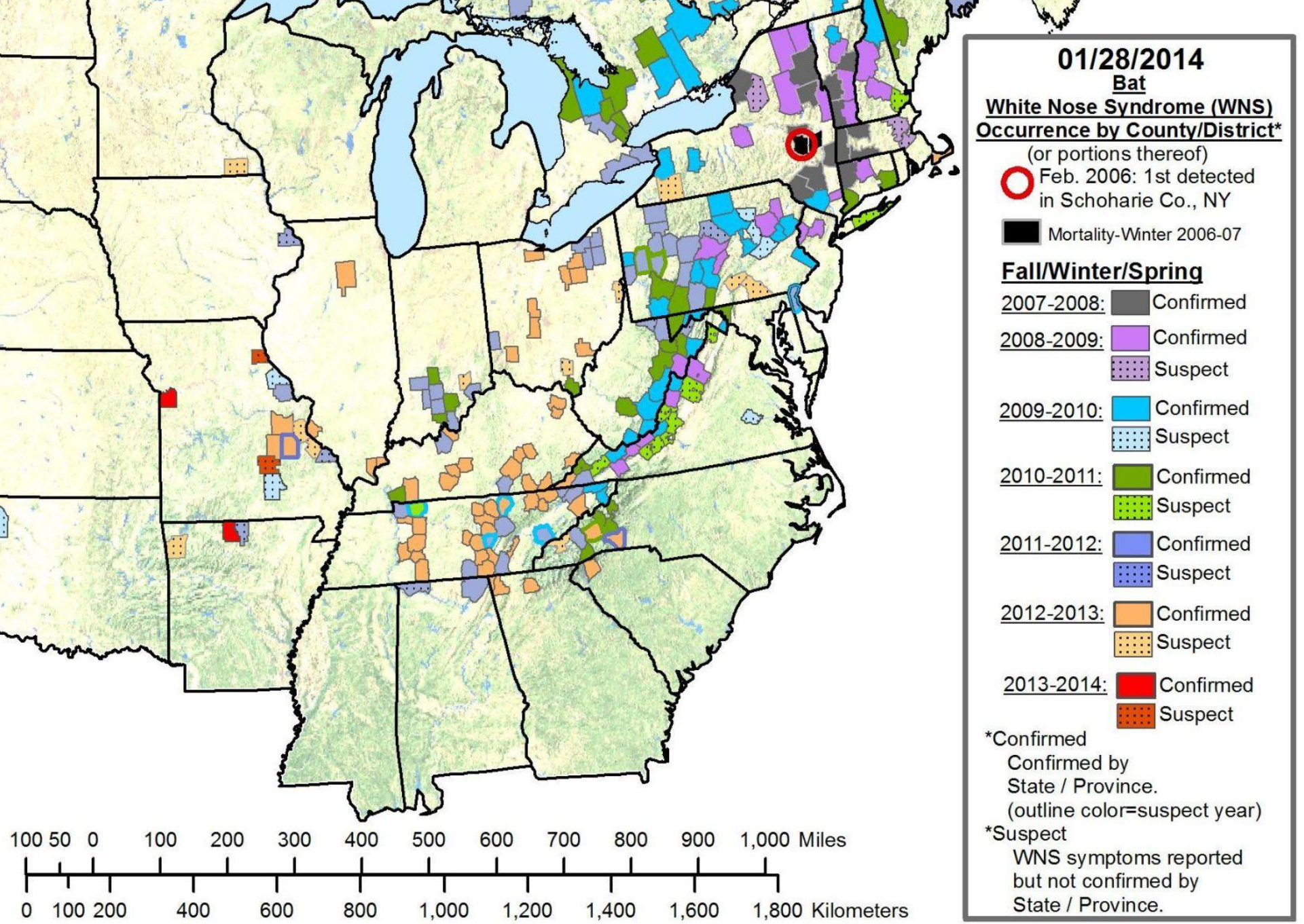
- Large-scale patterns[1]
  - Feasibility
  - Necessity

[1] Vierling et al. 2008. Frontiers in Ecology & the Environment 6: 90-98.
Hudak et al. 2009. Remote Sensing 1: 934-951.

Bats at Mammoth Cave

- Variable foraging & habitat use across species[1]
  - Prey availability & forest canopy structure
- White-nose syndrome
  - Now at Mammoth Cave; changing predator-prey dynamics?

[1]Swartz et al. 2003. Pp. 257-300 in: Bat Ecology.
Lacki et al. 2007. Pp. 83–128 in: Bats in Forests: Conservation and Management



Map by: Cal Butchkoski, PA Game Commission

01/28/2014

Bat

White Nose Syndrome (WNS) Occurrence by County/District*

(or portions thereof)

Feb. 2006: 1st detected in Schoharie Co., NY

Mortality-Winter 2006-07

Fall/Winter/Spring

2007-2008: Confirmed

2008-2009: Confirmed, Suspect

2009-2010: Confirmed, Suspect

2010-2011: Confirmed, Suspect

2011-2012: Confirmed, Suspect

2012-2013: Confirmed, Suspect

2013-2014: Confirmed, Suspect

*Confirmed
Confirmed by State / Province.
(outline color=suspect year)

*Suspect
WNS symptoms reported but not confirmed by State / Province.

100 50 0 100 200 300 400 500 600 700 800 900 1,000 Miles

0 100 200 400 600 800 1,000 1,200 1,400 1,600 1,800 Kilometers

Map by: Cal Butchkoski, PA Game Commission

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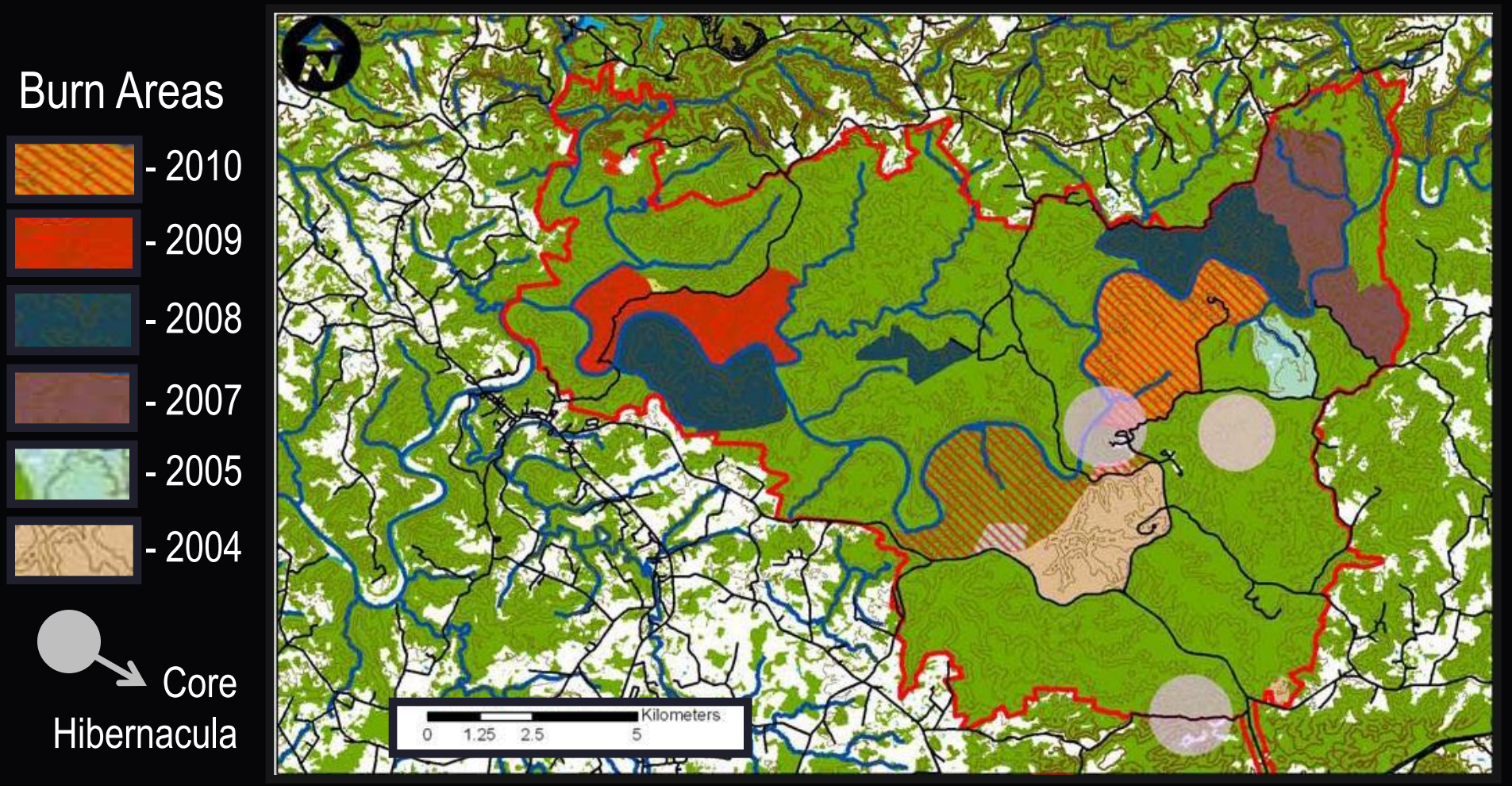
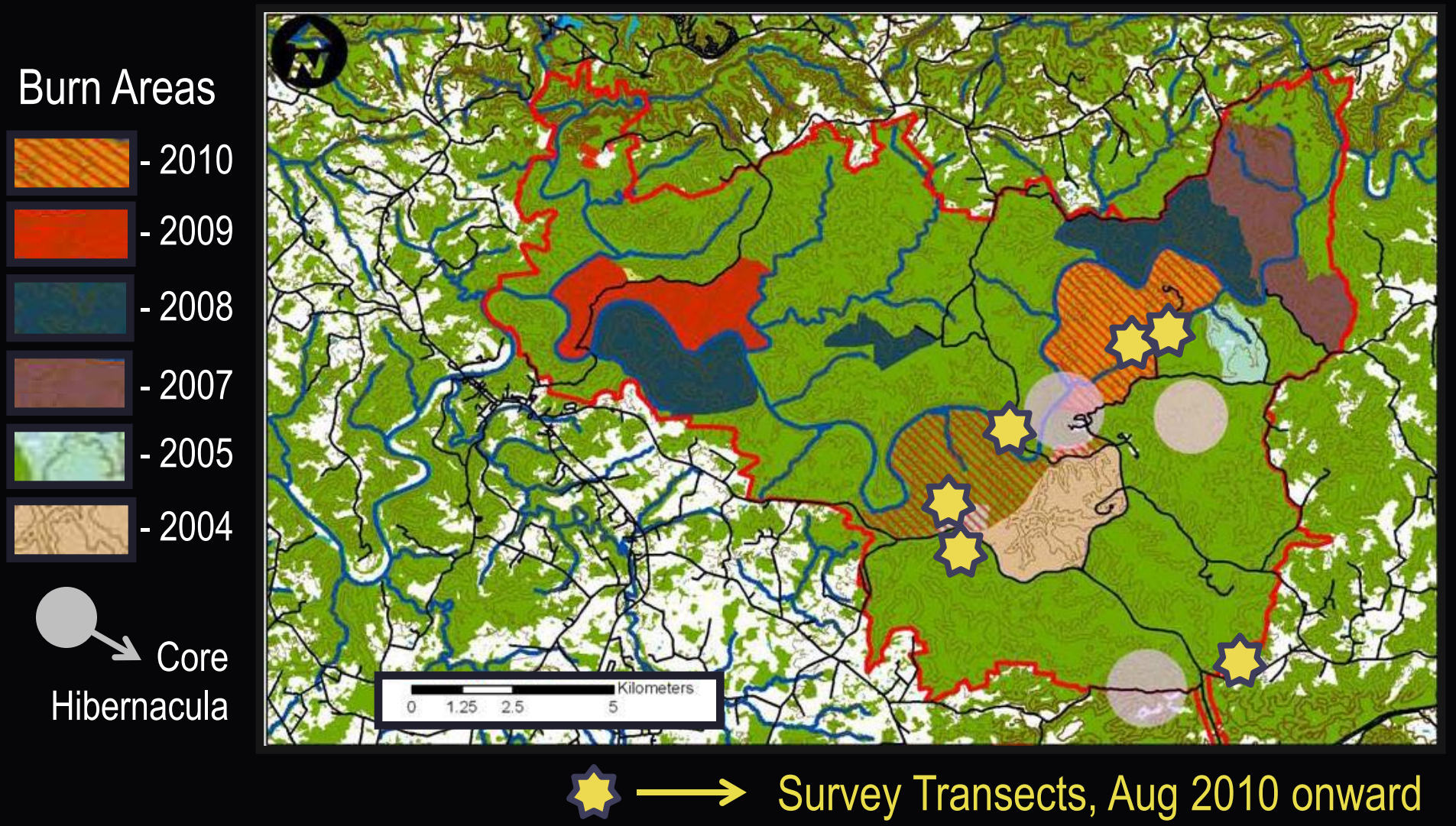
Mammoth Cave Nat'l Park



