What We Know About the Efficacy of Curtailment After a Decade of Research and Why it Matters.

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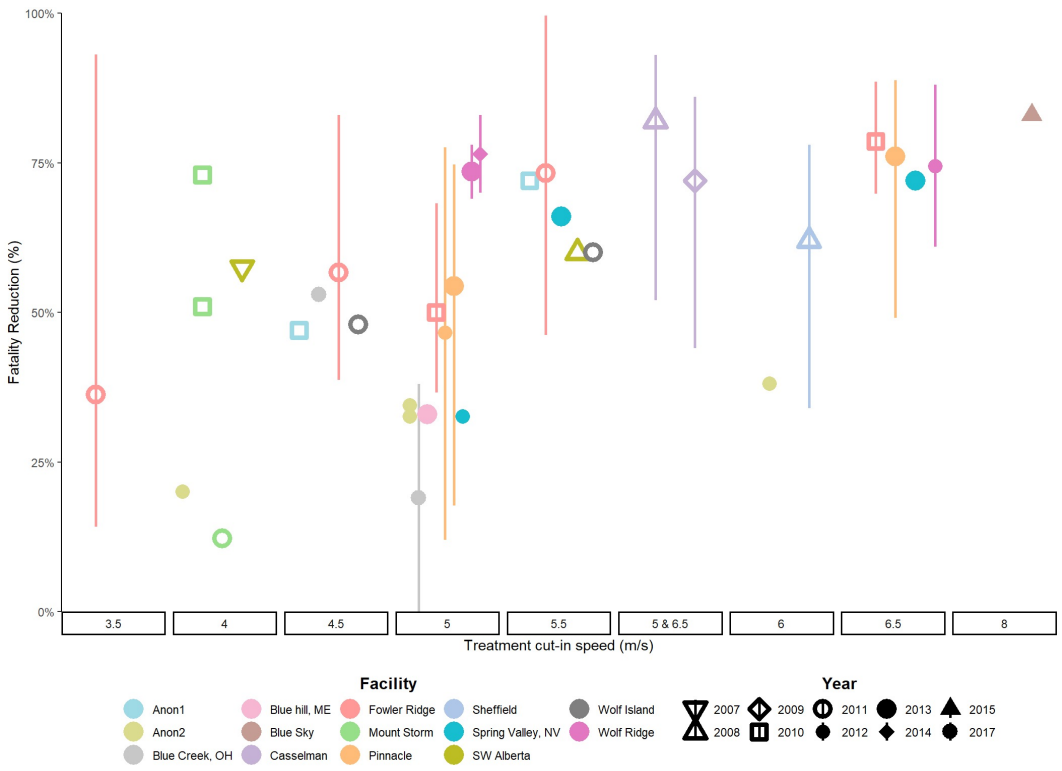
Over a Decade of Research!

- Concerned about bat fatalities since 2004
- Curtailment as a research priority since 2008
    - First studies in 2008 (CA & US)

- Summarized in 2013 ~50% reduction with curtailment.

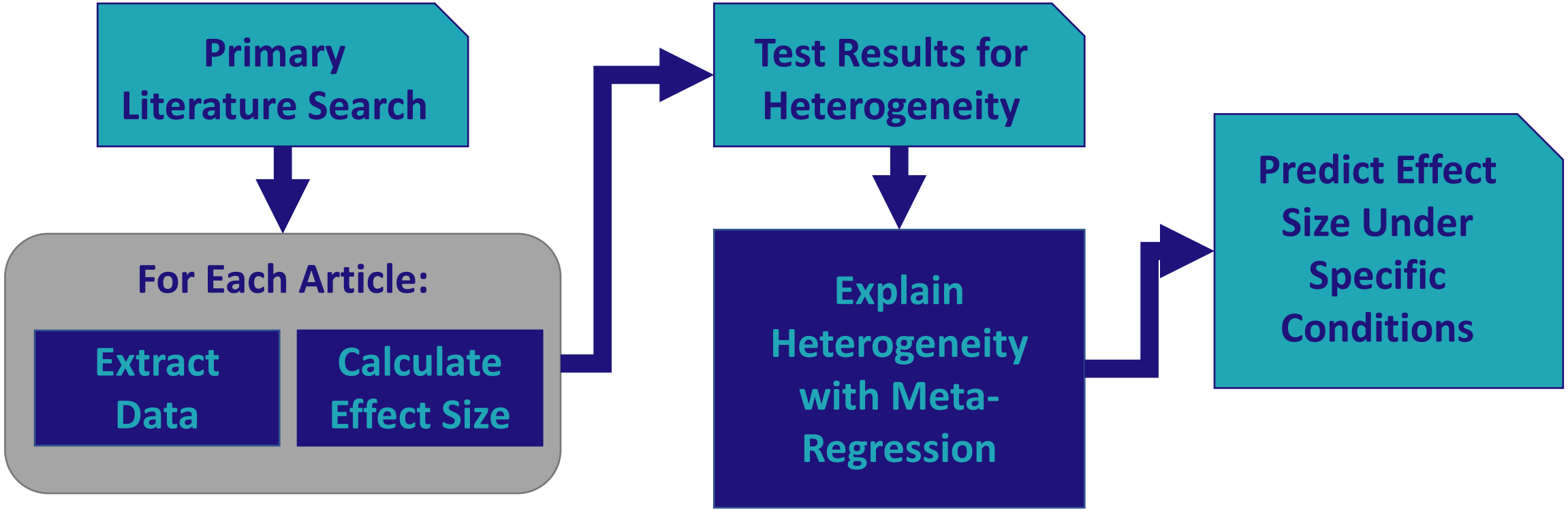
... increasing cut-in speed between 1.5 and 3.0 m/s or feathering blades and slowing rotor speed up to the turbine manufacturer's cut-in speed yields substantial reductions in fatality of bats. (Arnett 2013)

Publicly Available Studies



- Most studies show a reduction in fatalities
- High degree of uncertainty within each study
  - Few turbines in each treatment
  - Low number of bat fatalities at individual turbines
- Variability between studies makes them hard to compare
  - Turbine make/model
  - Original cut-in speed
  - Treatment cut-in speed
  - Feathering
  - Study design

Quantitative Meta-Analysis can attribute differences in results to specific study conditions