Mammoth Cave Nat'l Park



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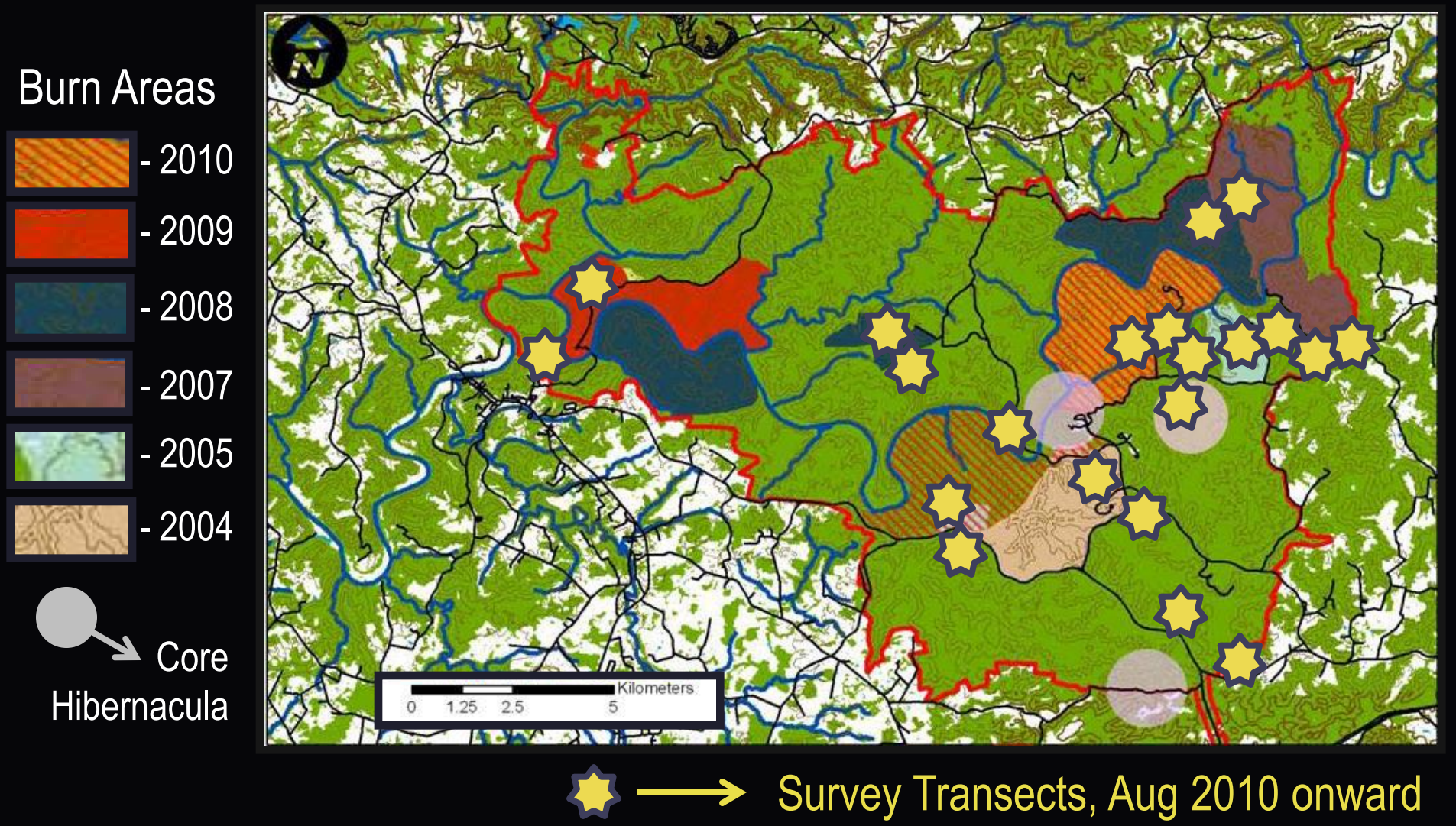
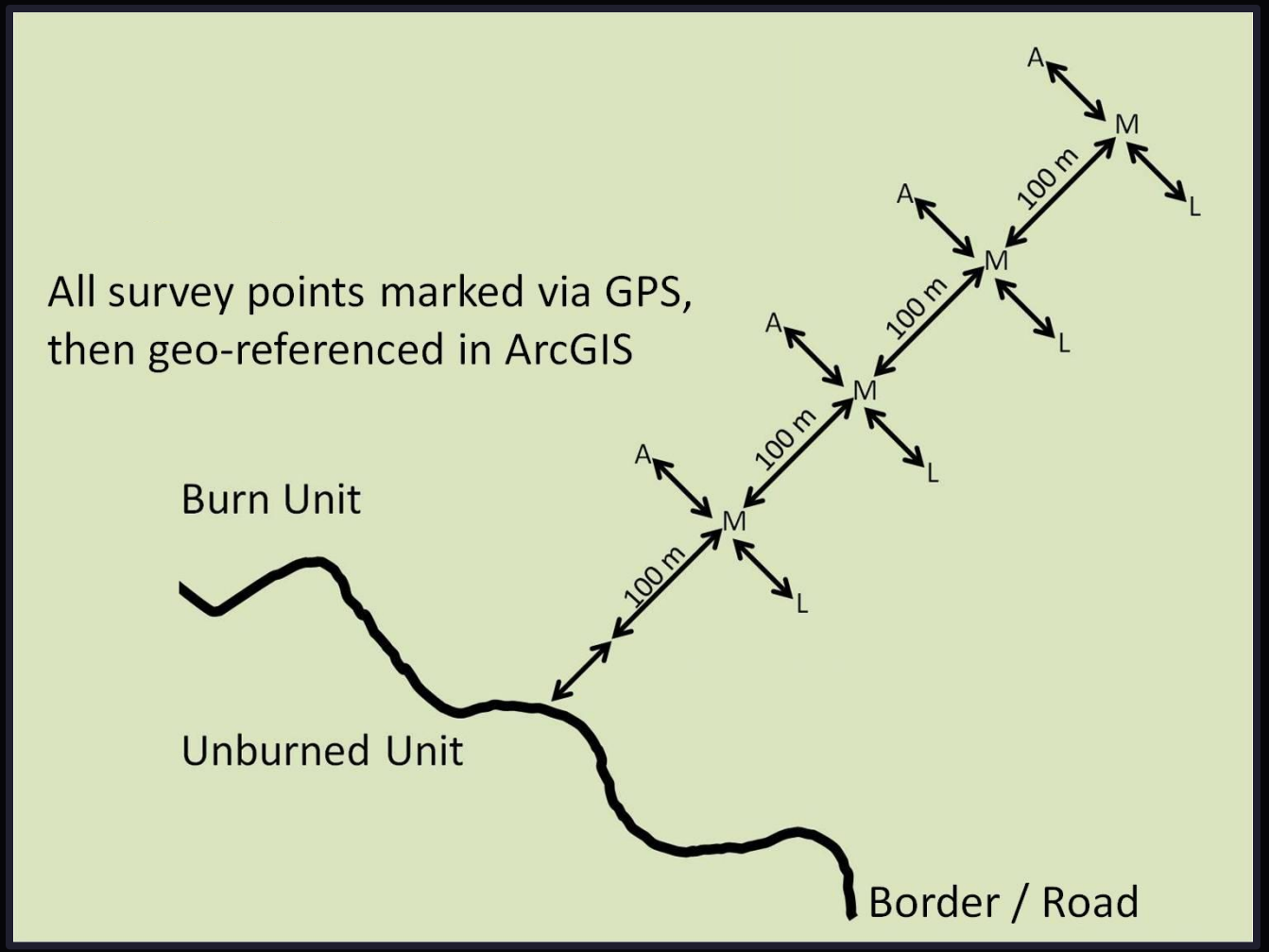
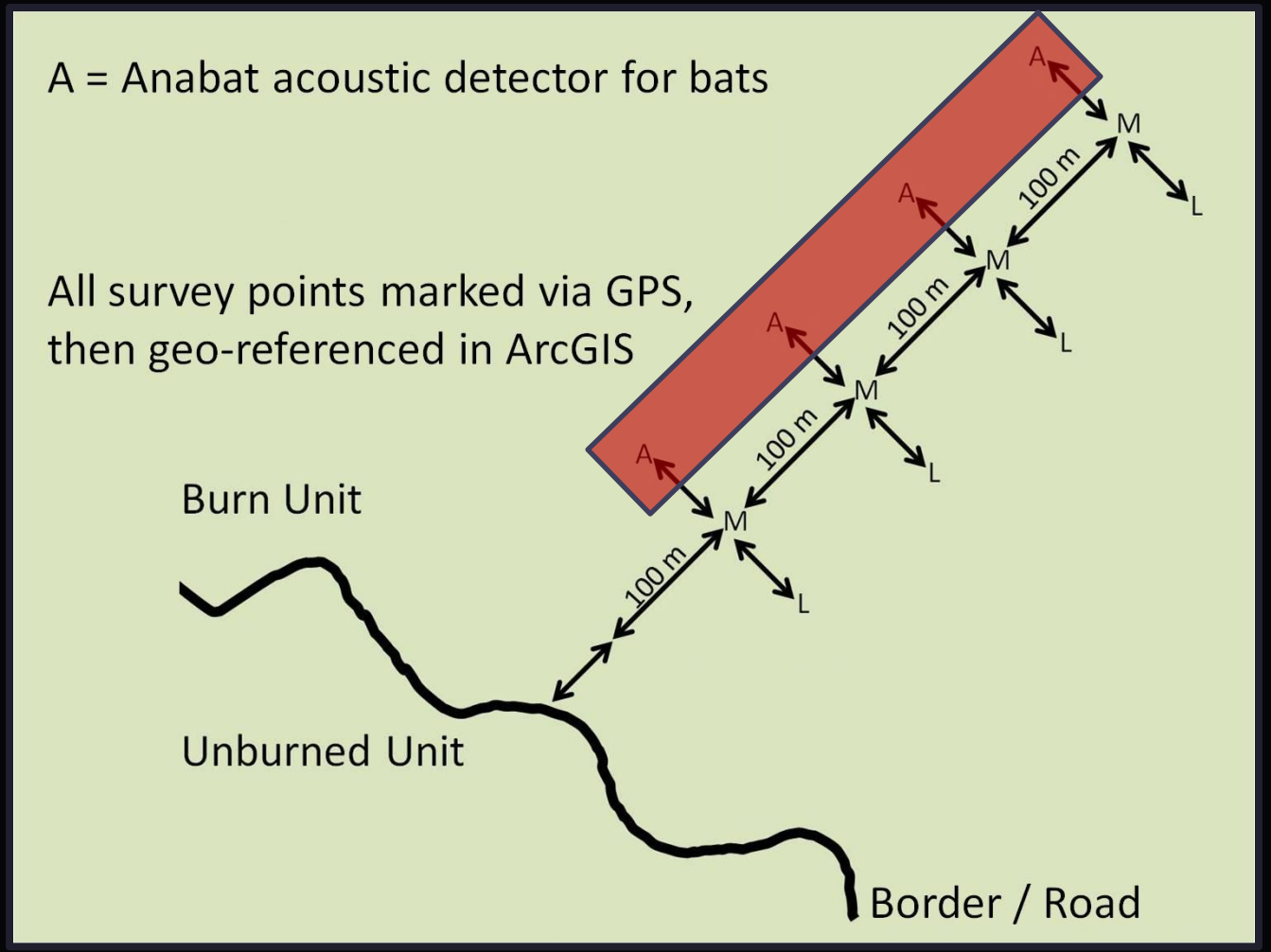


Methods


All survey points marked via GPS, then geo-referenced in ArcGIS
Burn Unit
Unburned Unit
Border / Road
A
M
L
100 m

Methods


A = Anabat acoustic detector for bats
All survey points marked via GPS, then geo-referenced in ArcGIS
A
M
L
100 m
Burn Unit
Unburned Unit
Border / Road

Methods

Bat Activity

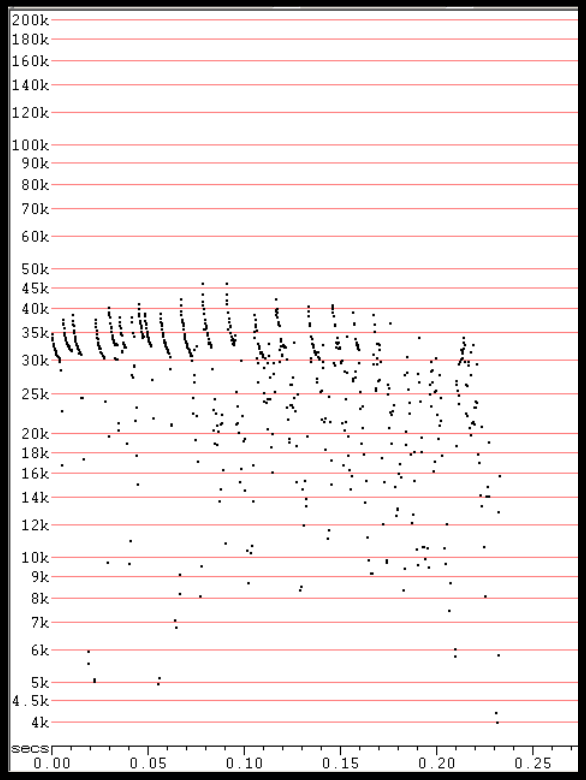
- Zero-crossing acoustic surveys
- Spanning 2010-2012 (still ongoing)
  - 170 nights (1,086 detector / nights)
  - Emphasis on April-May, Aug-Oct

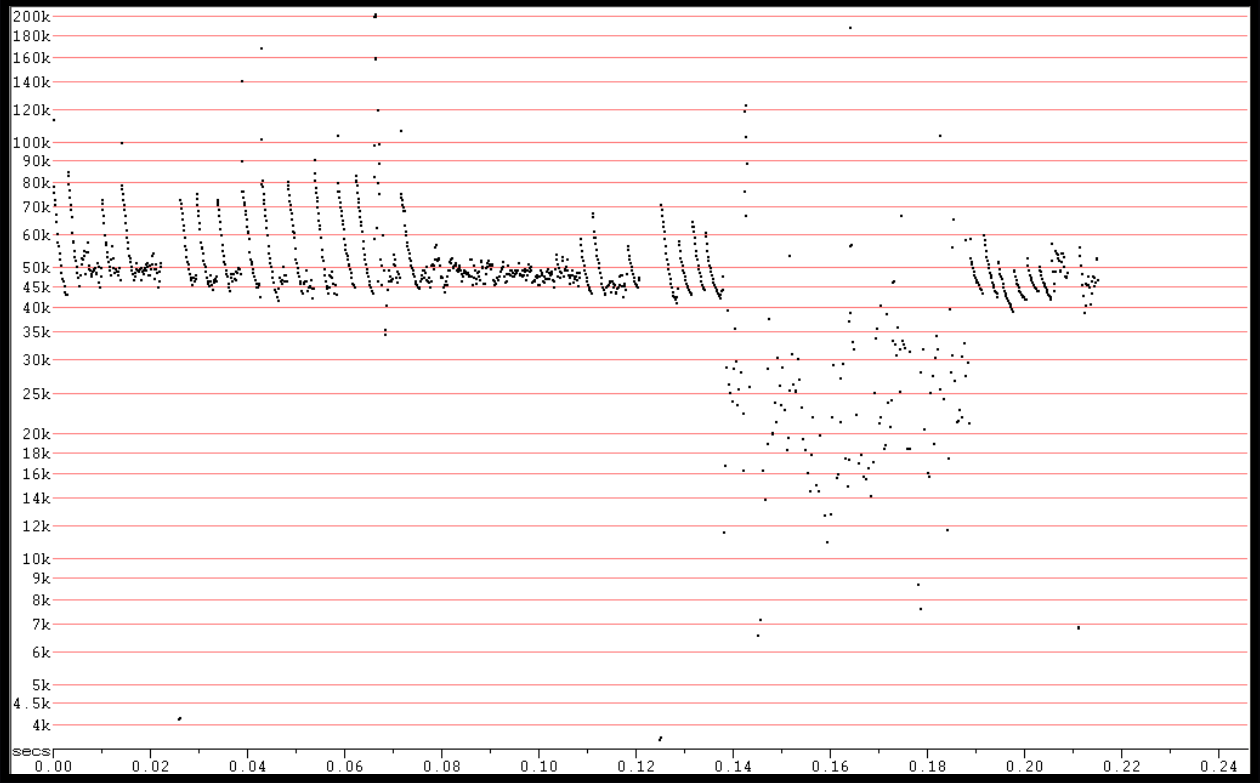
Methods

Bat Variables

- Echoclass v.1.1[1]

- High freq (> 34 kHz)
- Low freq (≤ 34 kHz)
- Feeding buzzes





[1]USFWS. Indiana Bat Survey Guidance.
http://www.fws.gov/midwest/Endangered/mammals/inba/inbasummersurveyguidance.html

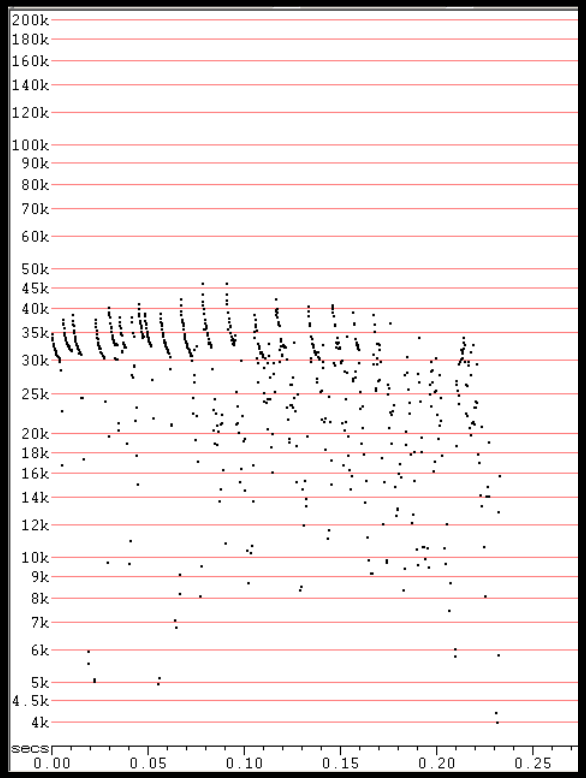
Methods

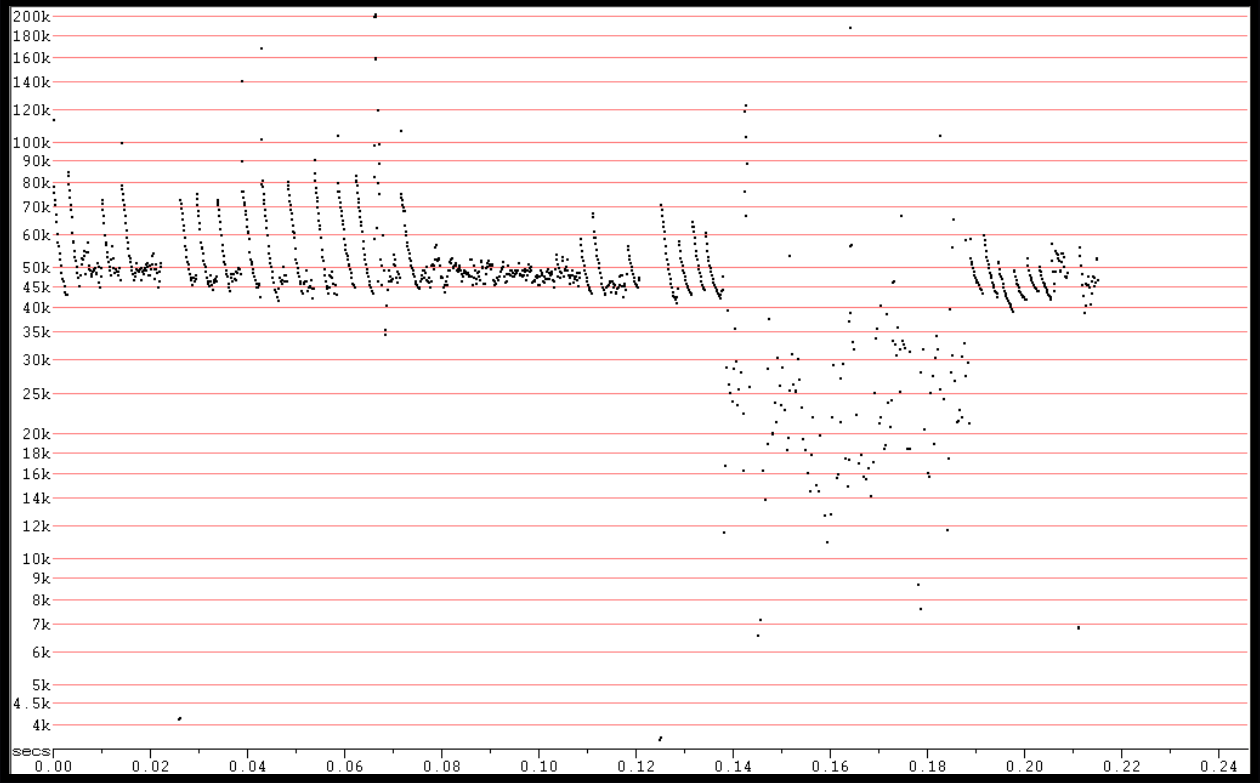
Bat Variables

- Echoclass v.1.1[1]

- High freq (> 34 kHz)
- Low freq (≤ 34 kHz)
- Feeding buzzes

} Total Activity





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Methods

LiDAR Survey

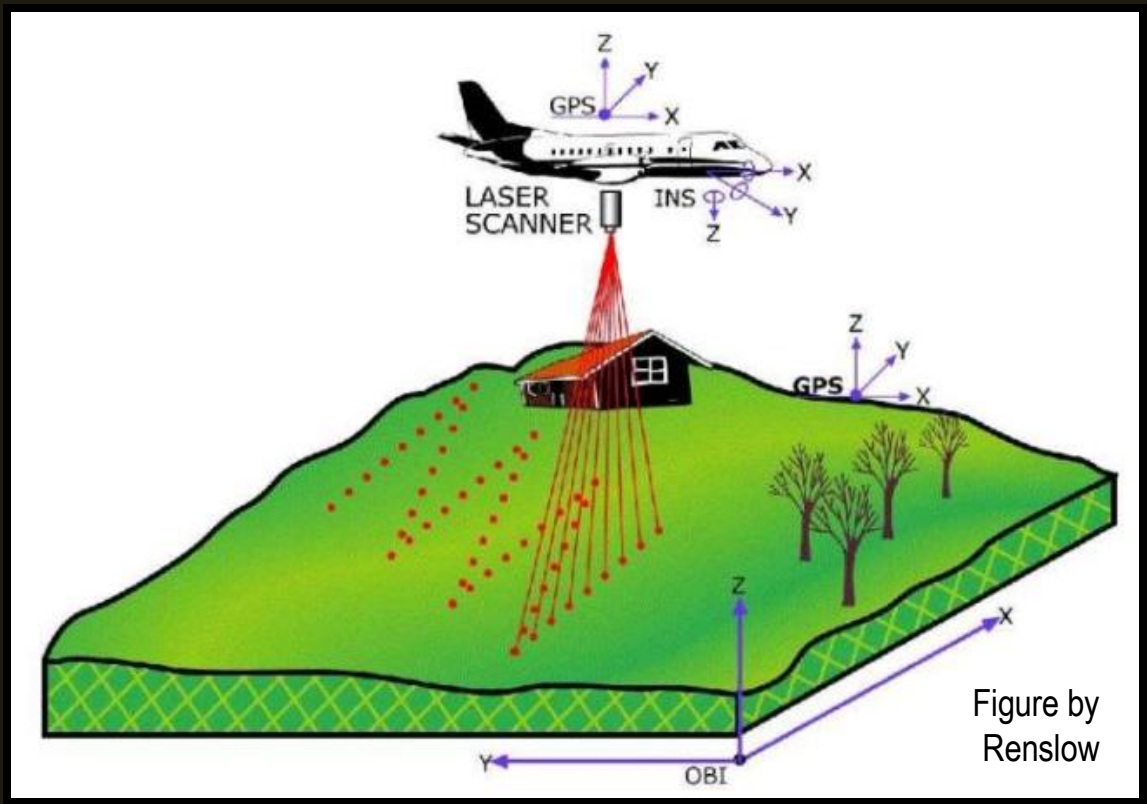


Figure by Renslow

- LiDAR = Light Detection and Ranging
- Discrete-return scanning LiDAR[1]
  - 900-1,600 nm wavelength
  - > 4 pulses / m^2

[1]Skowronski et al. 2007. Remote Sensing of Environment 108: 123-129.

Methods

LiDAR Survey

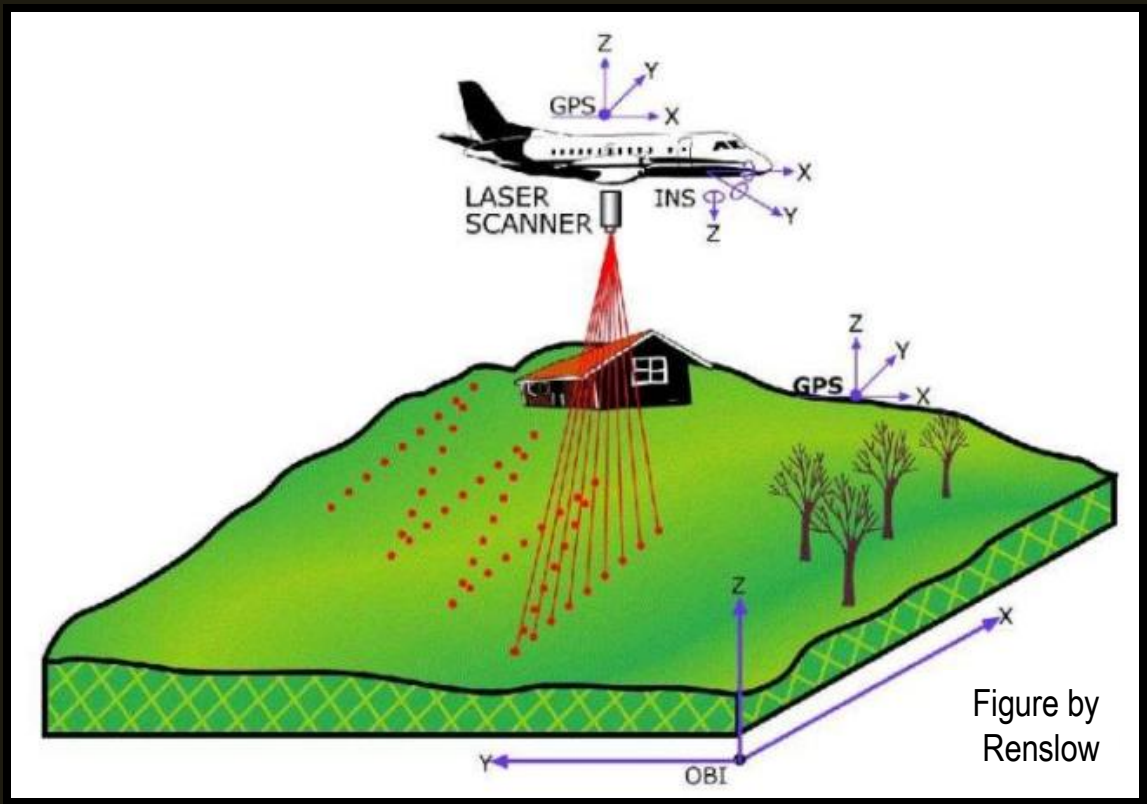


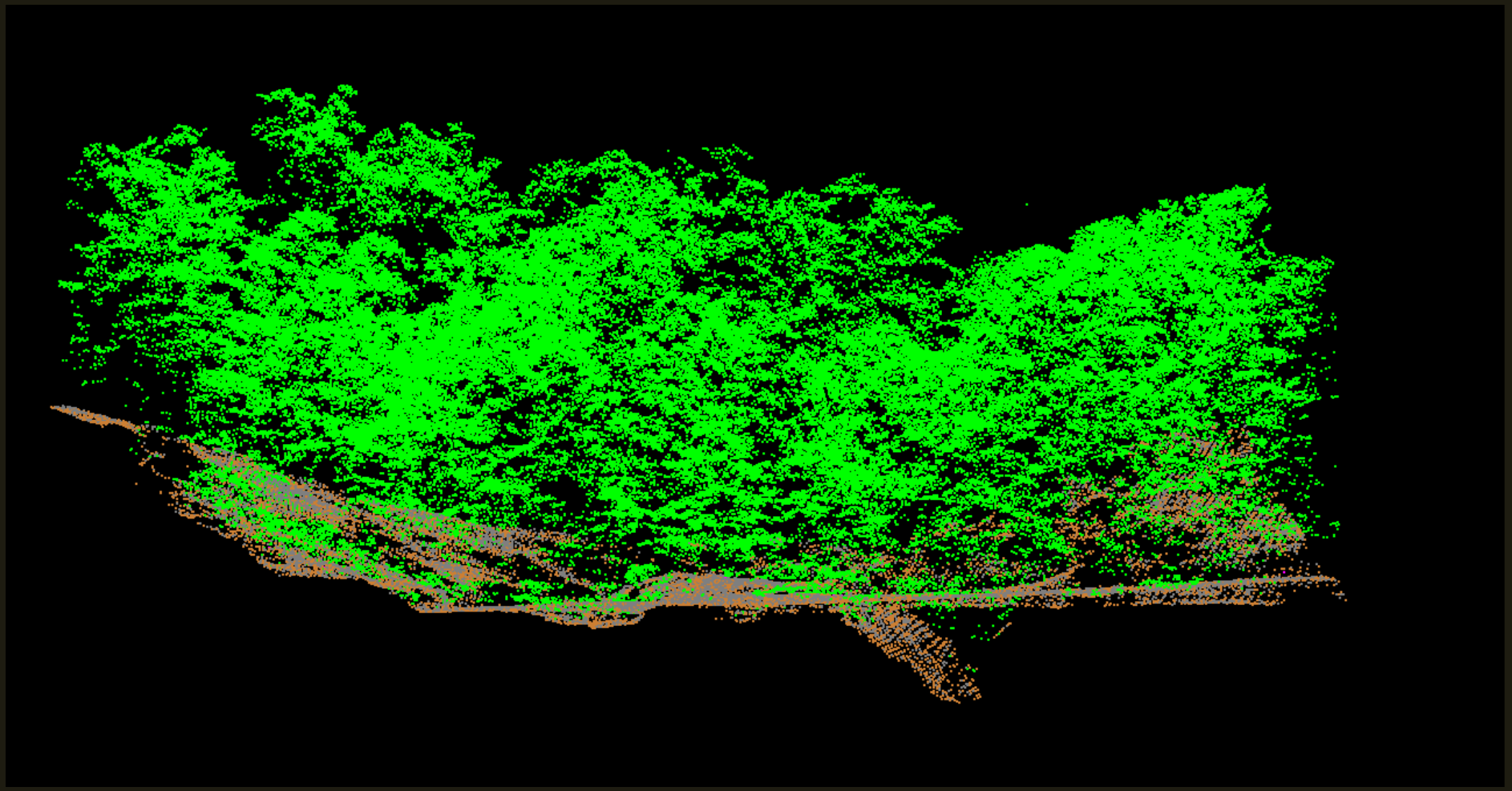
Figure by Renslow

- LiDAR = Light Detection and Ranging
- Data collected Fall 2010 (leaf-off) via fixed-wing aircraft

Methods

LiDAR Variables

- What scale is meaningful?



Methods

LiDAR Variables

- Laser returns across over-, mid-, & understory strata[1]

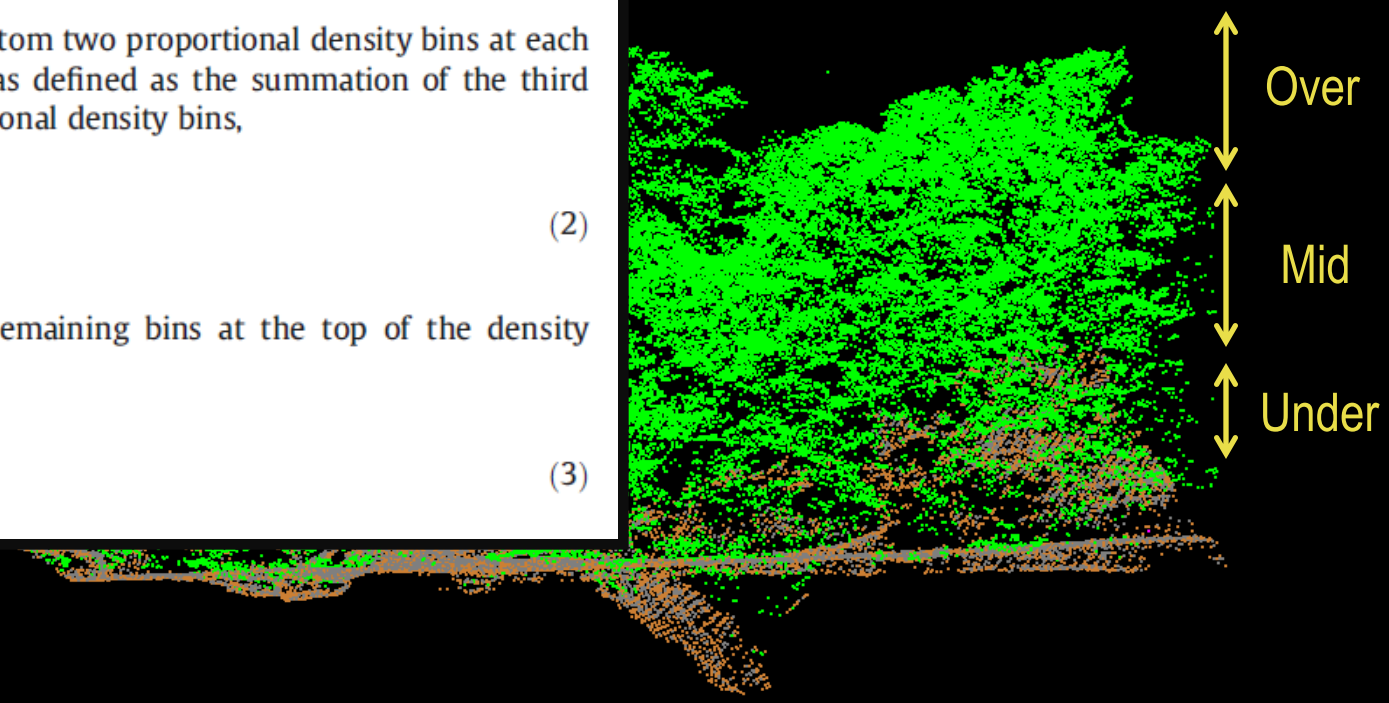
$$p_{under} = \sum_{i=10}^{i=20} p_i, \quad (1)$$

where p_{under} sums the bottom two proportional density bins at each location. The midstory was defined as the summation of the third through the sixth proportional density bins,

$$p_{mid} = \sum_{i=30}^{i=60} p_i, \quad (2)$$

and the canopy by the remaining bins at the top of the density distribution,

$$p_{can} = \sum_{i=70}^{i=100} p_i. \quad (3)$$

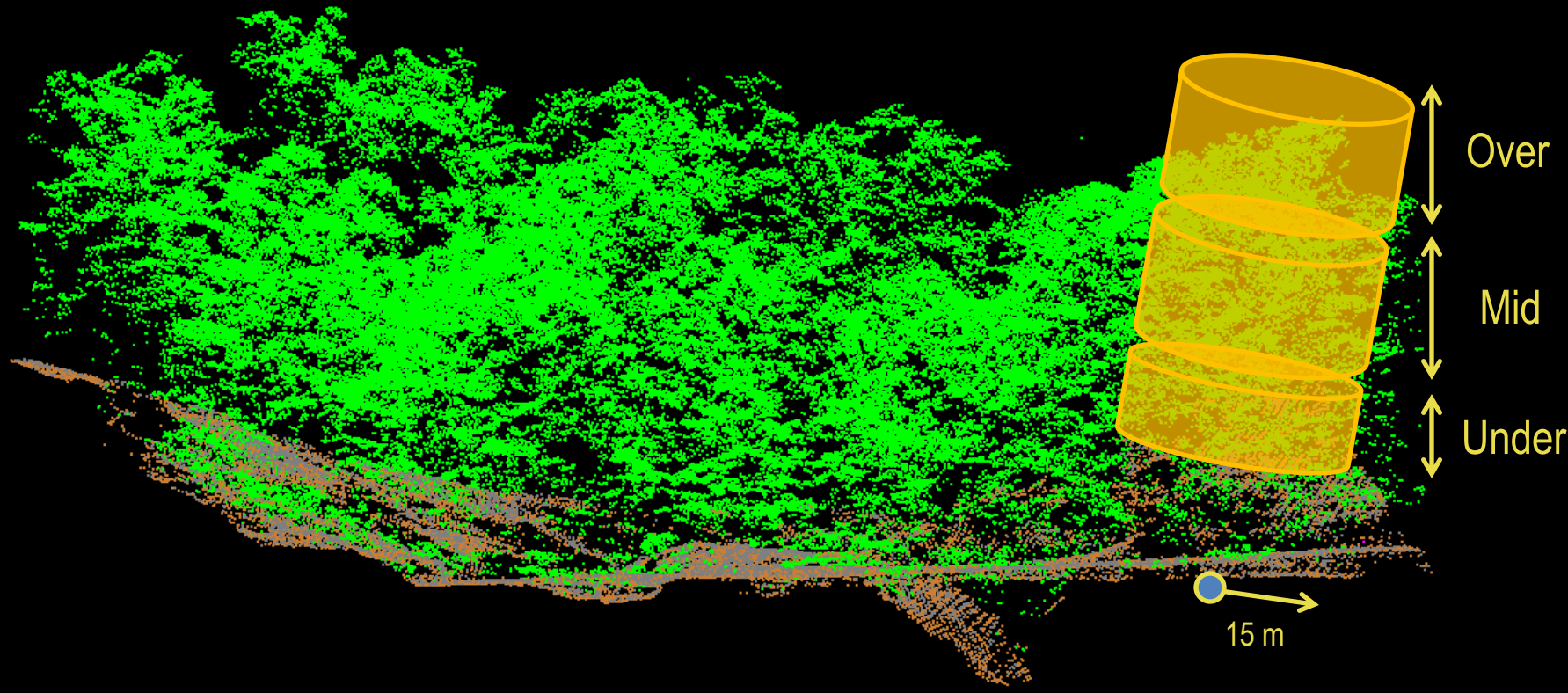


[1]Lesak et al. 2011. Remote Sensing of Environment 115: 2823-2835

Methods

LiDAR Variables

- Laser returns across over-, mid-, & understory strata[1]
- 15 m radii around survey points[1]