Studies with appropriately reported data

Facility	Year	Location	Source(s)	Data Source	Treatments	Species
Blue Creek	2017	Ohio, USA	Schirmacher 2020	Calculated from raw data[1]	5.0 m/s	L. cinereus L. borealis L. noctivagans
Blue Sky – Green Field	2015	Wisconsin, USA	Hayes et al. 2019* EPRI 2017	Hayes et al. 2019[2]	7.9 m/s (if bats present)	L. cinereus L. borealis L. noctivagans
Casselman	2008	Pennsylvania, USA	Arnett et al. 2011*[3] Arnett et al. 2009	Arnett et al. 2009	5.0 m/s 6.5 m/s	
	2009		Arnett et al 2010	Arnett et al. 2010	5.0 m/s 6.5 m/s	
Fowler Ridge[4]	2010	Indiana, USA	Good et al. 2011	Calculated from raw data in report[1]	5.0 m/s[5] 6.5 m/s[5]	L. cinereus L. borealis L. noctivagans
	2011		Good et al. 2012	Calculated from raw data in report[1]	3.5 m/s[6] 4.5 m/s 5.5 m/s	L. cinereus L. borealis L. noctivagans
Pinnacle	2012	West Virginia, USA	Hein et al. 2013	Combined species from Hein et al. 2015[3] Species-specific from BCI raw data[1]	6.0 m/s	L. cinereus L. borealis L. noctivagans
	2013		Hein et al. 2014	Hein et al. 2014	6.0 m/s	L. cinereus L. borealis L. noctivagans
Sheffield	2012 2013	Vermont, USA	Martin et al. 2017*[3] Martin 2015	Martin 2015[2]	6.0 m/s	
Summer View	2007	Alberta, CA	Baerwald et al. 2009*	Baerwald et al. 2009*	5.5 m/s Low wind speed idle	L. cinereus L. noctivagans
Wolf Ridge	2011 2012 2013 2014	Texas, USA	Hale and Bennet 2014	Provided by authors	5 m/s	L. cinereus[7] L. borealis[7]

[1]See Appendix III for methods used to calculate fatality rates from raw data; [2]Data is presented for comparison purposes only. It is not used in the meta-analysis due to unique study design that involves acoustic detections (Blue Sky – Green Field) and temperature (Sheffield);[3]This later report included standardized results from multiple years; [4]Data from Fowler Ridge was split into to an effect size for each of 3 turbine models (GE, Vestas, and Clipper) that were used in the study to allow for meta-regression using turbine specific characteristics; [5]Treatments at Fowler Ridge in 2010 did not feather below the cut-in Speed; [6]3.5 m/s at Fowler Ridge 2011 was simply feathering of blades below the cut-in speed; [7]Species fatality rates from Wolf Ridge were only available for 2013 and 2014.

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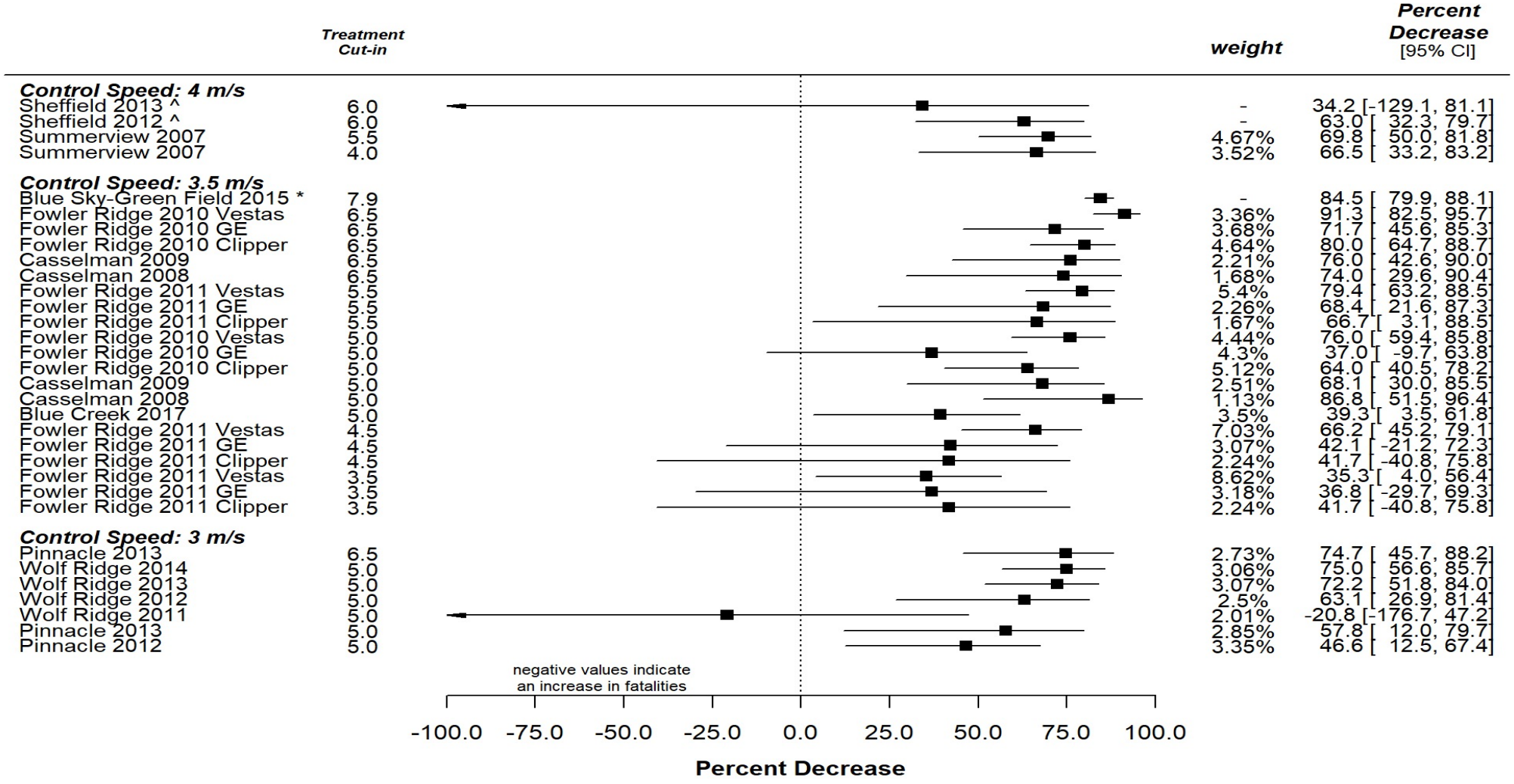
Total Bat Fatalities

Heterogeneity in results (Q_{28} = 68.12, p-value <0.001).



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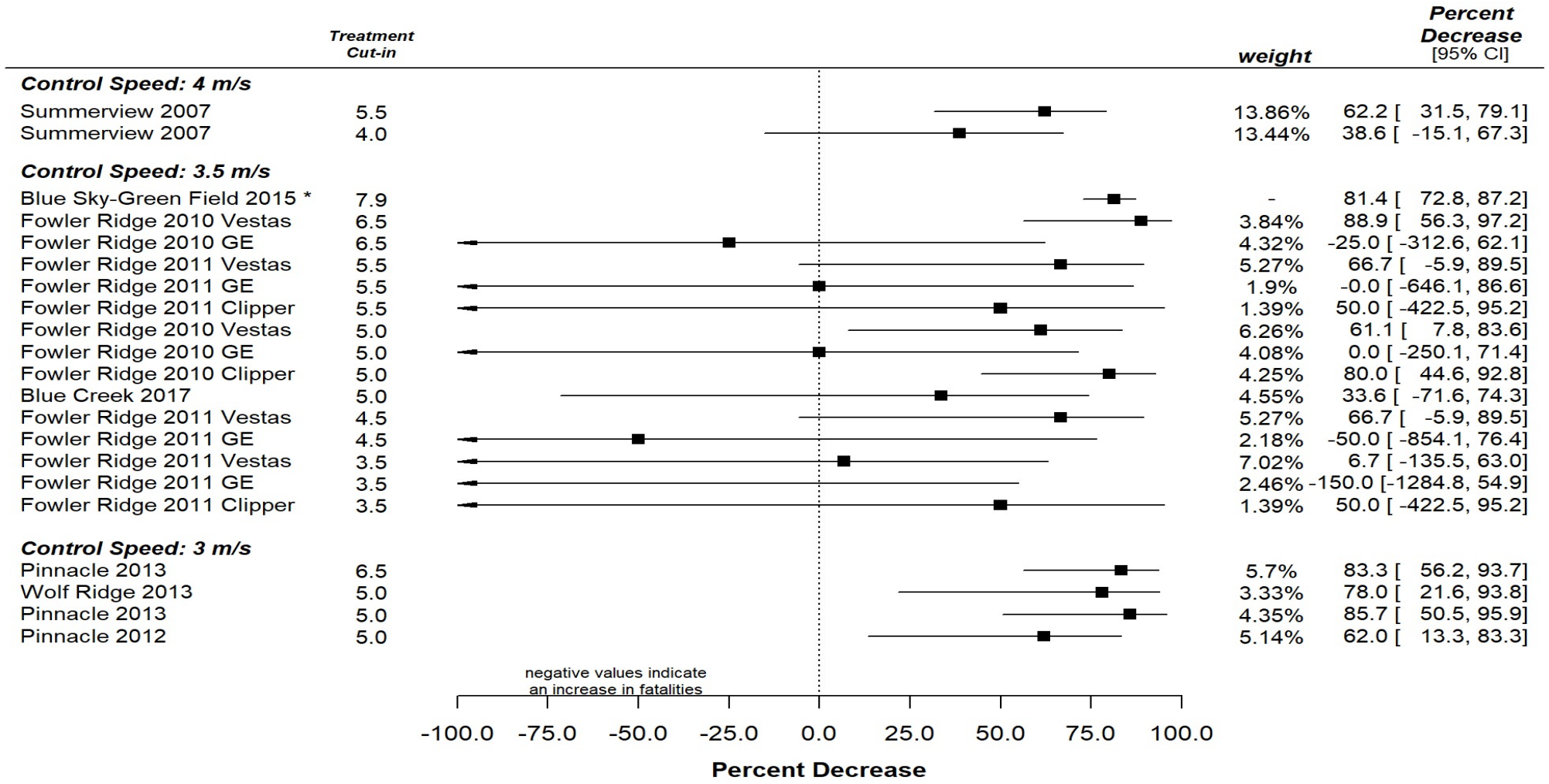
Hoary Bat Fatalities

Heterogeneity in Results (Q_{19} = 30.45, p = 0.046),



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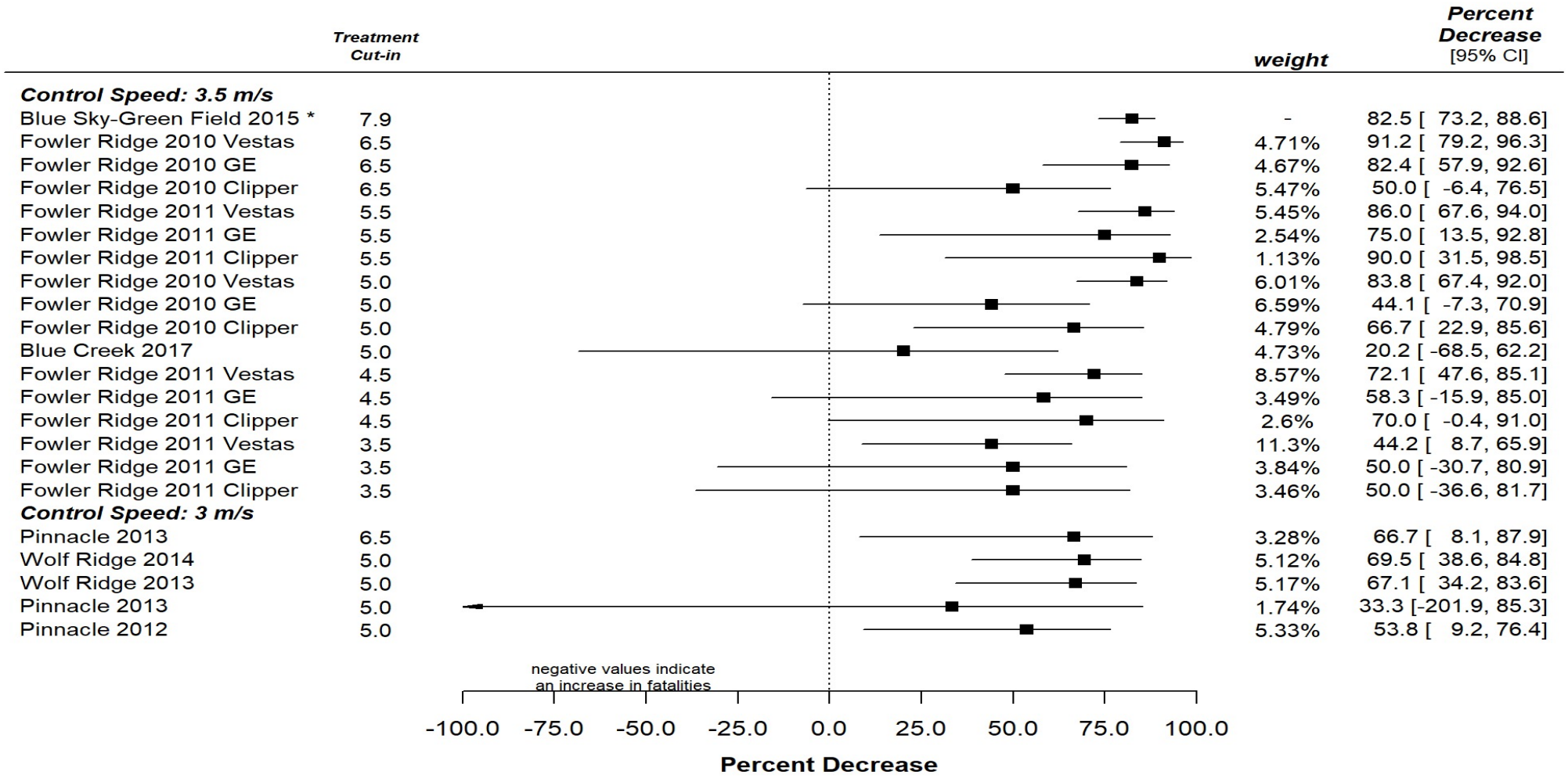
Eastern Red Bat Fatalities

Heterogeneity in results: (Q=37.65, p-value = =0.010).