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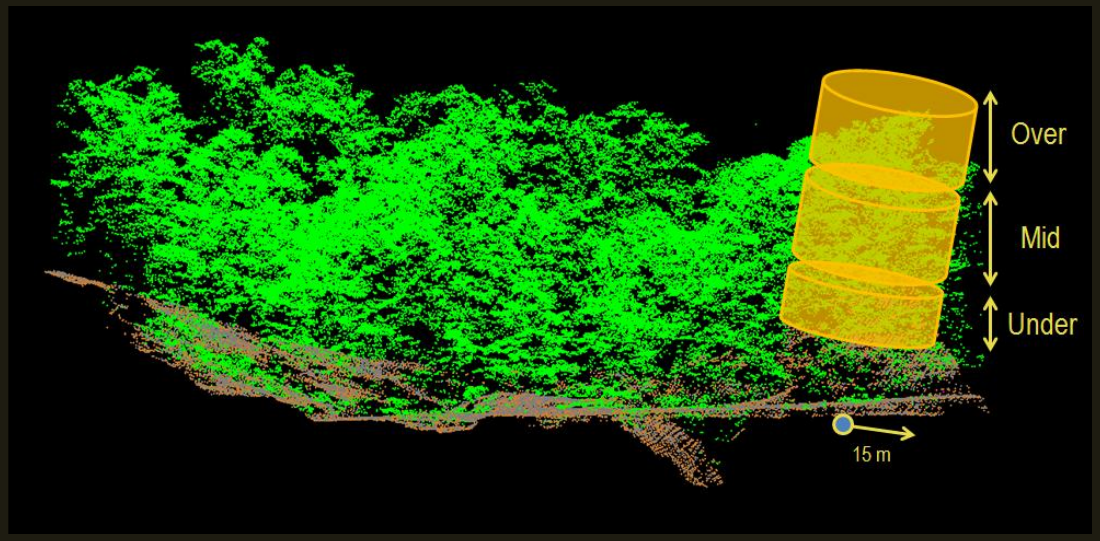
Methods

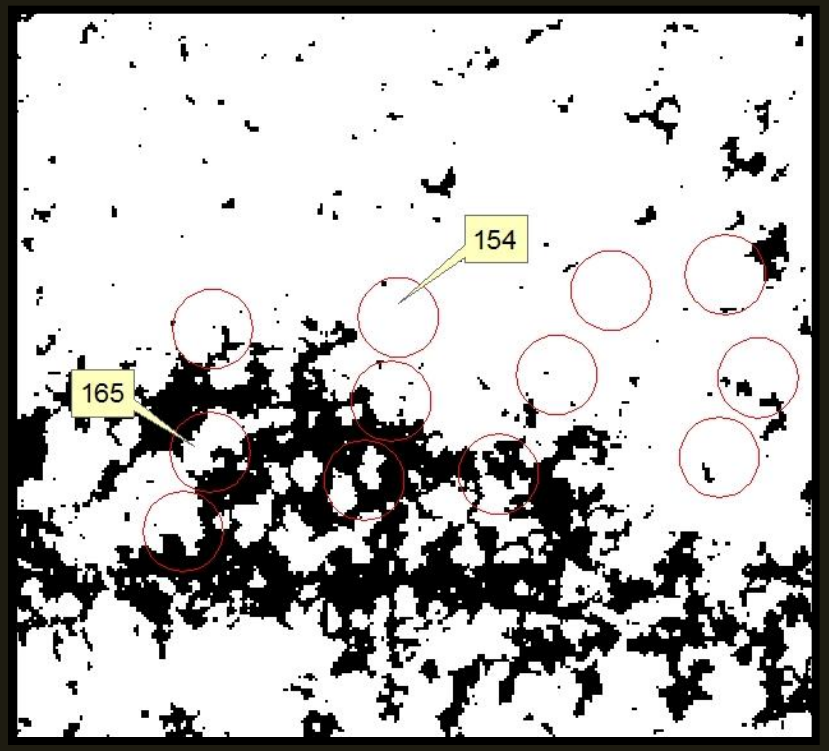
LiDAR Variables



- Strata (absolute & relative)
  - Over-, mid-, & understory
- Determining canopy shape
  - Mid:Over, Under:Mid, & Under:Over

Methods

LiDAR Variables



- Strata (absolute & relative)
  - Over-, mid-, & understory
- Determining canopy shape
  - Mid:Over, Under:Mid, & Under:Over
- Gap Index
  - Percentage of pixels with no laser returns >3 m height

Analysis & Results

- ANOVAs for site, temporal, & fire effects

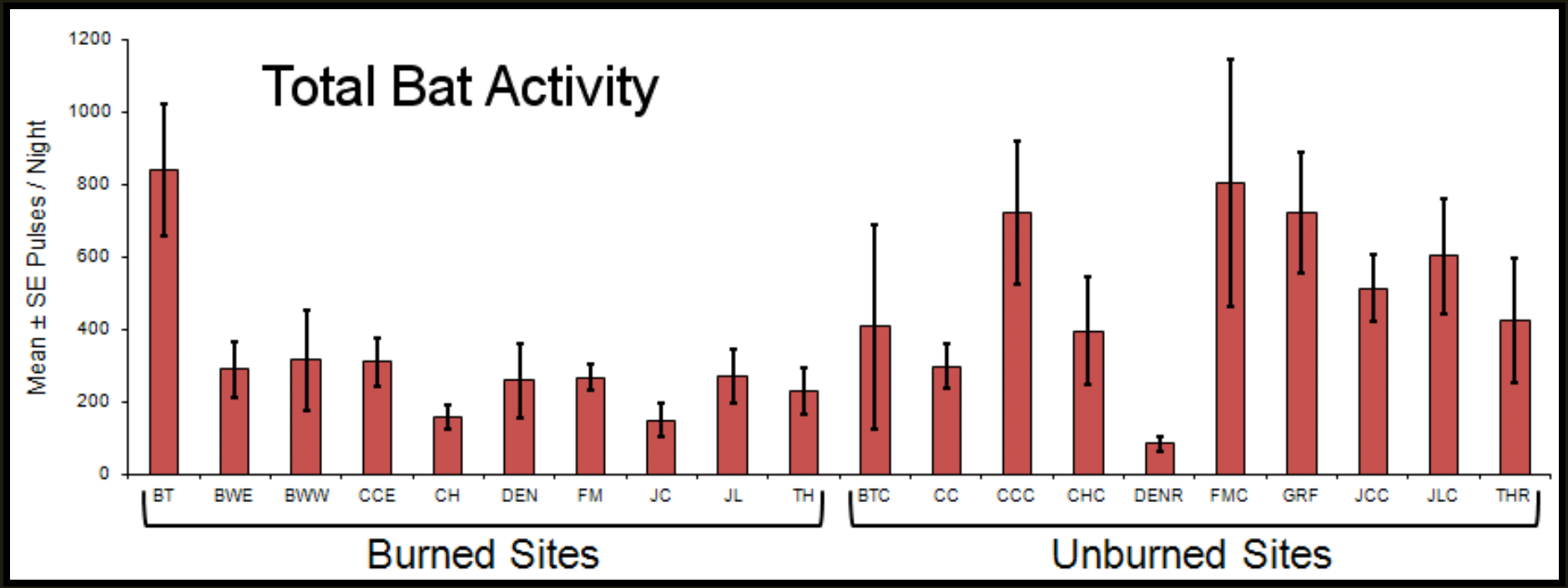
Analysis & Results

- ANOVAs for site, temporal, & fire effects
- Multiple linear regressions relating activity to forest veg
  - Response variables:
    - high freq pulses - low freq pulses - feeding buzzes
  - Predictive models:
    - understory - midstory - overstory - "total" clutter
  - Model selection using Akaike's Information Criterion
  - Models in SAS 9.0, then protocol of Burnham & Anderson[1]

[1]Model Selection & Multimodal Inference, 2nd Edition

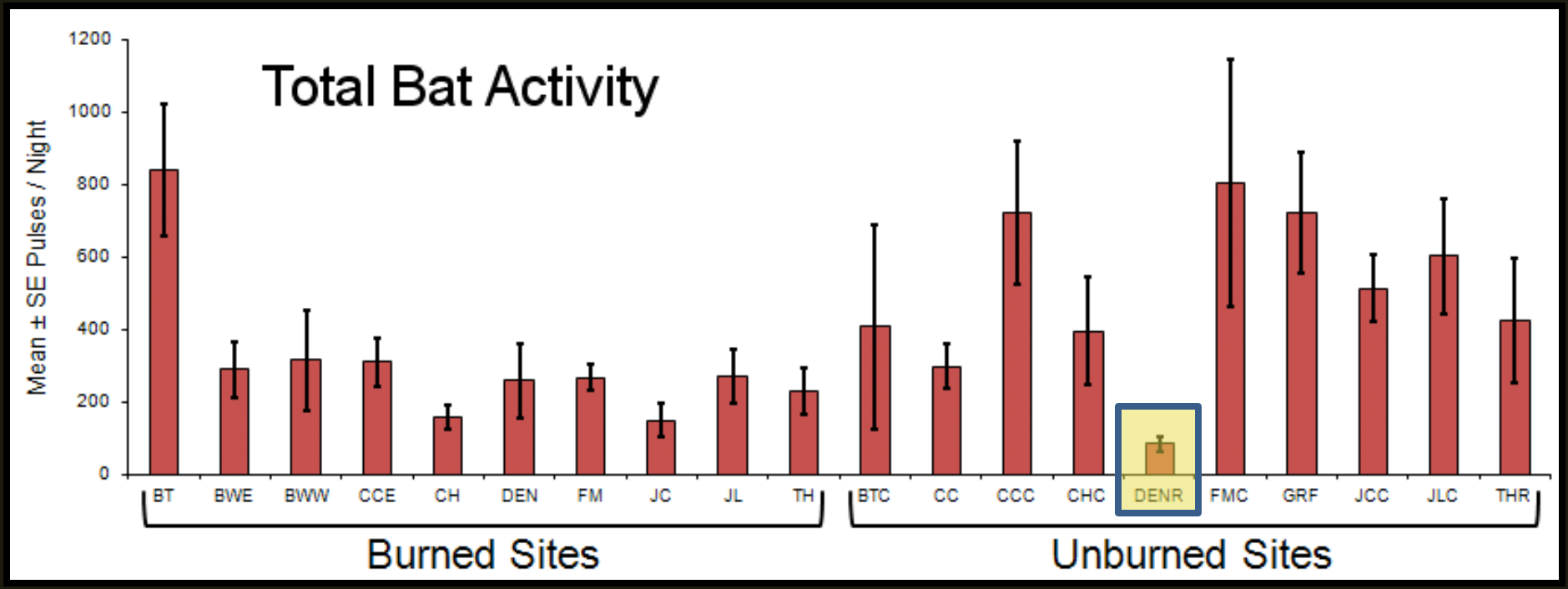
Site, Season, & Annual Effects

Site, Season, & Annual Effects



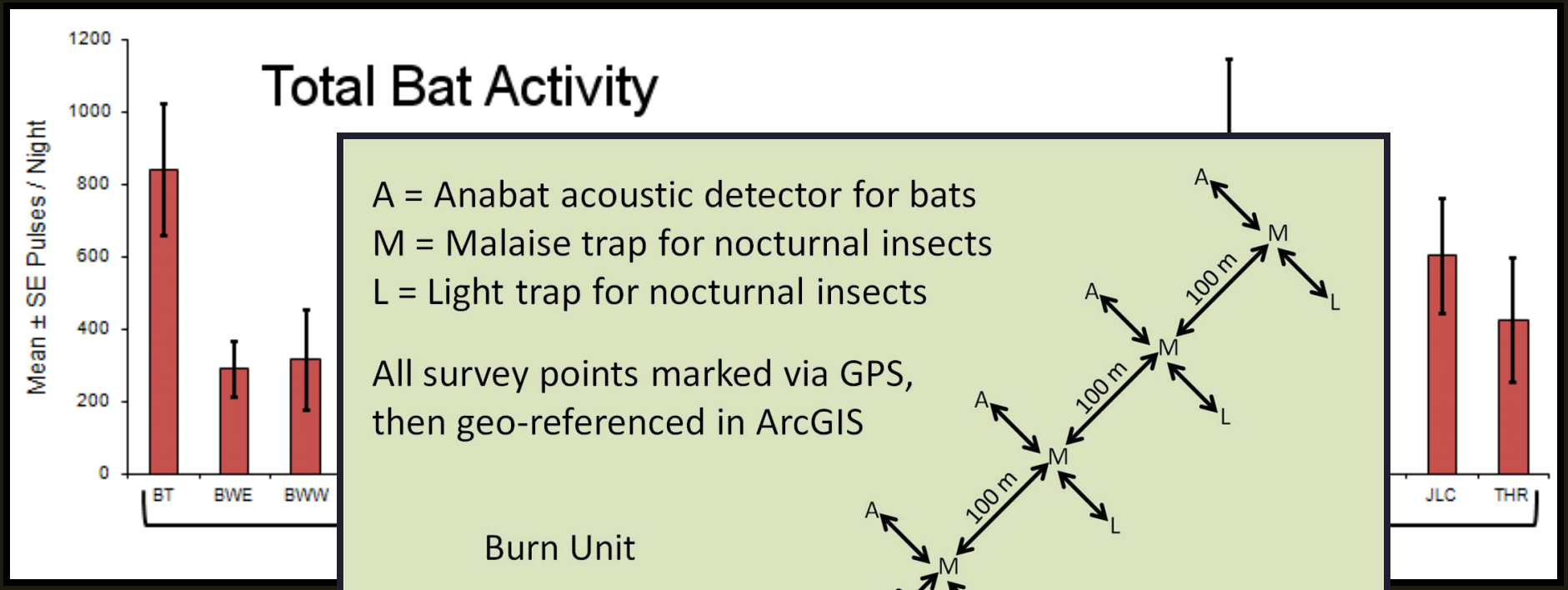
- Unsurprisingly, lots of variation across sites!

Site, Season, & Annual Effects

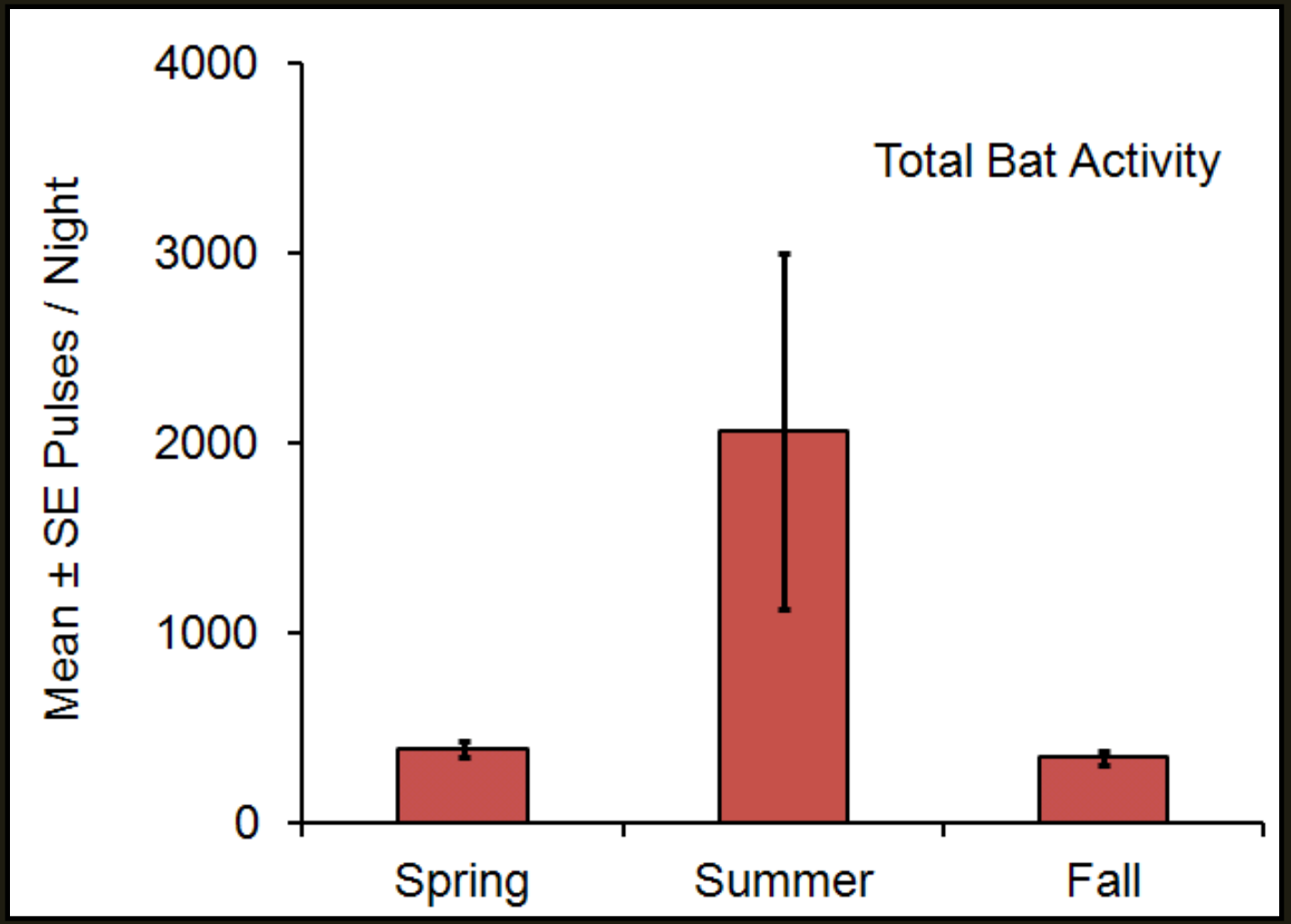


Far fewer replicates (n = 6)