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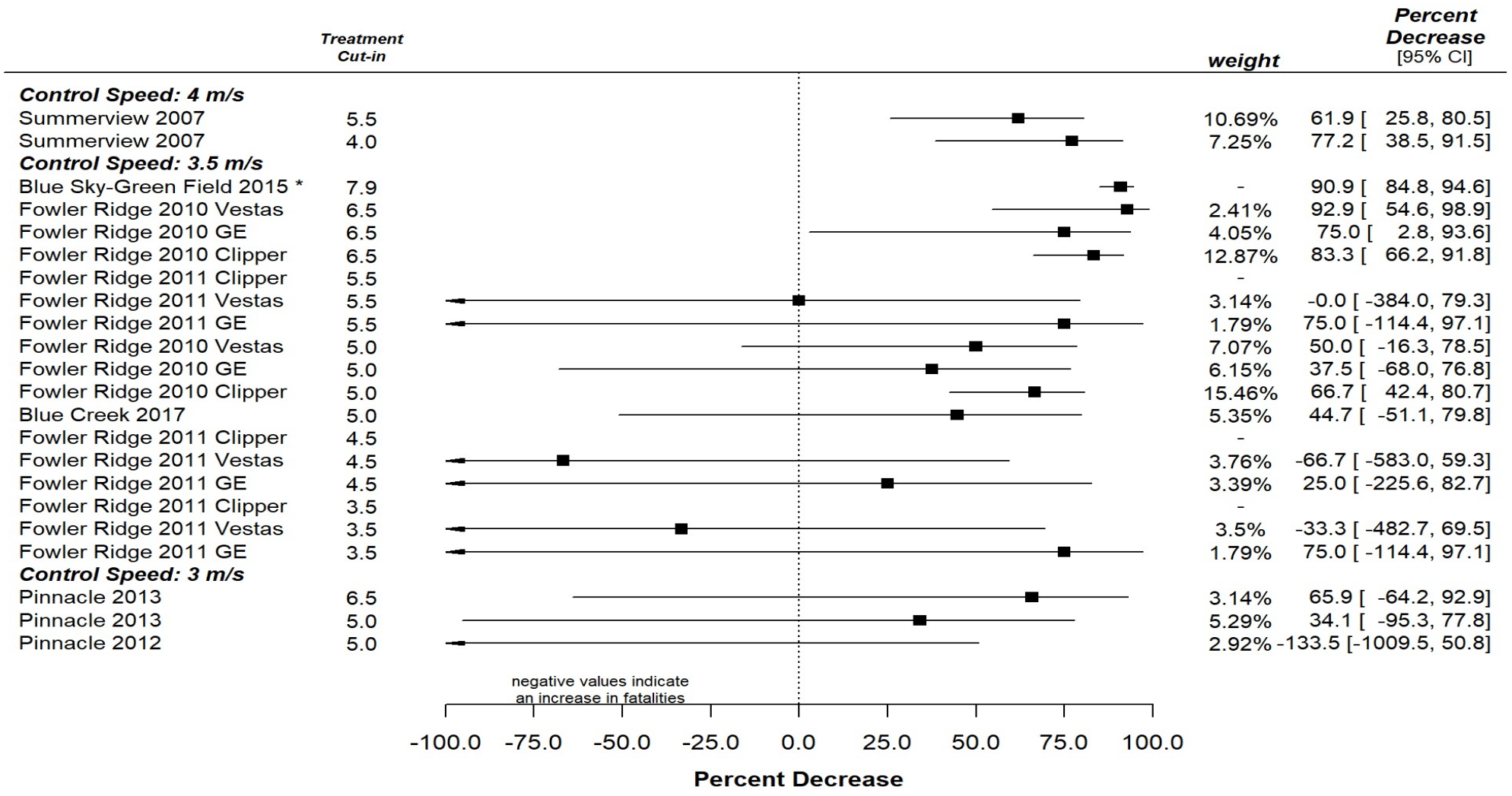
Silver-haired Bat Fatalities

Heterogeneity (Q17 =27.46, p-value =0.05)



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Meta-Regression

Model Name	Moderators	Prediction
Treatment Cut-in	Treatment Cut-In Speed	Increasing cut-in speed has a linear effect on fatality reduction
Control & Treatment Cut-in Speed	Control Cut-In Speed + Treatment Cut-In Speed	Higher cut-in speeds reduce fatality levels
Non-linear Treatment Cut-in	Natural Spline of Treatment Cut-In Speed with 3 degrees of Freedom	Increasing cut-in speed has a diminishing effect on fatality reduction
Cut-in Speed & Feathering	Control Cut-In Speed + Control Feathering + Treatment Cut-In Speed + Treatment Feathering	Higher cut-in speeds and feathering reduce fatality levels
Turbine characteristics	Rotor Swept Area + Hub Height	Curtailment effect will vary based on the size of the turbine
Study design	Plot Size + Treatment Allocation[1]	The study design will determine the strength of the results
Geographic	Latitude*Longitude	Curtailment effect will vary based on location of the wind facility

[1]Randomized Block Design—treatments were rotated so every turbine received all treatment or Completely Randomized Design—each turbine had a fixed treatment

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Meta-Regression

Model ranks and delta AICc values (from top model) for candidate model set (n=17) tested for each species and total bat fatalities. See Table 1.2 for model descriptions. All models included the same random effect of year nested within facility and a covariance matrix to account for multiple treatments being compared to a single control.

	Total Bats			Hoary bat[1]			Eastern red bat			Silver-haired bat		
Model Name	**Rank**	**ΔAICc**	**Weight**	**Rank**	**ΔAICc**	**Weight**	**Rank**	**ΔAICc**	**Weight**	**Rank**	**ΔAICc**	**Weight**
Treatment cut-in speed	1	0	0.72	1	0	0.41	1	0	0.76	1	0	0.44
Control & Treatment Cut-in speed	2	2.25	0.23	4	2.34	0.13	2	3.12	0.16	2	0.51	0.34
Non-linear treatment cut-in	3	6.05	0.04	5	6.24	0.02	4	6.86	0.02	4	1.81	0.18
Cut-in speed & feathering	4	8.33	0.01	8	11.21	<0.01	3	6.82	0.03	5	5.53	0.03
Null model (Random effects only)	5	21.16	<0.01	3	2.06	0.15	5	6.91	0.02	3	7.5	0.01
Turbine characteristics	6	24.92	<0.01	2	0.72	0.29	6	8.97	0.01	6	8.15	<0.01
Study design	7	26.53	<0.01	6	8.35	<0.01	7	10.75	<0.01	7	8.29	<0.01
Geographic	8	29.68	<0.01	7	8.77	<0.01	8	12.86	<0.01	8	11.38	<0.01

[1]Because the turbine characteristics and treatment cut-in speed models were <2 ΔAICc units apart, we combined the significant effects of both models (RSA in turbine characteristics). This new model was the top model and had a weight of 0.48. Treatment cut-in speed had a ΔAICc of 1.60 and weight of 0.21. Adding 1.60 to the shown ΔAICc values determines the other model values.

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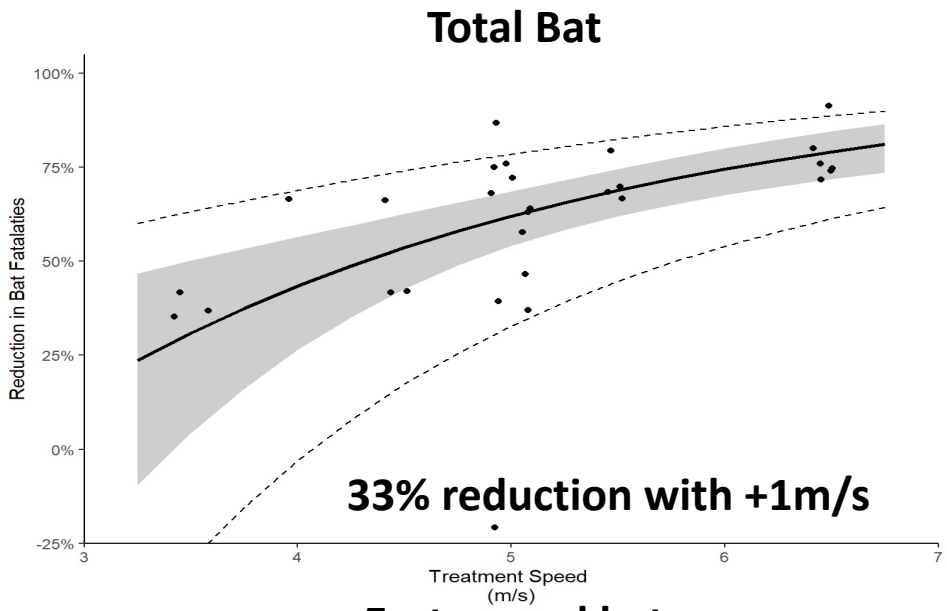
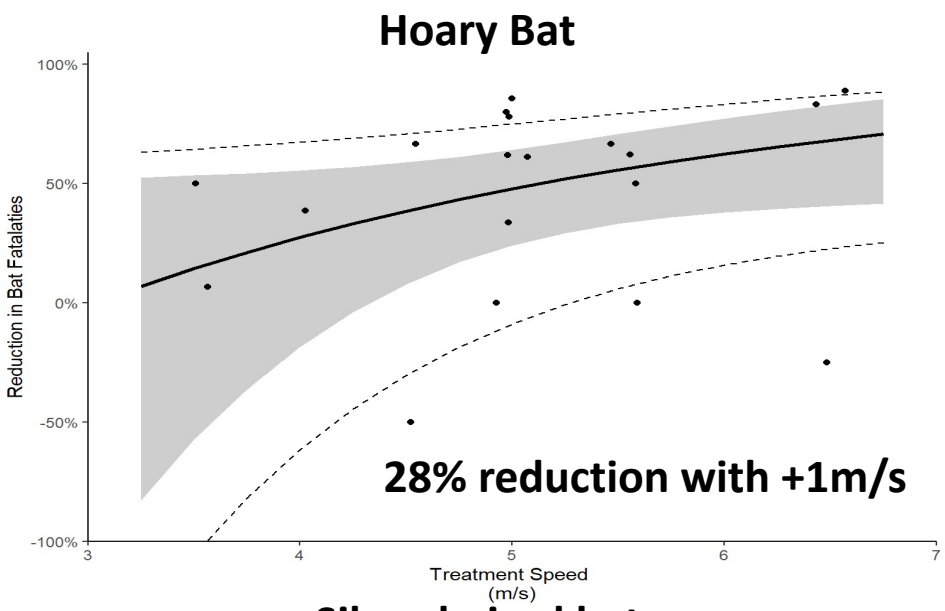
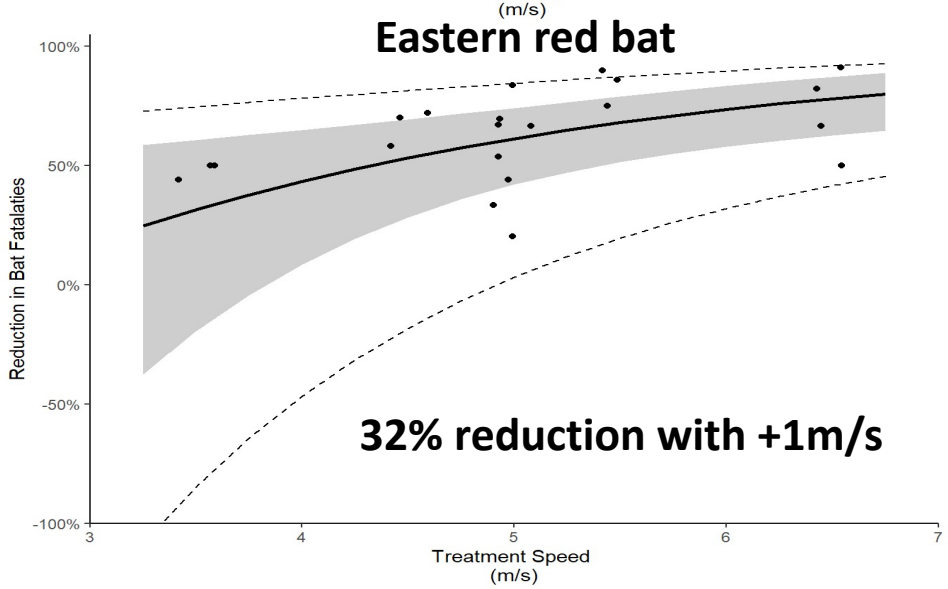
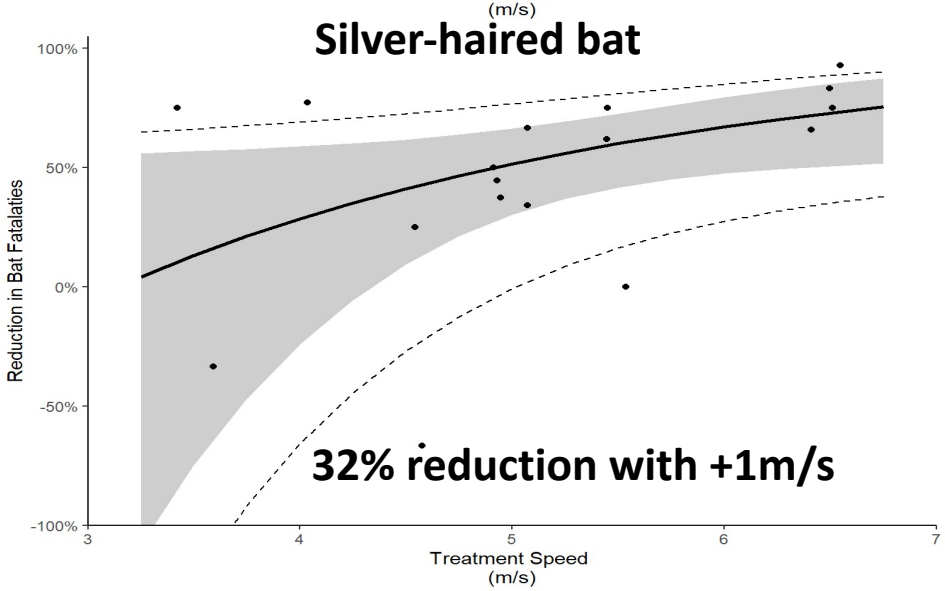
Fatality Reduction