Site, Season, & Annual Effects



Site, Season, & Annual Effects



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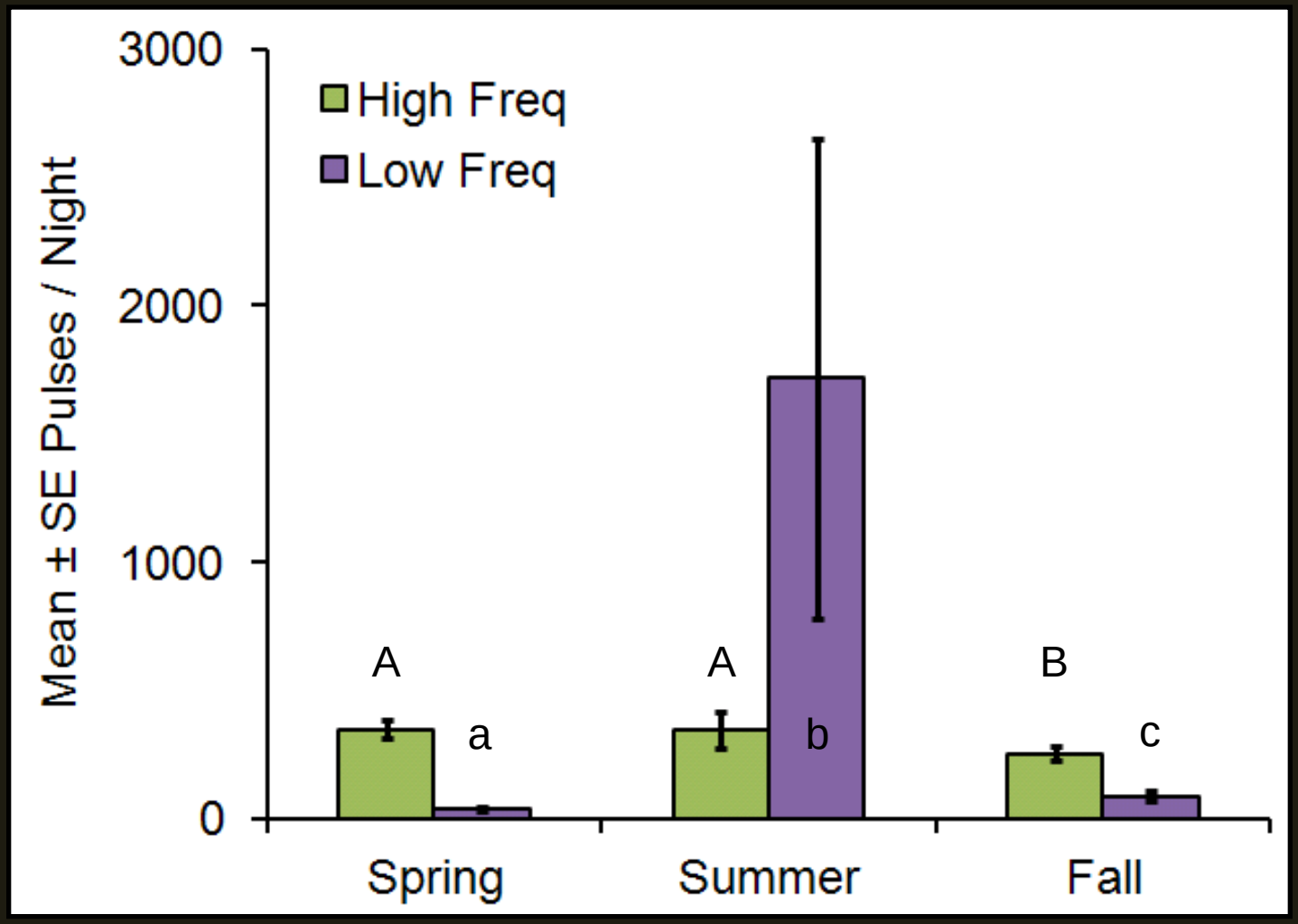


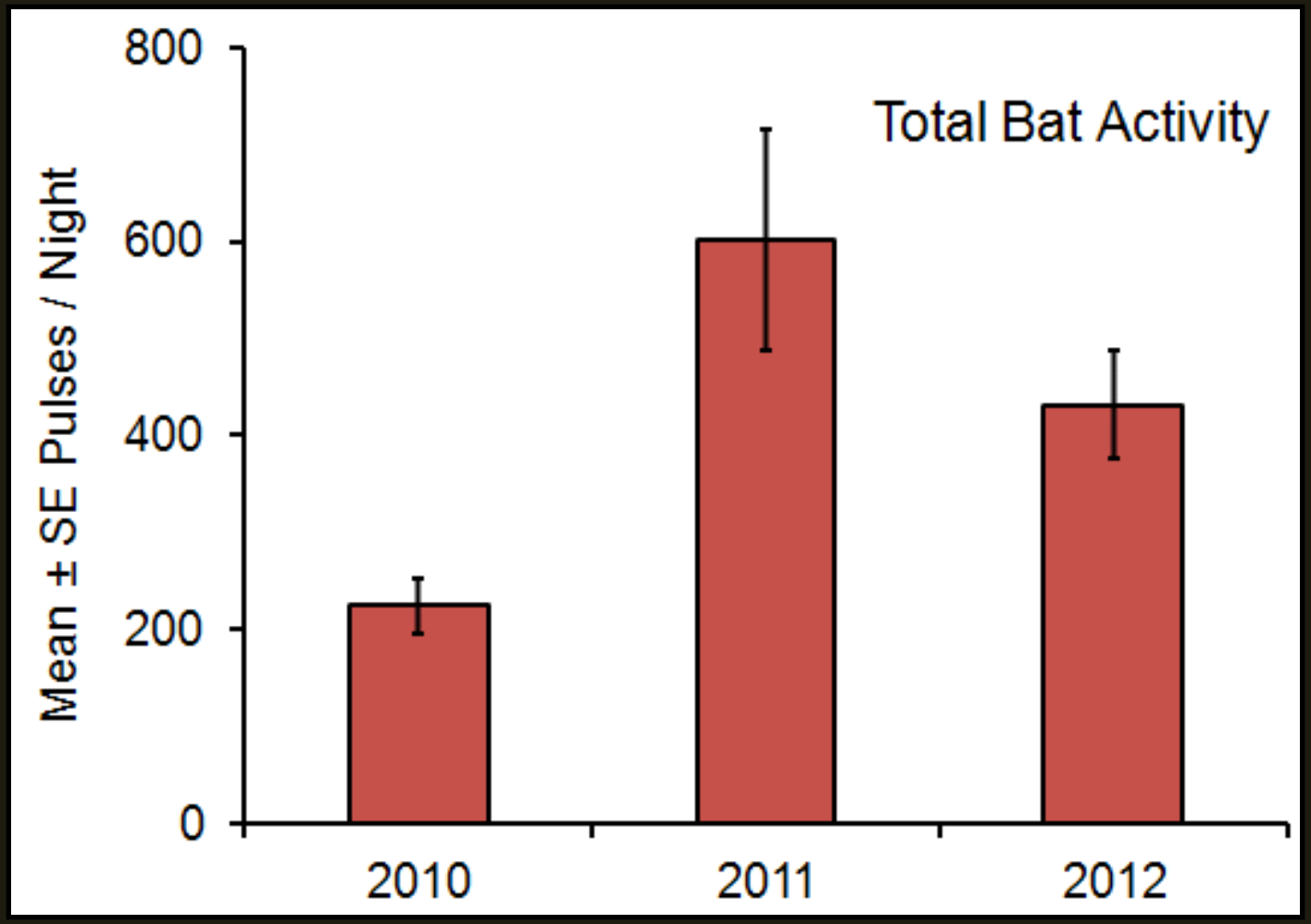
High Freq:

$F_{2,1083} = 3.6$, $P = 0.02$

Low Freq:

$F_{2,1083} = 29.2$, $P < 0.01$

Site, Season, & Annual Effects



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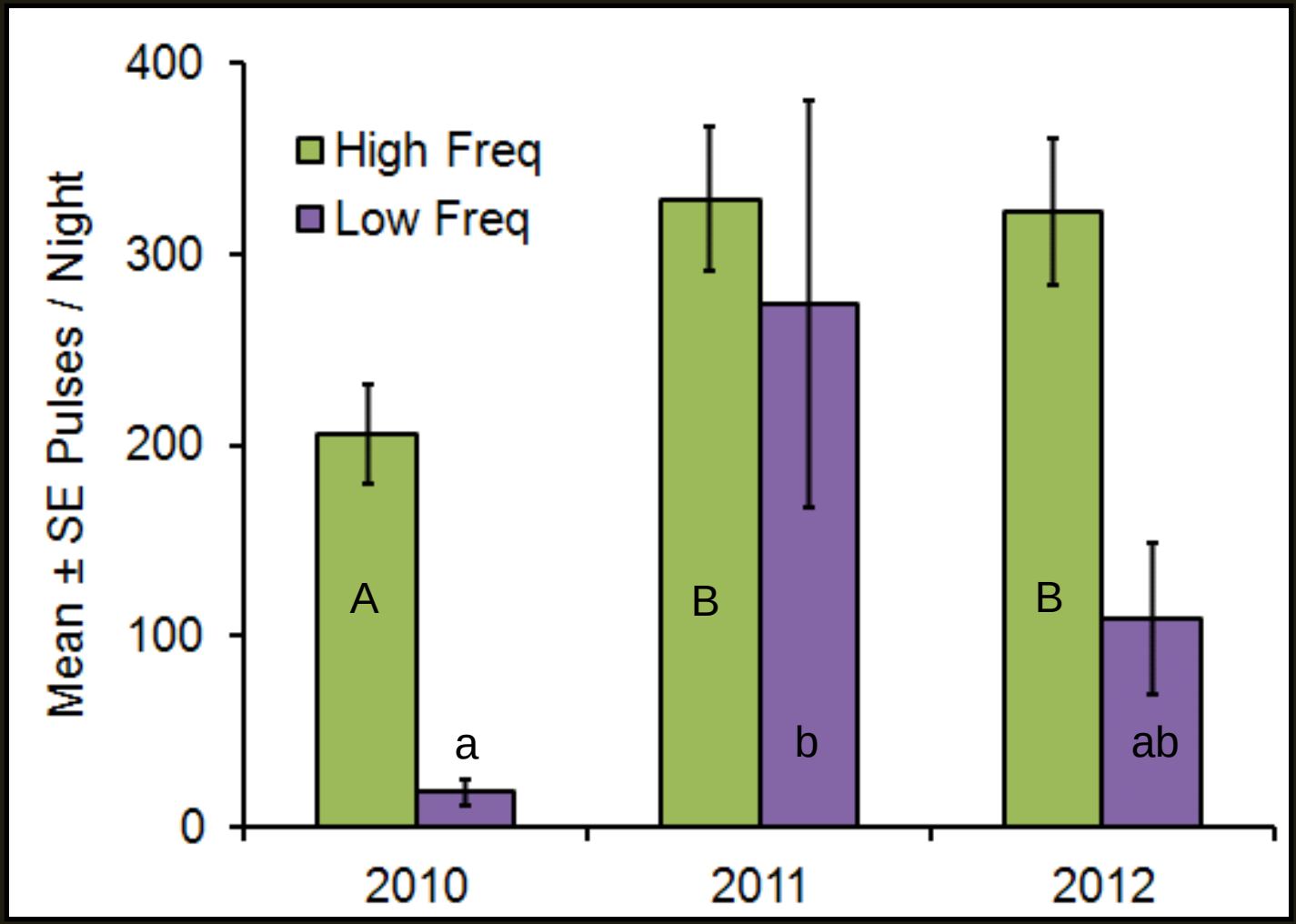


High Freq:

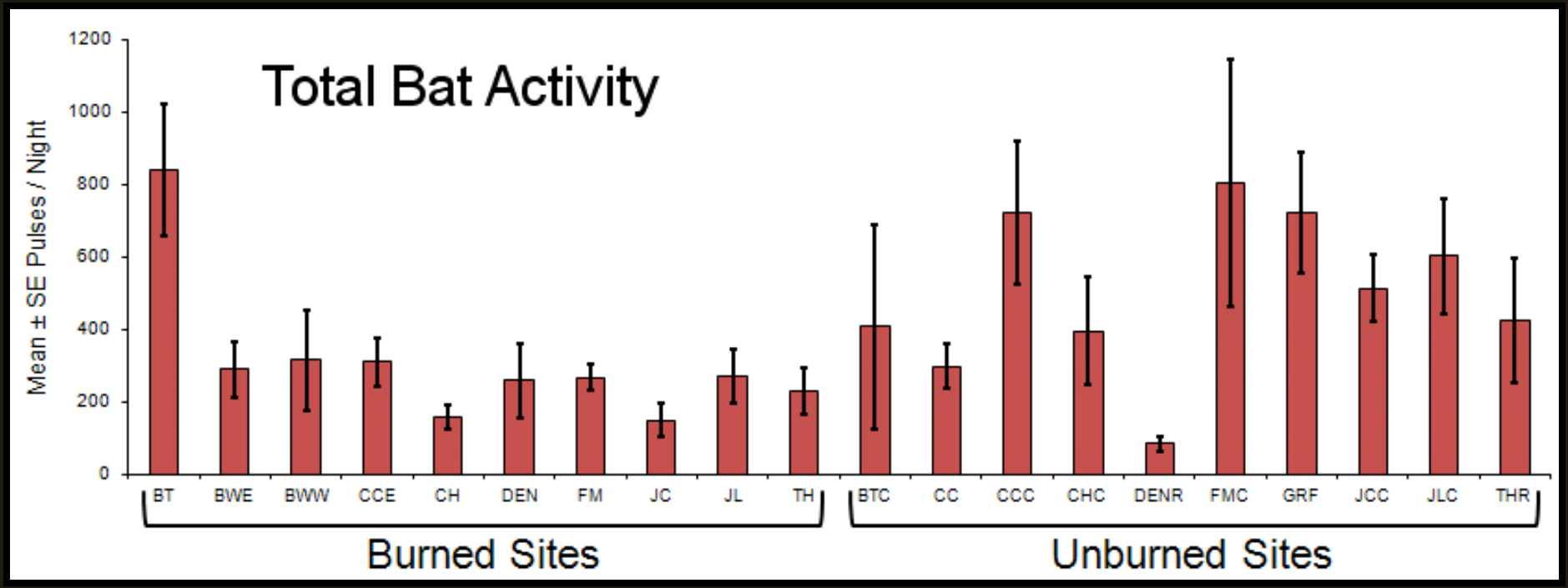
$F_{2,1083} = 4.1$, $P = 0.02$

Low Freq:

$F_{2,1083} = 3.0$, $P = 0.05$

- No apparent WNS impacts in 2012…

Site, Season, & Annual Effects



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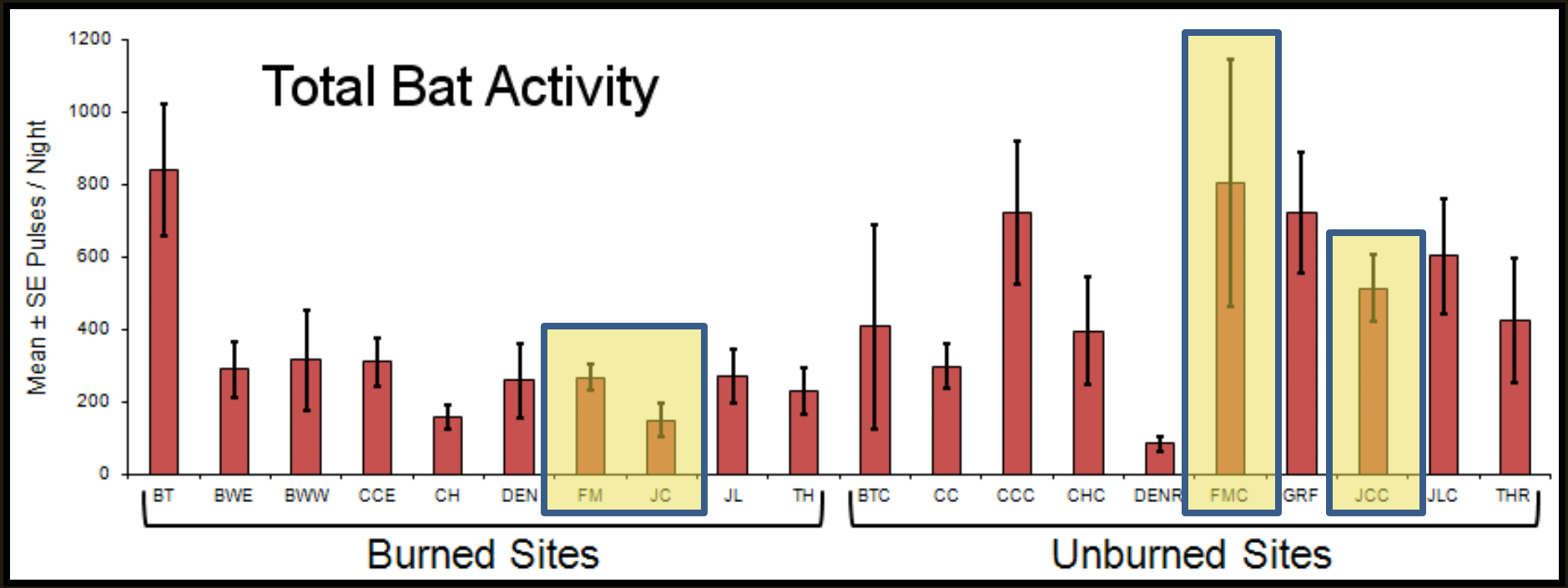
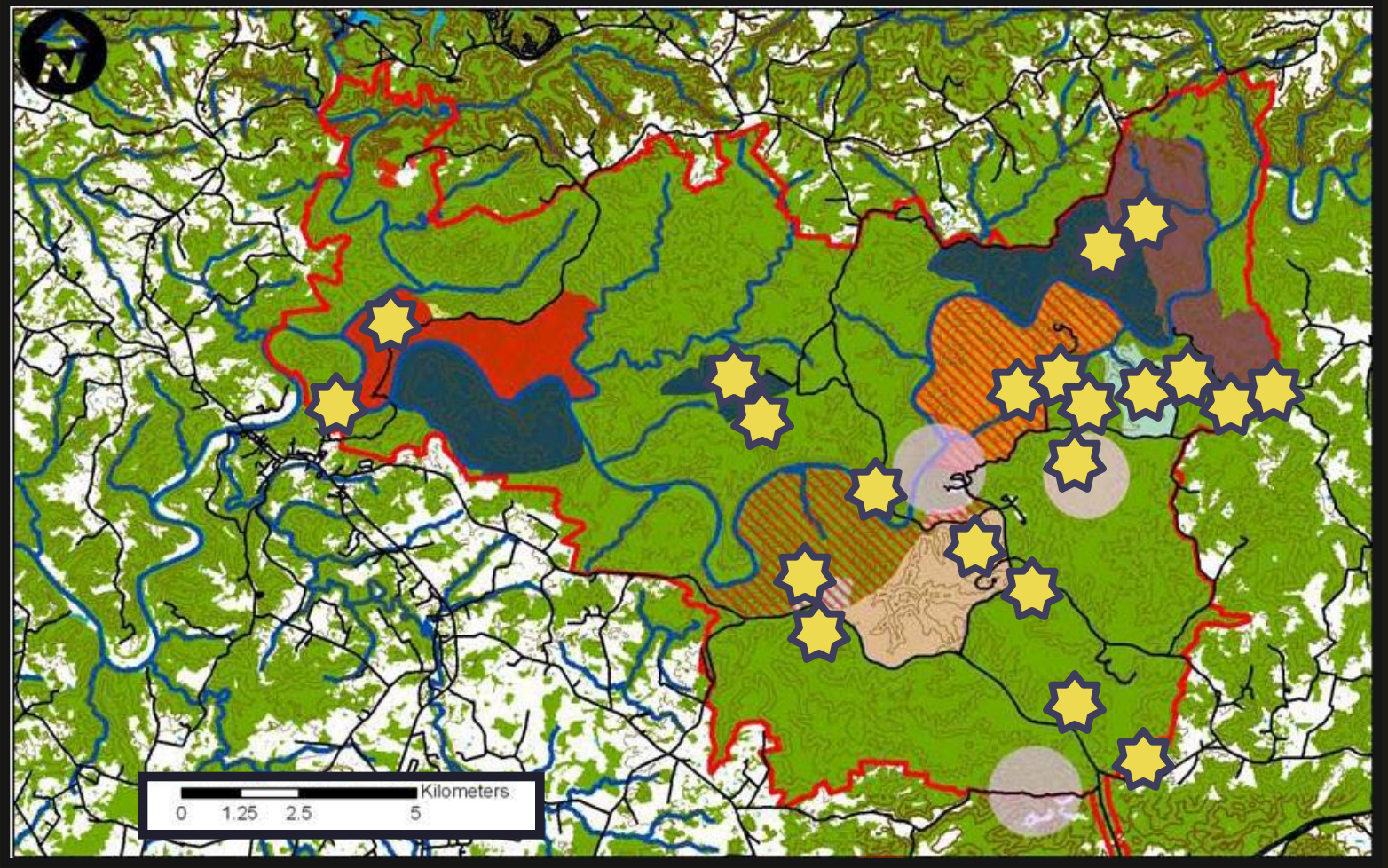


- Sites surveyed in Fall 2010

Effect of Fire

- Repeated visits have created a time-series…



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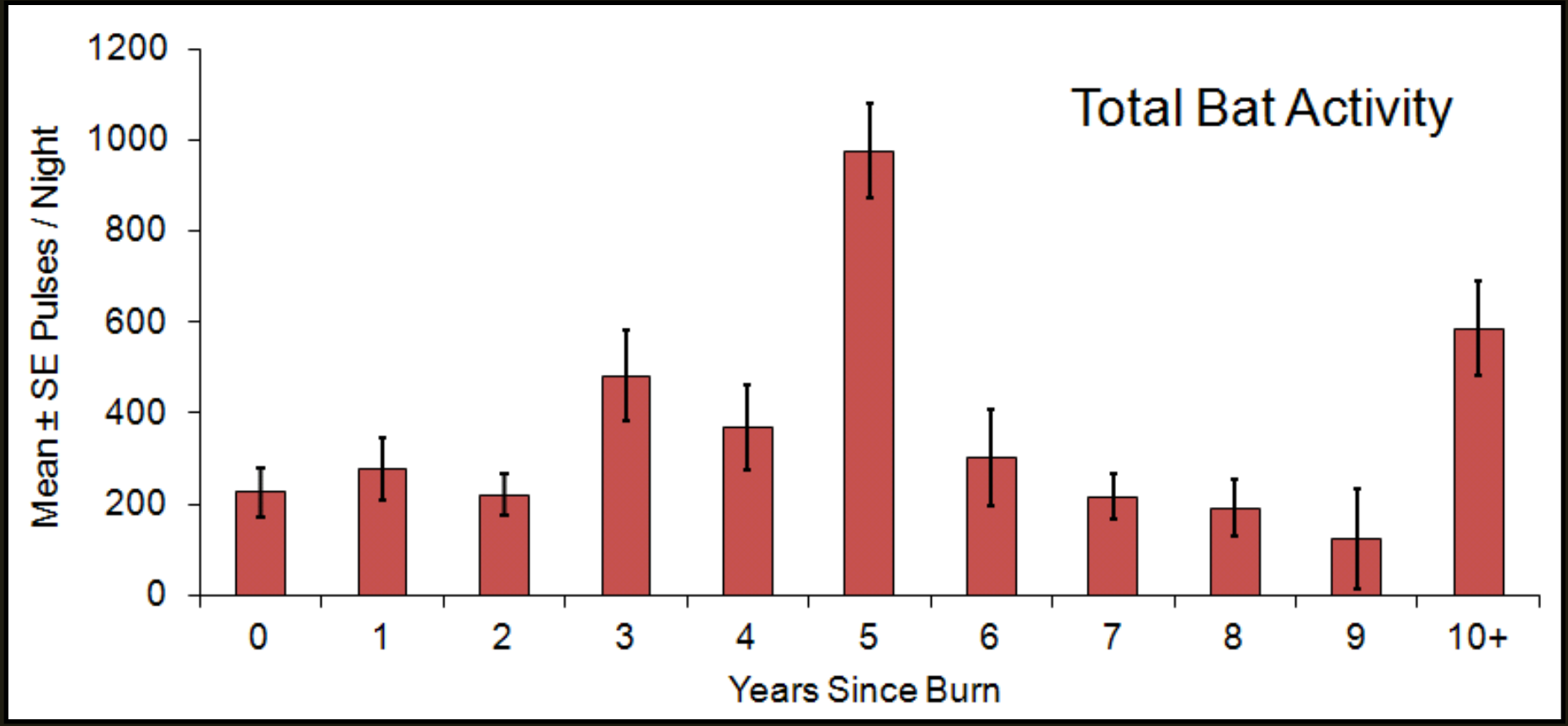
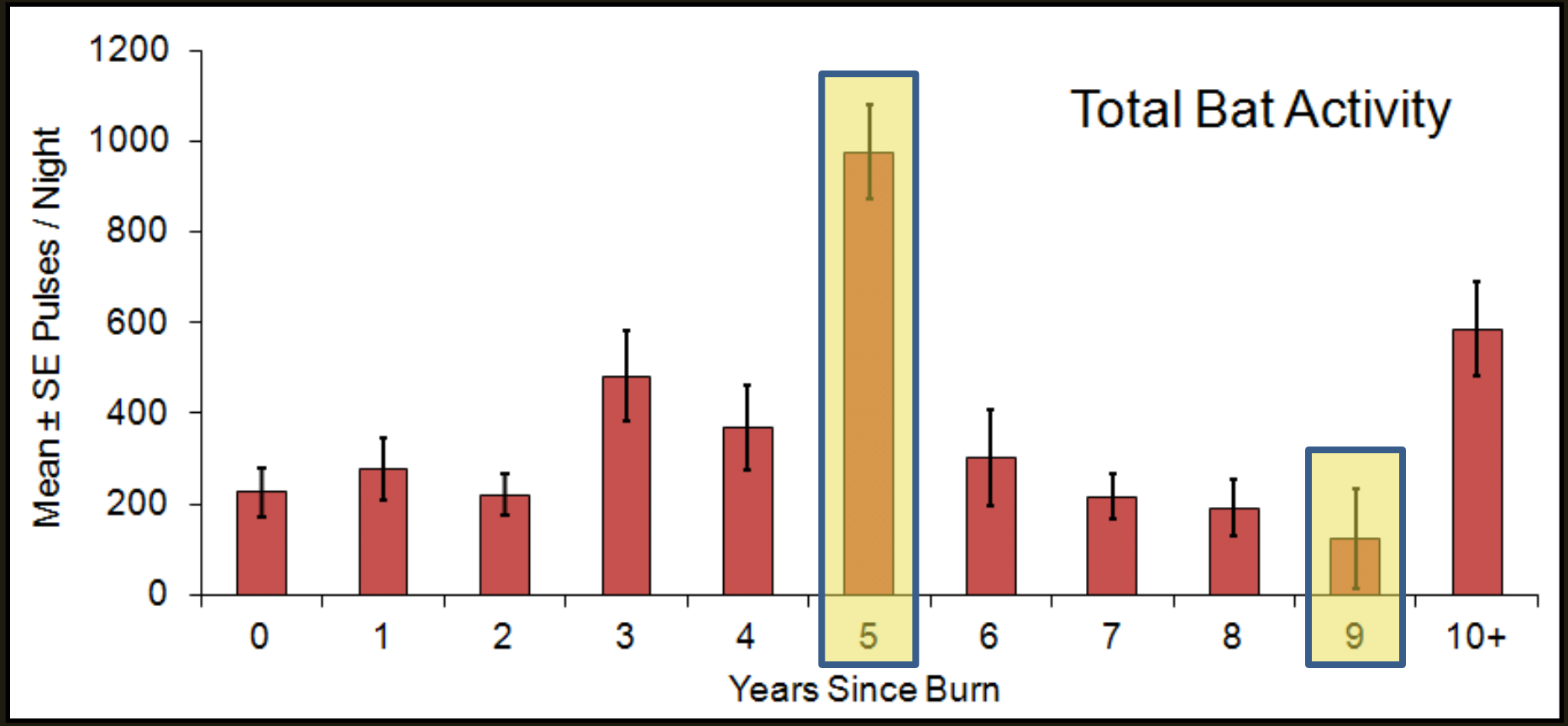


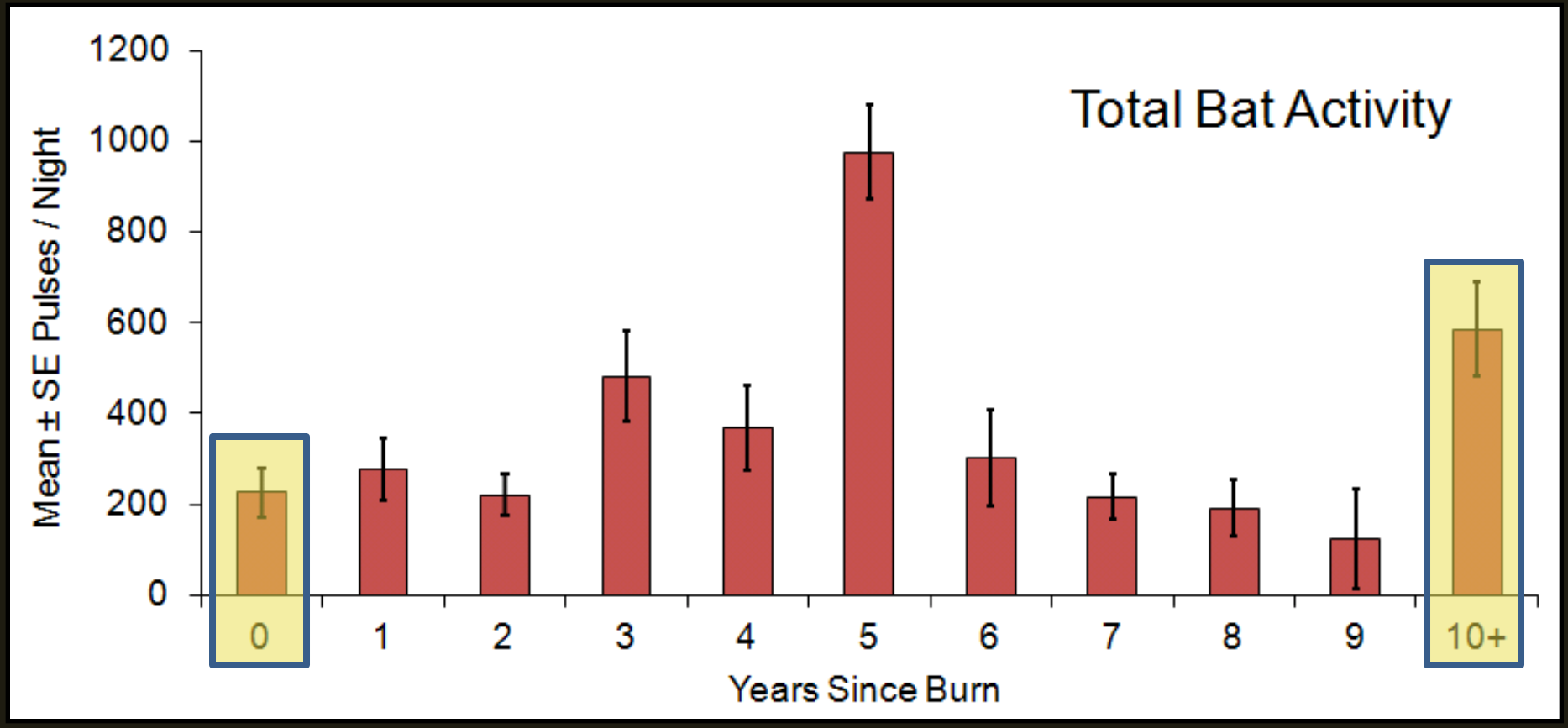
- As with sites, lots of variation across years since burn!