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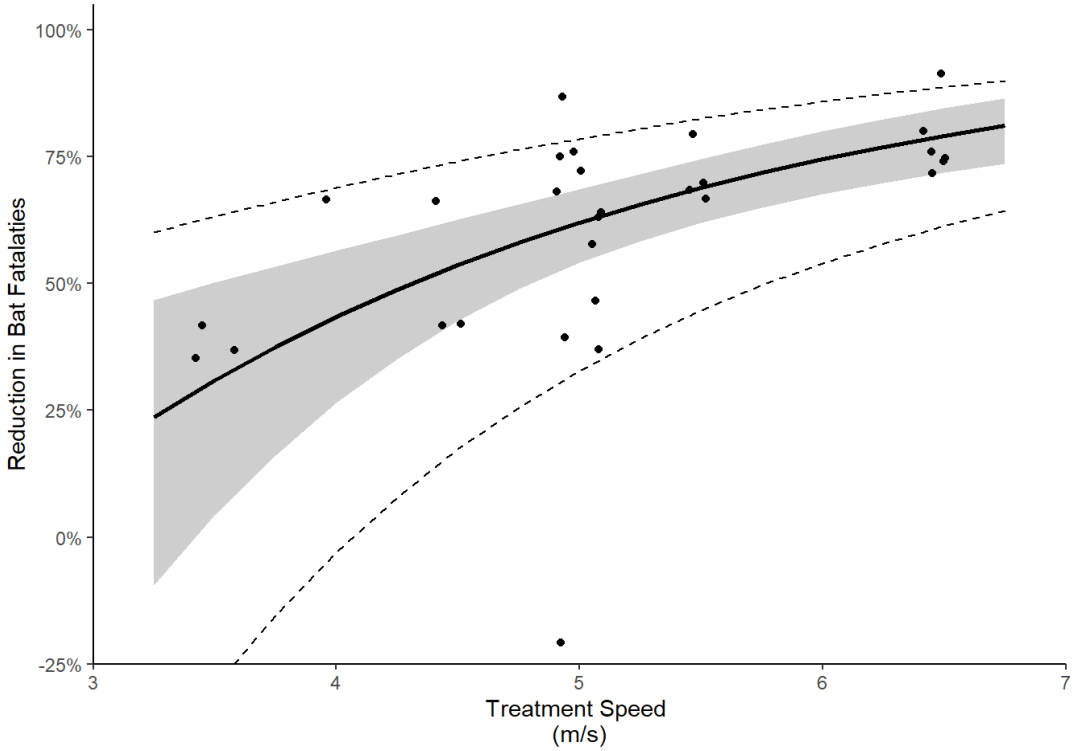
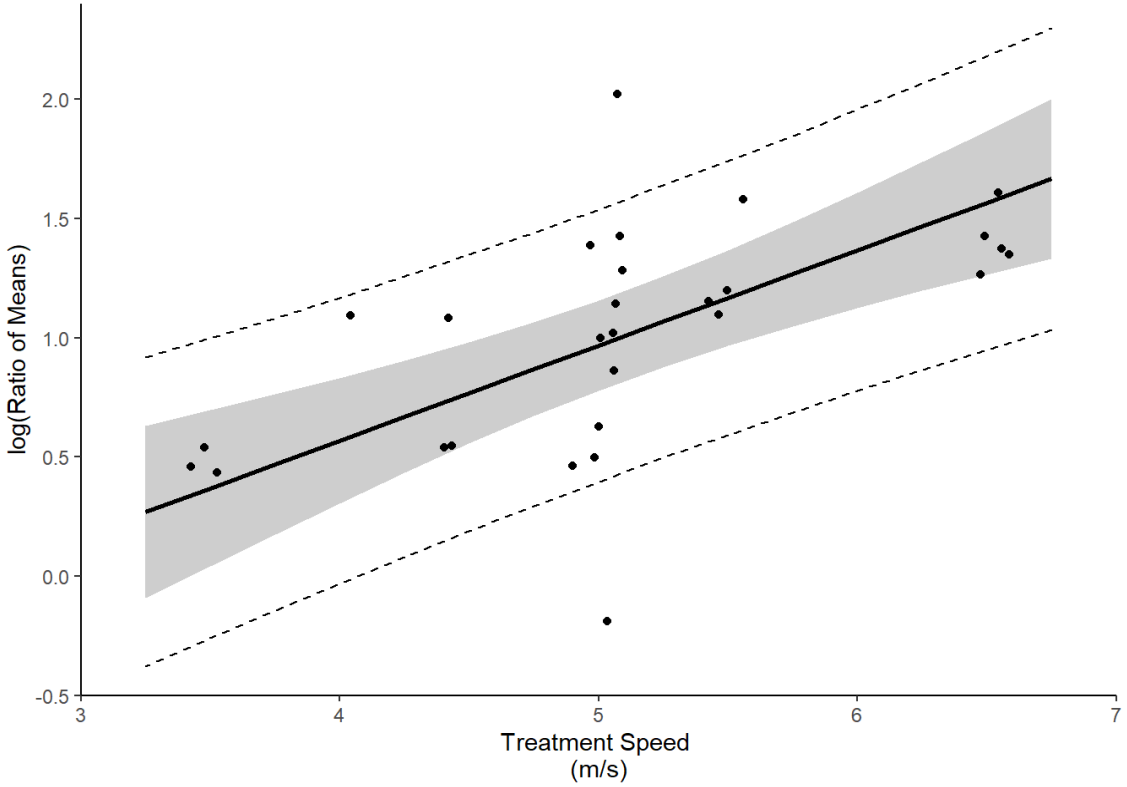
Linear effect





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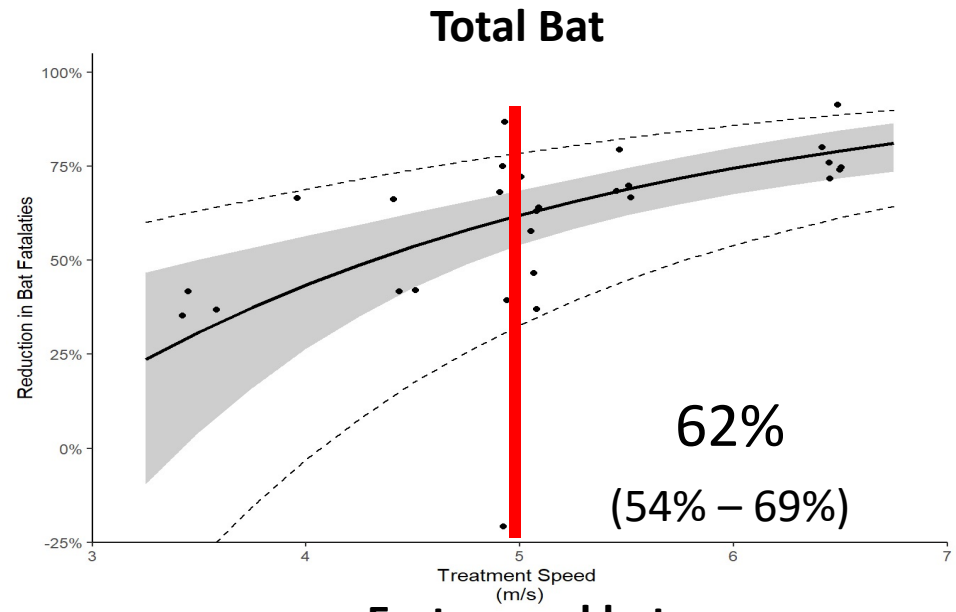
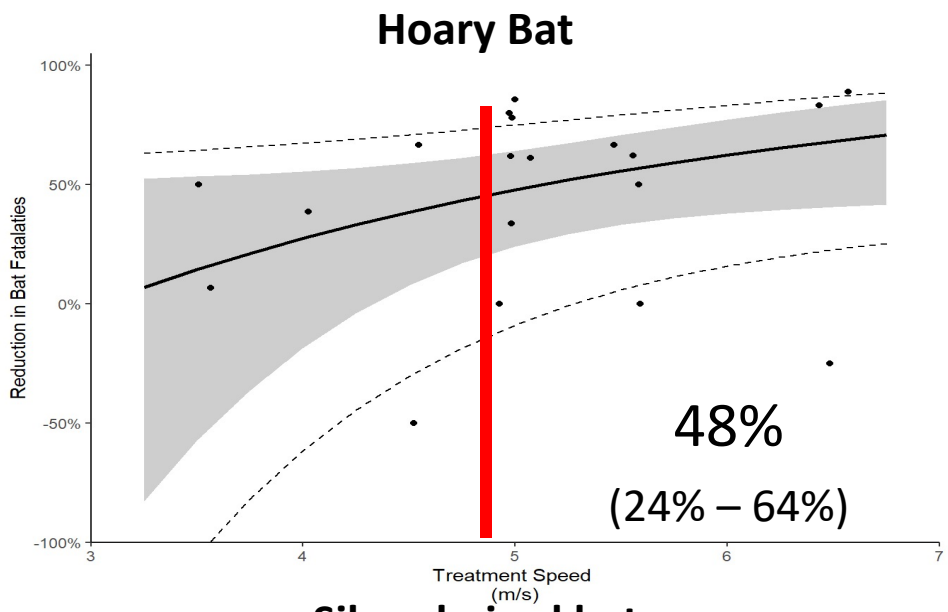
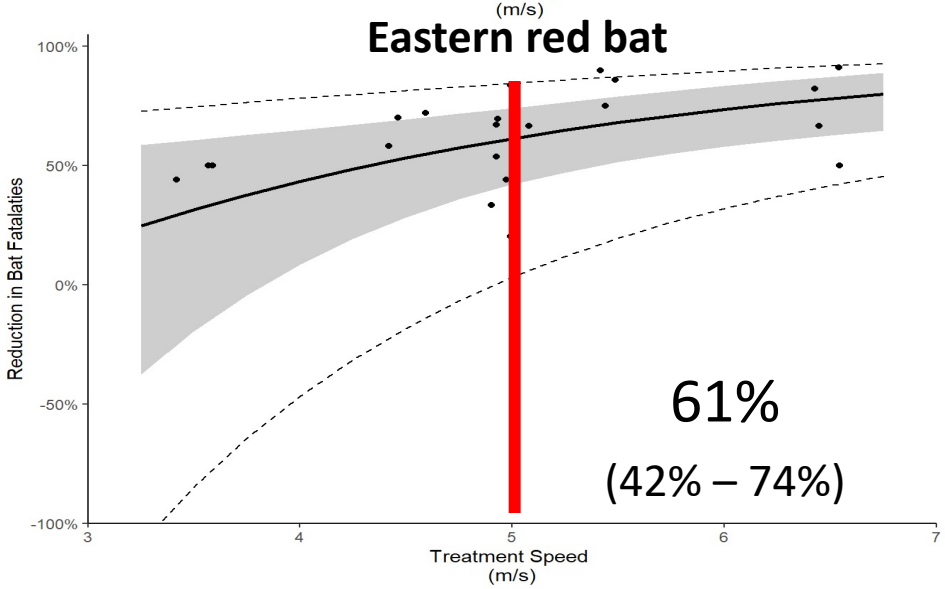
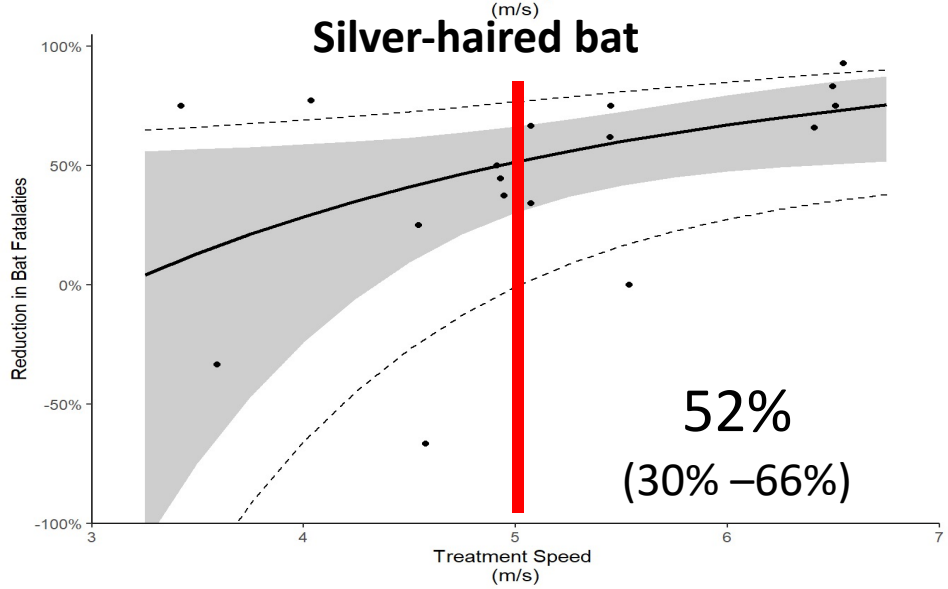
Average Fatality Reduction at 5.0 m/s cut-in speed