Effect of Fire



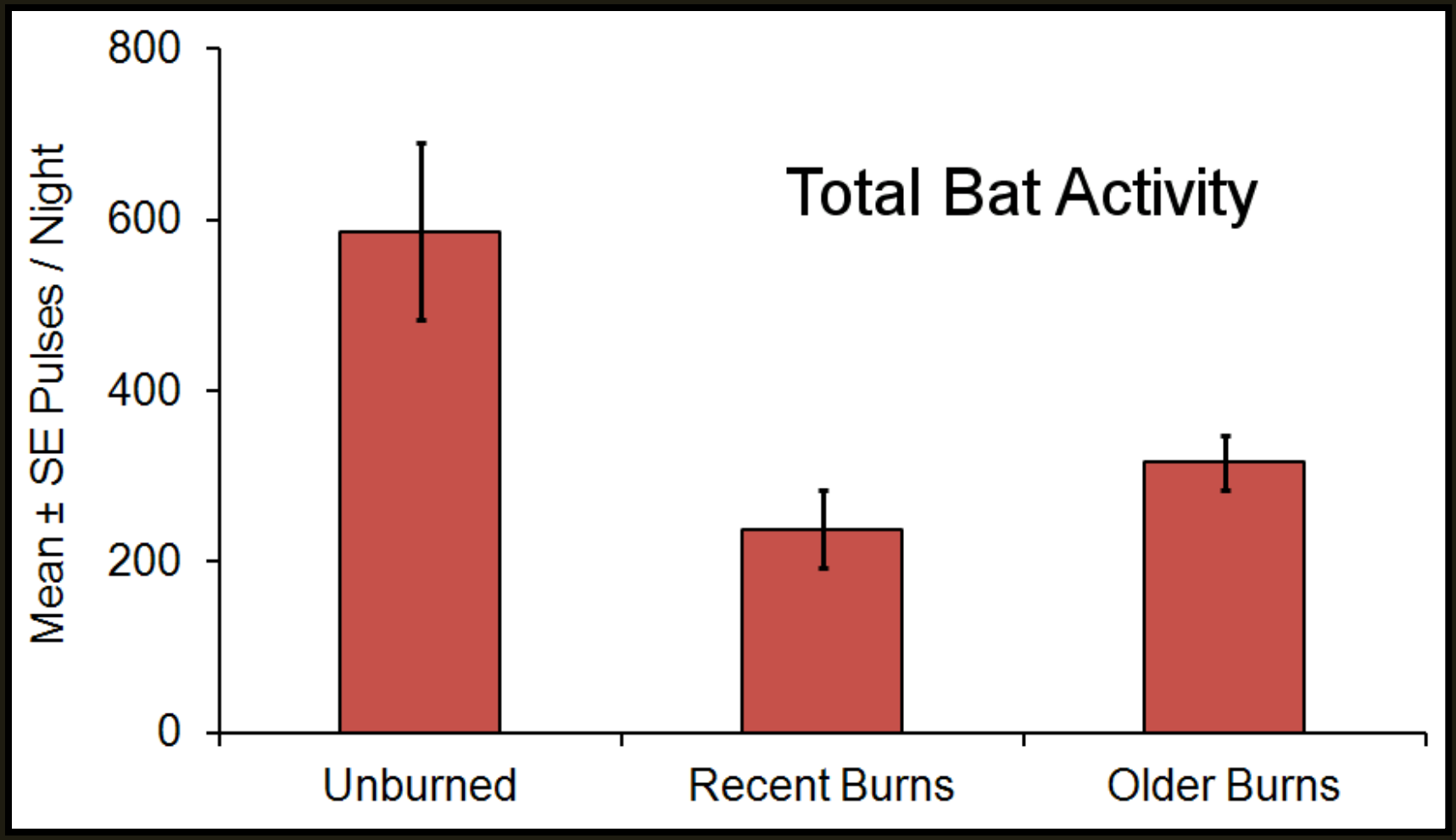
Far fewer replicates (n ~ 5)

Effect of Fire

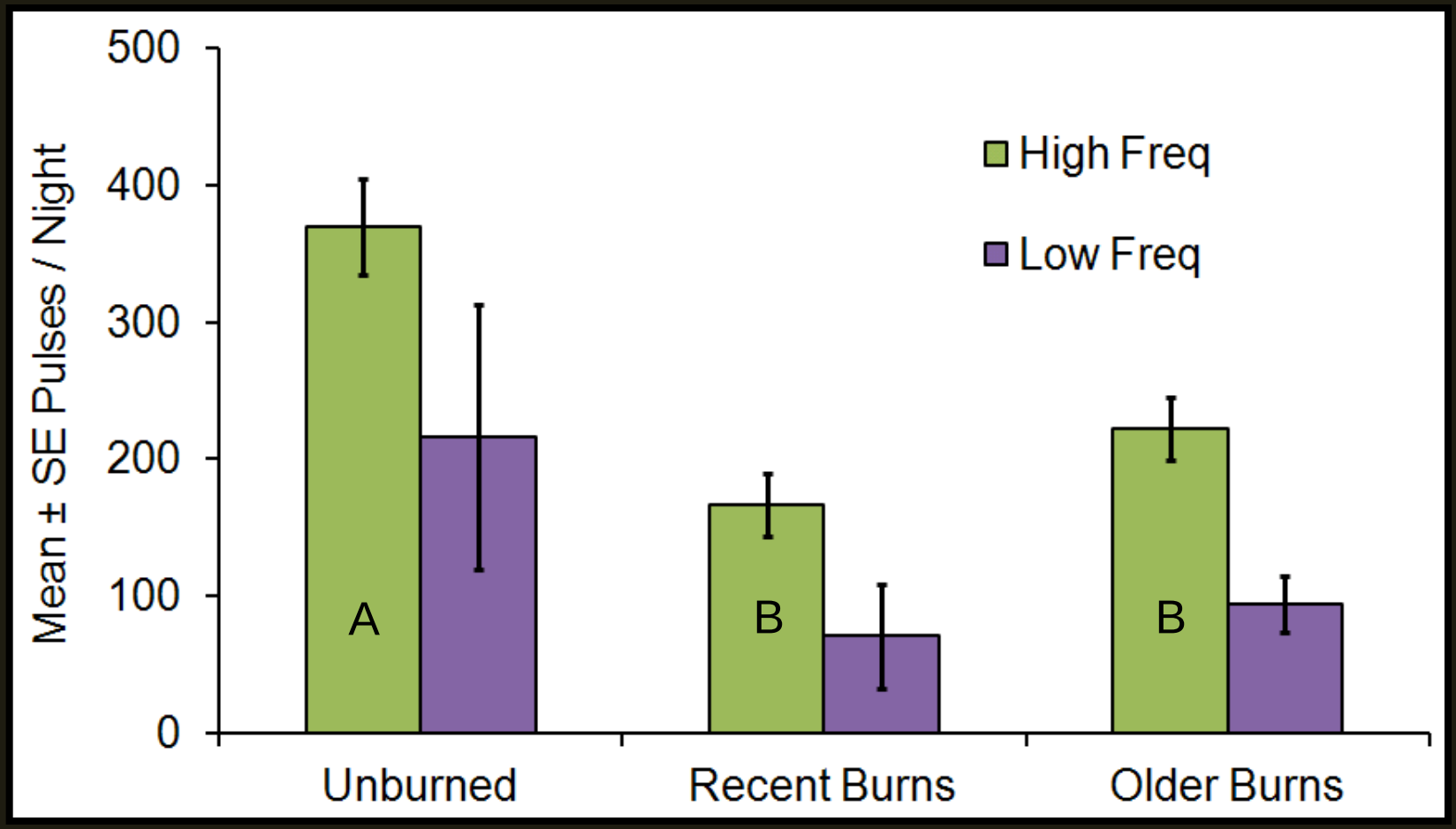


Far more replicates (n > 200 each)

Effect of Fire



Effect of Fire



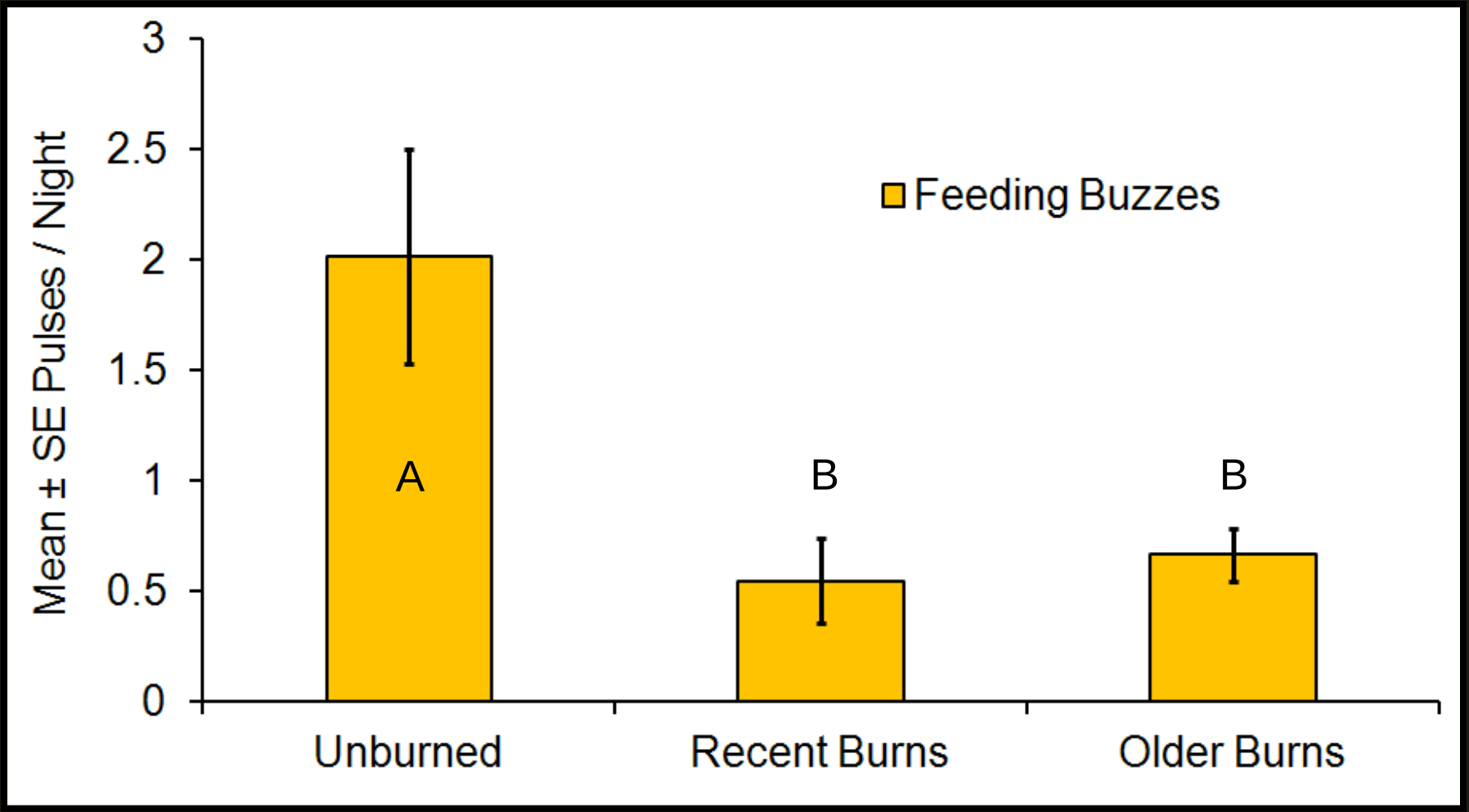
High Freq:

$F_{2,1083} = 11.1$, $P < 0.01$

Low Freq:

$F_{2,1083} = 1.0$, $P = 0.37$

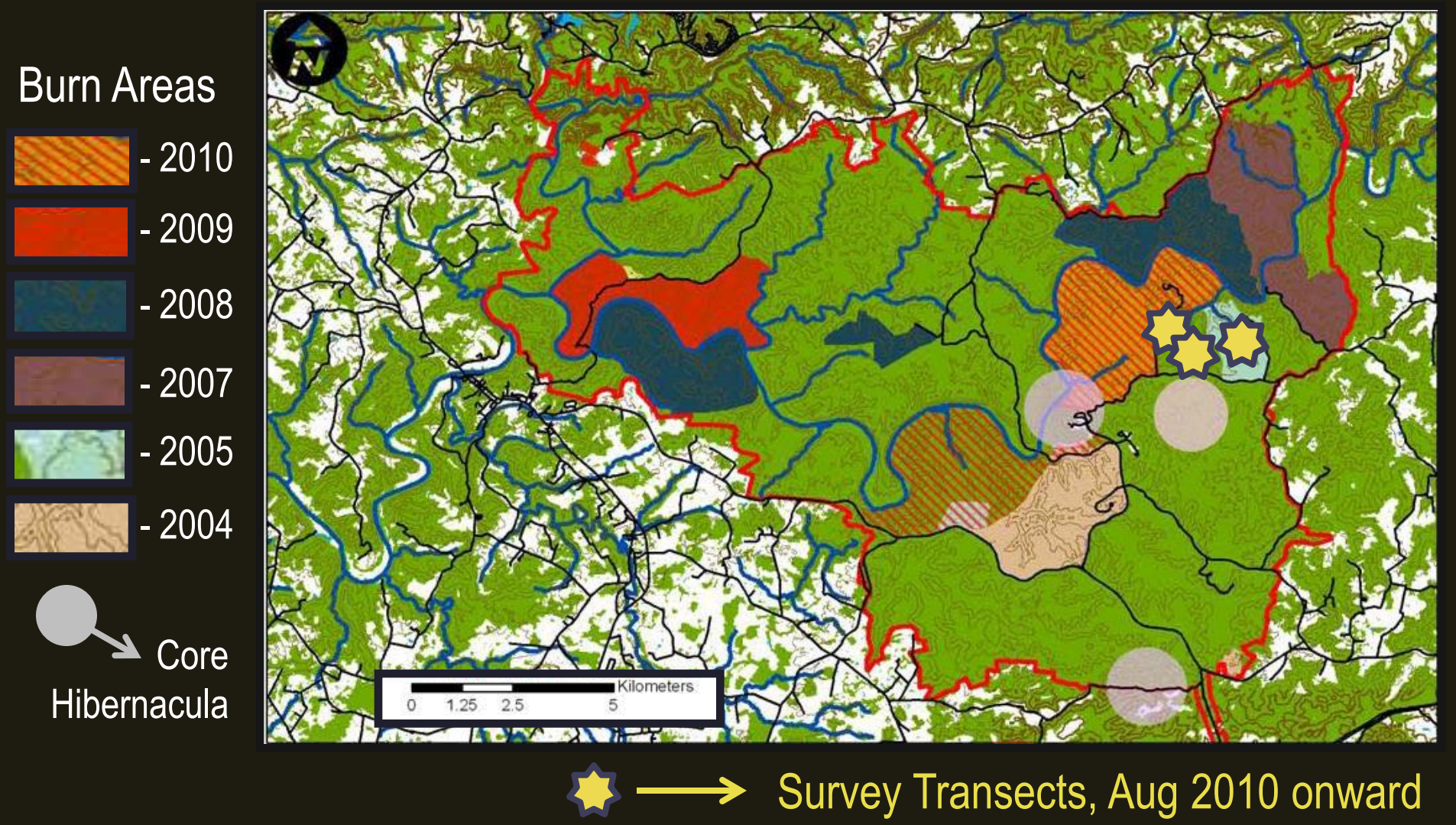
Effect of Fire



Feeding Buzzes

$F_{2,1083} = 11.1$, $P < 0.01$

Effect of Fire



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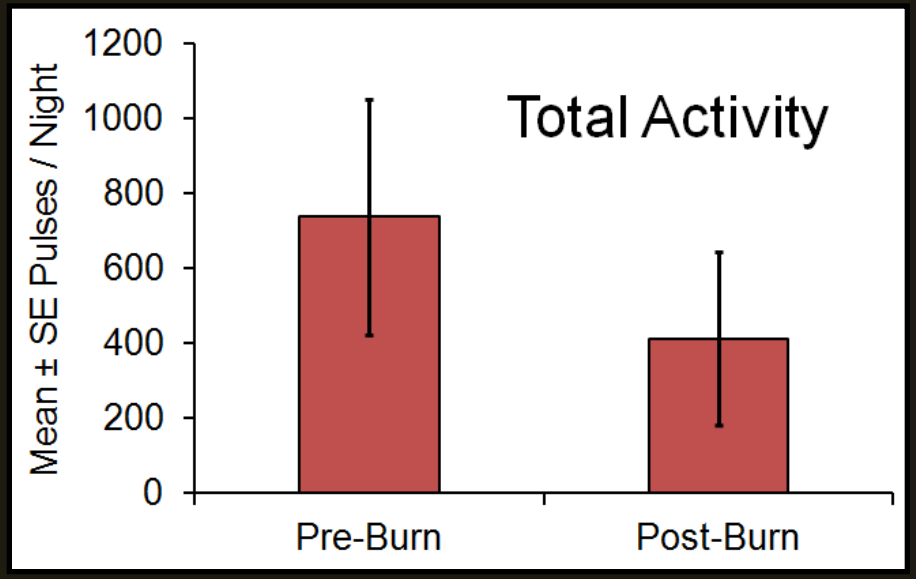
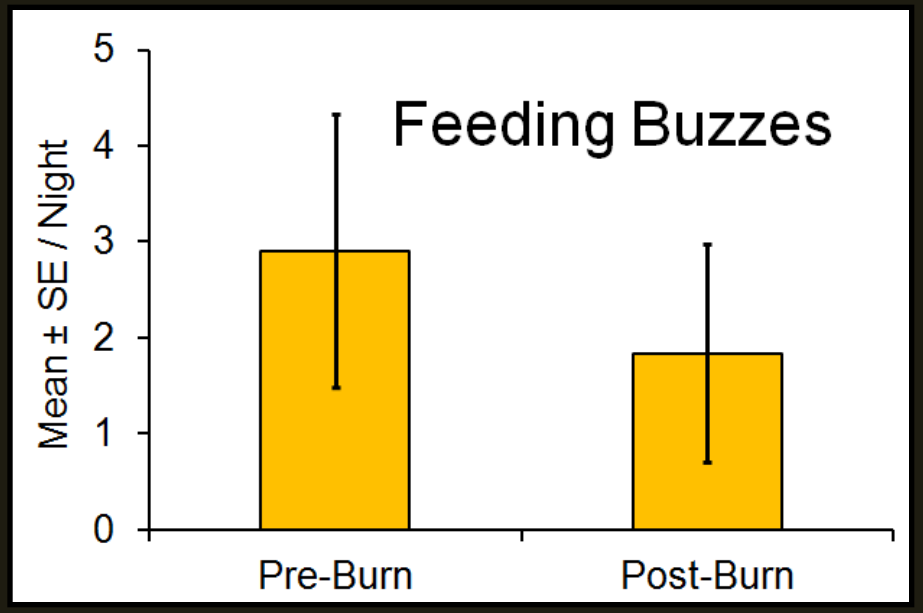
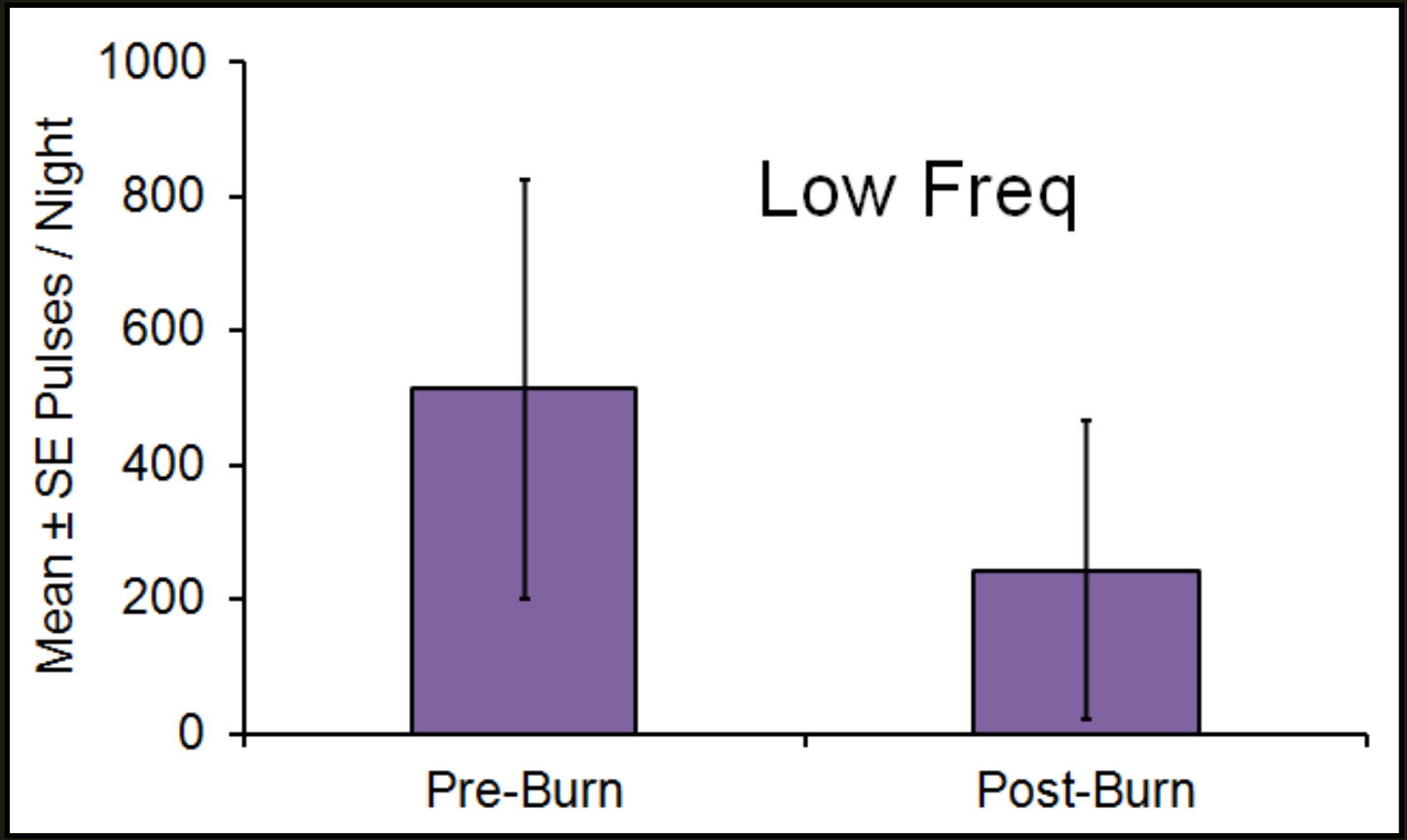




Analyses pending

Effect of Fire



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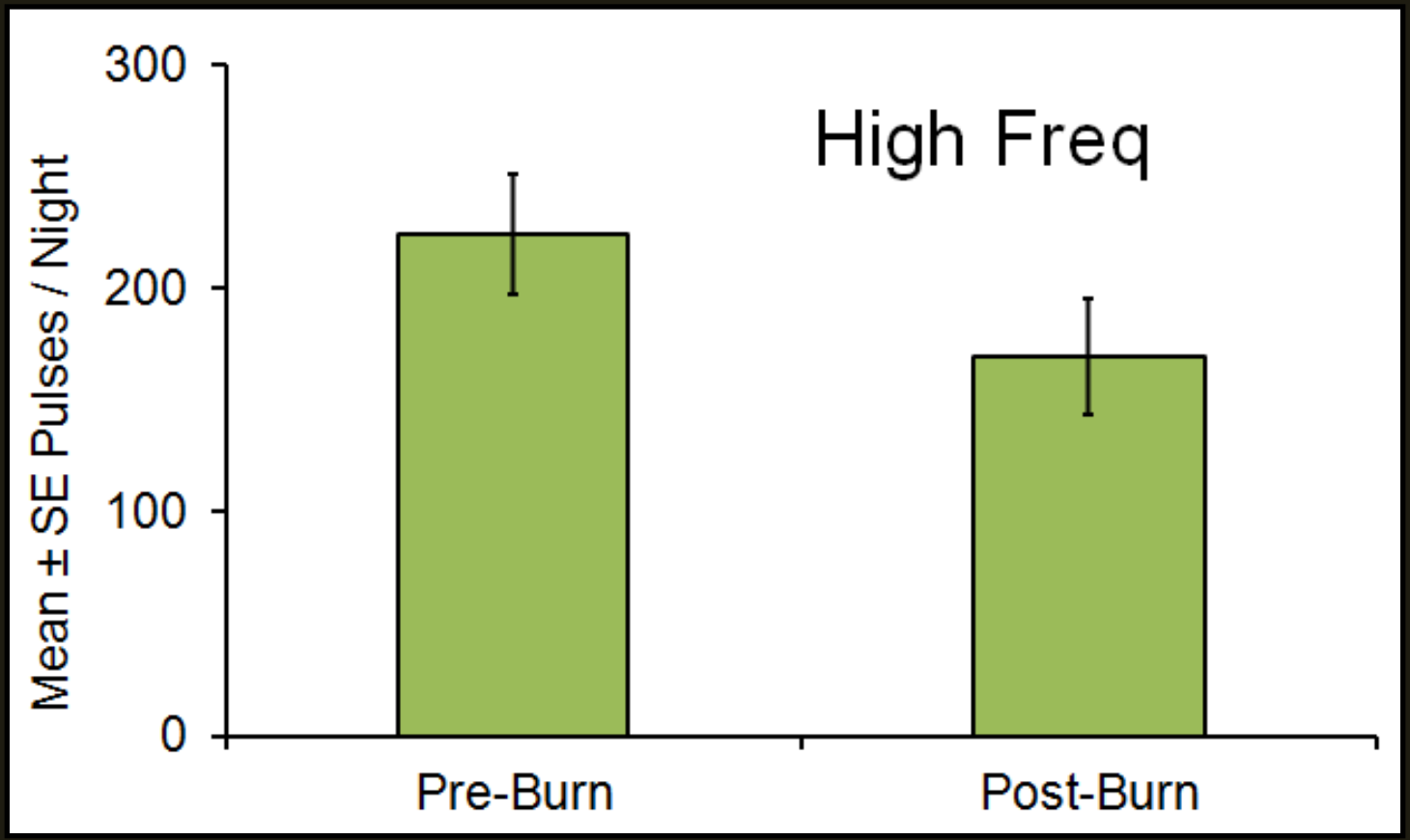

Analyses pending

Effect of Fire

Relation to Canopy Clutter

- Data within first year of burning (2010-2011)

Table 1. Akaike's Information Criterion scores (AIC), difference in AIC values (ΔAIC), Akaike weights (w_i), and number of parameters (K) for linear regression models of bat activity by LiDAR-derived descriptors of vegetation throughout the forest canopy at Mammoth Cave National Park, USA, from 2010-2011. Models with an asterisk were significant ($P \leq 0.05$).

Response Variable	Model	AIC	ΔAIC	w_i	K
High-Frequency Pulses (n = 846)	Understory*	11108.21	0	0.65	6
	Total Clutter	11110.81	2.6	0.18	5
	Midstory	11111.10	2.9	0.15	6
	Overstory	11115.04	6.8	0.02	5
Low-Frequency Pulses (n = 846)	Understory*	12626.19	0	0.38	6
	Overstory*	12626.45	0.3	0.33	5
	Total Clutter*	12626.79	0.6	0.28	5
	Midstory	12632.50	6.3	0.02	6
Feeding Pulses (n = 846)	Understory*	3614.88	0	0.61	6
	Total Clutter*	3617.13	2.2	0.20	5
	Overstory*	3617.25	2.4	0.19	5
	Midstory	3624.11	9.2	0.01	6

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Table 1. Akaike's Information Criterion scores (AIC), difference in AIC values (ΔAIC), Akaike weights (w_i), and number of parameters (K) for linear regression models of bat activity by LiDAR-derived descriptors of vegetation throughout the forest canopy at Mammoth Cave National Park, USA, from 2010-2011. Models with an asterisk were significant ($P \leq 0.05$).

Response Variable	Model	AIC	ΔAIC	w_i	K
Low-Frequency Pulses (n = 846)	Understory*	12626.19	0	0.38	6
	Overstory*	12626.45	0.3	0.33	5
	Total Clutter*	12626.79	0.6	0.28	5
	Midstory	12632.50	6.3	0.02	6
Feeding Pulses (n = 846)	Understory*	3614.88	0	0.61	6
	Total Clutter*	3617.13	2.2	0.20	5
	Overstory*	3617.25	2.4	0.19	5
	Midstory	3624.11	9.2	0.01	6

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Table 2. Parameter estimates (β) and standard errors (SE) for LiDAR-derived descriptors of the forest canopy used for models of bat activity at Mammoth Cave National Park, USA, from 2010-2011. Parameter estimates with an asterisk were significant ($P \leq 0.05$).

Model	LiDAR Descriptor	Parameter Estimate (β) ± SE		
		High-Frequency Pulses	Low-Frequency Pulses	Feeding Pulses
Total Clutter	Total Returns	-61.04 ± 36.57	-91.1 ± 89.58	-0.27 ± 0.44
	Gap Index	-70.07 ± 278.45	978.87 ± 682.14	5.81 ± 3.32
	Canopy Height	6.18 ± 5.79	16.7 ± 14.19	0.09 ± 0.07
Overstory	Returns at 20-30 m	-20.91 ± 63.19	123.67 ± 154.38	0.39 ± 0.75
	Returns at 30-42 m	198.04 ± 291.17	-350.99 ± 711.34	-1.21 ± 3.46
	Percent Returns in Overstory	-12.66 ± 79.02	-520.32 ± 193.05*	-2.34 ± 0.94*
Midstory	Returns at 10-20 m	83.93 ± 60.6	-117.86 ± 148.94	-0.34 ± 0.73
	Percent Returns in Midstory	-176.27 ± 82.39	-145.15 ± 202.48	-0.76 ± 0.99
	Returns in Understory : Returns in Midstory	-20.43 ± 12.07	-3.04 ± 29.67	-0.01 ± 0.14
	Returns in Midstory : Returns in Overstory	27.94 ± 25.91	-13.51 ± 63.68	0.04 ± 0.31
Understory	Returns at 0-10 m	-170.96 ± 78.95*	-548.51 ± 193.64*	-2.75 ± 0.94*
	Total Returns : Returns at 0-10 m	108.04 ± 239.2	1690.27 ± 586.66*	8.9 ± 2.85*
	Percent Returns in Understory	31.51 ± 123.4	287.59 ± 302.65	1.38 ± 1.47
	Returns in Understory : Returns in Overstory	-9.02 ± 12.56	-53.44 ± 30.8	-0.28 ± 0.15

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- High frequency echolocators negatively associated a cluttered understory

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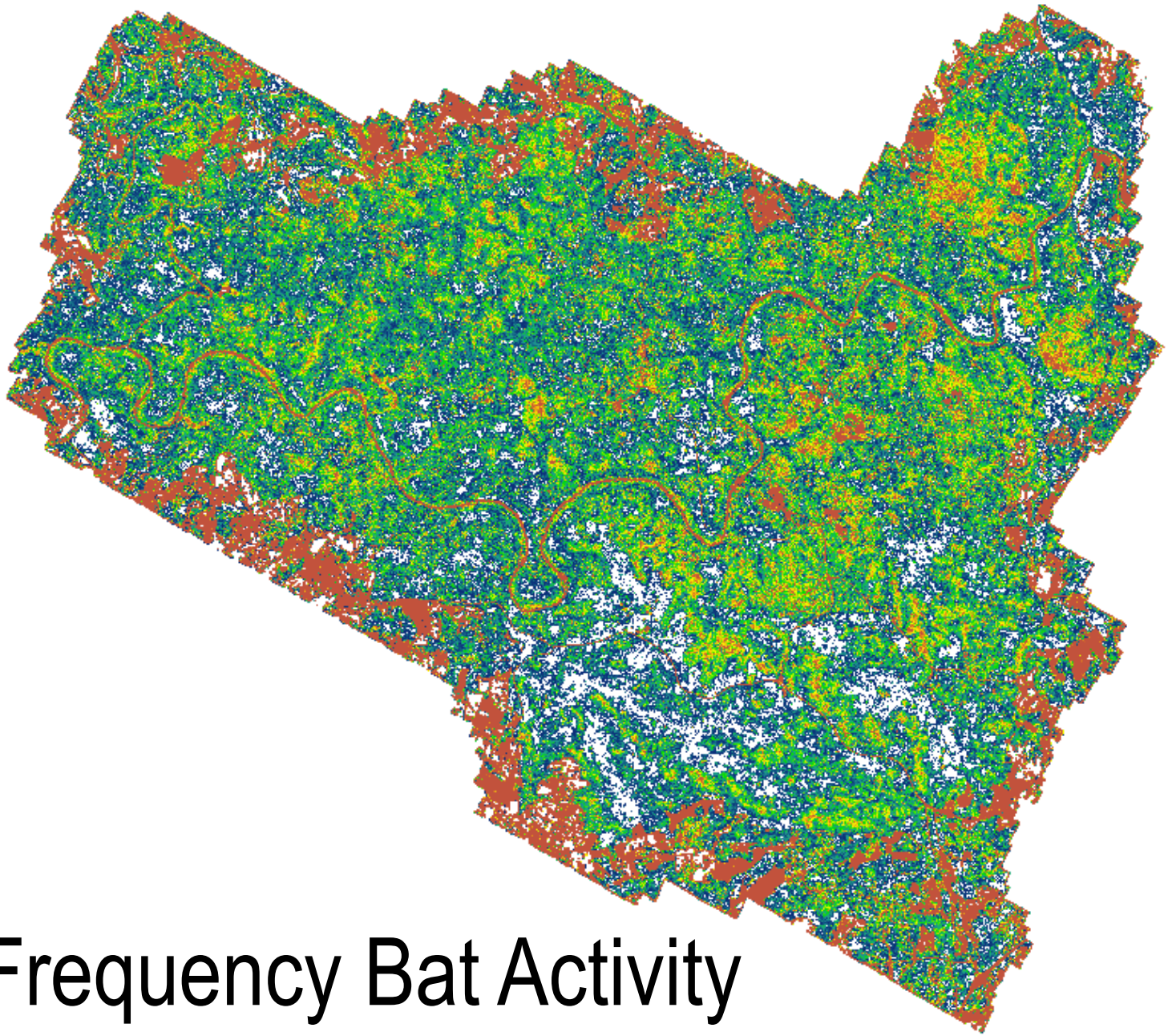
- Feeding buzzes negatively associated with a cluttered understory & overstory; positively associated with canopy gaps



Low Frequency Bat Activity

Predictive Map – Total Clutter

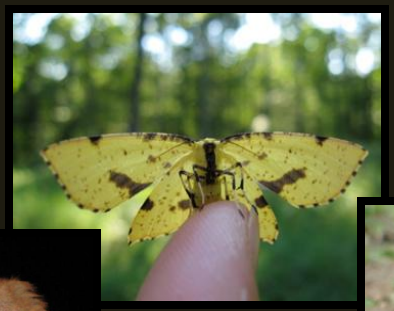
Discussion & Implications

- Activity lower at burned sites, but models suggest activity is also positively related to less-cluttered canopy conditions…

- High frequency & low frequency echolocators both respond to differences in clutter… And are relatable to management!

- How does this relate to longer-term fire management plans?





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