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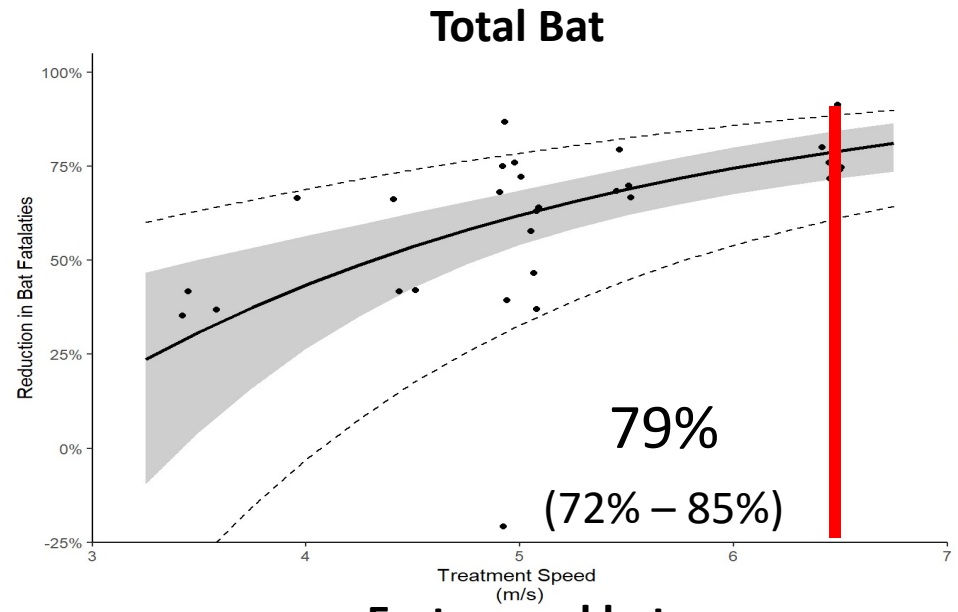
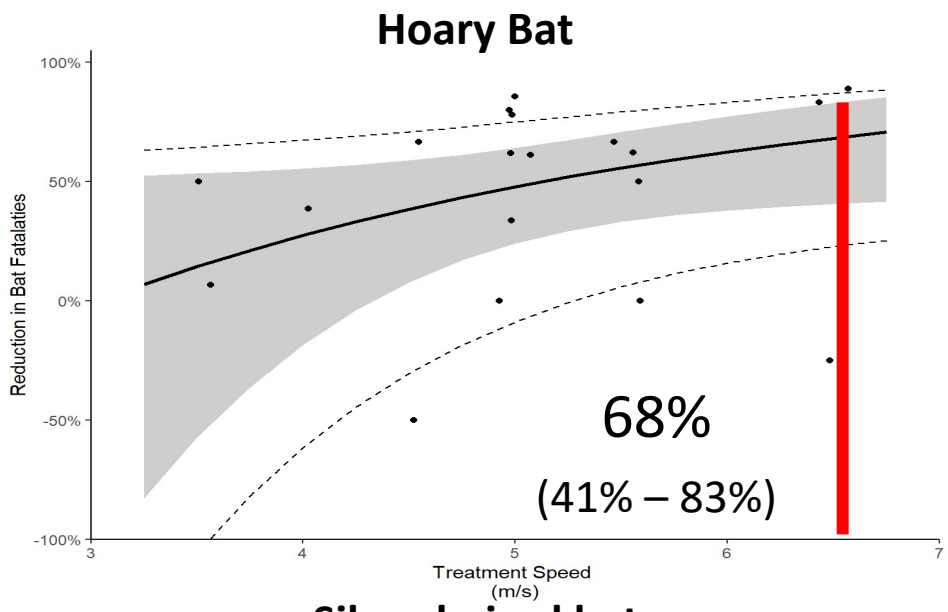
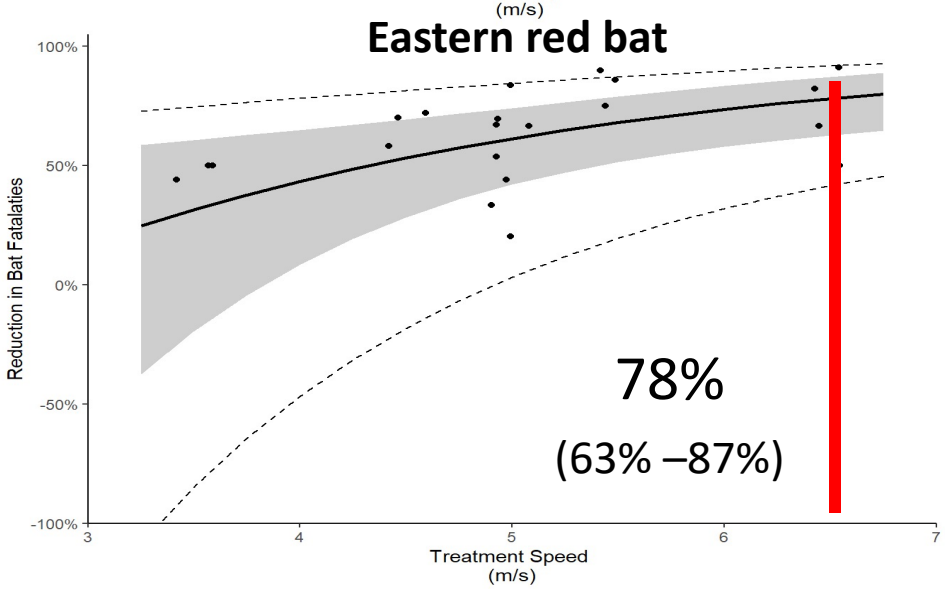
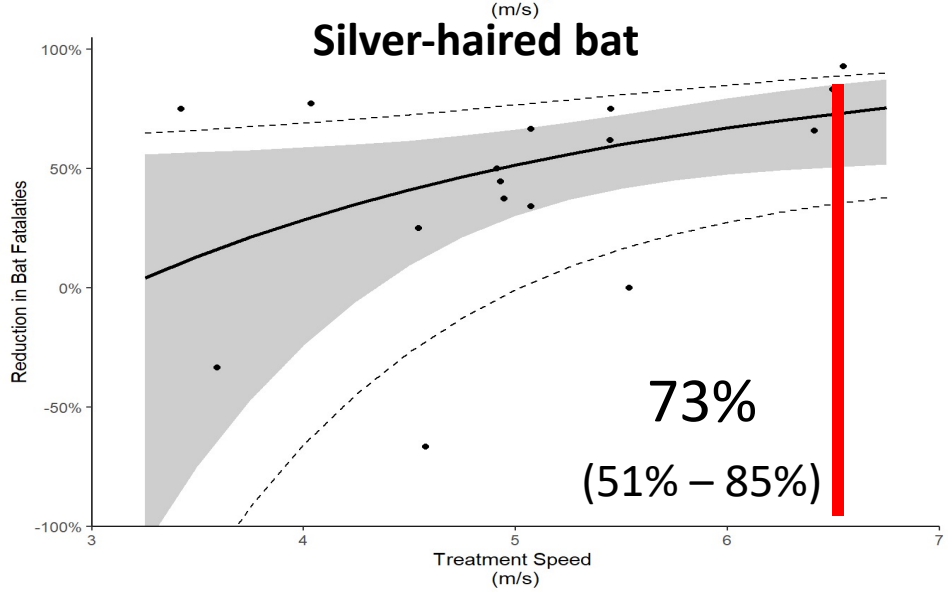
Average Fatality Reduction at 6.5 m/s cut-in speed









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Why it Matters

Contents lists available at ScienceDirect

Biological Conservation

Biological Conservation 262 (2021) 109309

Assessing fatality minimization for hoary bats amid continued wind energy development

Nicholas A. Friedenberg [a,*,1], Winifred F. Frick [b,c]

Table 2. Target reduction of bat fatalities at wind turbines to manage risk of hoary bat decline

Risk type	Abundance (millions)	Target reduction of bat fatalities (%)	
		Low build-out $\lambda = 1.18$ to 1.0	High build-out $\lambda = 1.18$ to 1.0
50% Decline by 2050	1	75–100*	88–100*
	2.25	35–100*	66–100*
	4	0–93	38–98
	10	0–30	0–63

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Conclusions

- Strong evidence ***curtailment is effective*** at reducing bat fatalities
- Urgent need to reduce fatalities to prevent catastrophic declines
    - *Reductions from curtailment reduce the risk of decline of hoary bats*
- Refining curtailment can improve long-term operational minimization strategies
- Top Priority: Overcome implementation barriers

THANK YOU!

Join us to end bat extinctions worldwide.

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