Improving Methods for Estimating Fatality of Birds and Bats at Wind Energy Facilities

California Wind Energy Association Public Webinar

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CalWEA

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Background

- 2007 CEC/CDFG Guidelines
  - *Guidelines for Reducing Bird & Bat Impacts from Wind Energy Development*
- 2008 CEC Research "Roadmap" on Impact Assessment Methods
- 2008 CEC PIER RFP
- 2009 CEC PIER Award to CalWEA
  - Address Guidelines' Appendix F
- 2011 Supplemental FWS Grant to CalWEA

Project Goals

- Improve the accuracy of methods for estimating the number of bird and bat fatalities associated with wind energy facilities
- Provide guidance leading to improved procedures for mortality monitoring at wind energy facilities

Preview of Conclusions

- Fatality estimators in use often produce biased results
- This calls into question the appropriate use of traditional estimators where the error would be of consequence, whether for project-specific results, industry averages, or industry totals
- Standardized methods are needed to generate fatality detection probabilities and fatality estimates
- Our proposed new estimator produces unbiased results, and requires new field protocols

Field Study Design and Findings

Field components:

1. Placement of carcasses (birds and bats) at study turbine strings by Project Field Managers (PFM)
2. Blind carcass searches of strings by Field Technicians (FT)
3. Status checks of placed carcasses by PFM

Findings:

1. Searcher Proficiency
2. Persistence Probability

Field Study Design Details

- In all cases, prior to searches the true number and location of carcasses is known to PFMs, but not to FTs
- Each string is searched for up to 60 days, or until all carcasses are removed
- Strings selected to represent various environmental conditions, including grass height, slope, vegetation type
- Carcasses are tagged and followed consistently throughout study period by PFMs

Survey Design Characteristics

- January 7, 2011 – April 1, 2011
- Weekly searches by FTs
- PFMs sampled and noted carcasses approx. every 3 days
- Blocks of strings sampled simultaneously, surrogate for time changes in ecology

Small bird carcasses placed during study	Bat carcasses placed during study	Incidentally found carcasses added to study	Study length (days)
90	78	21	113

FT conducting a search

Field Technician

Searching in tall grass

PFM Status Check

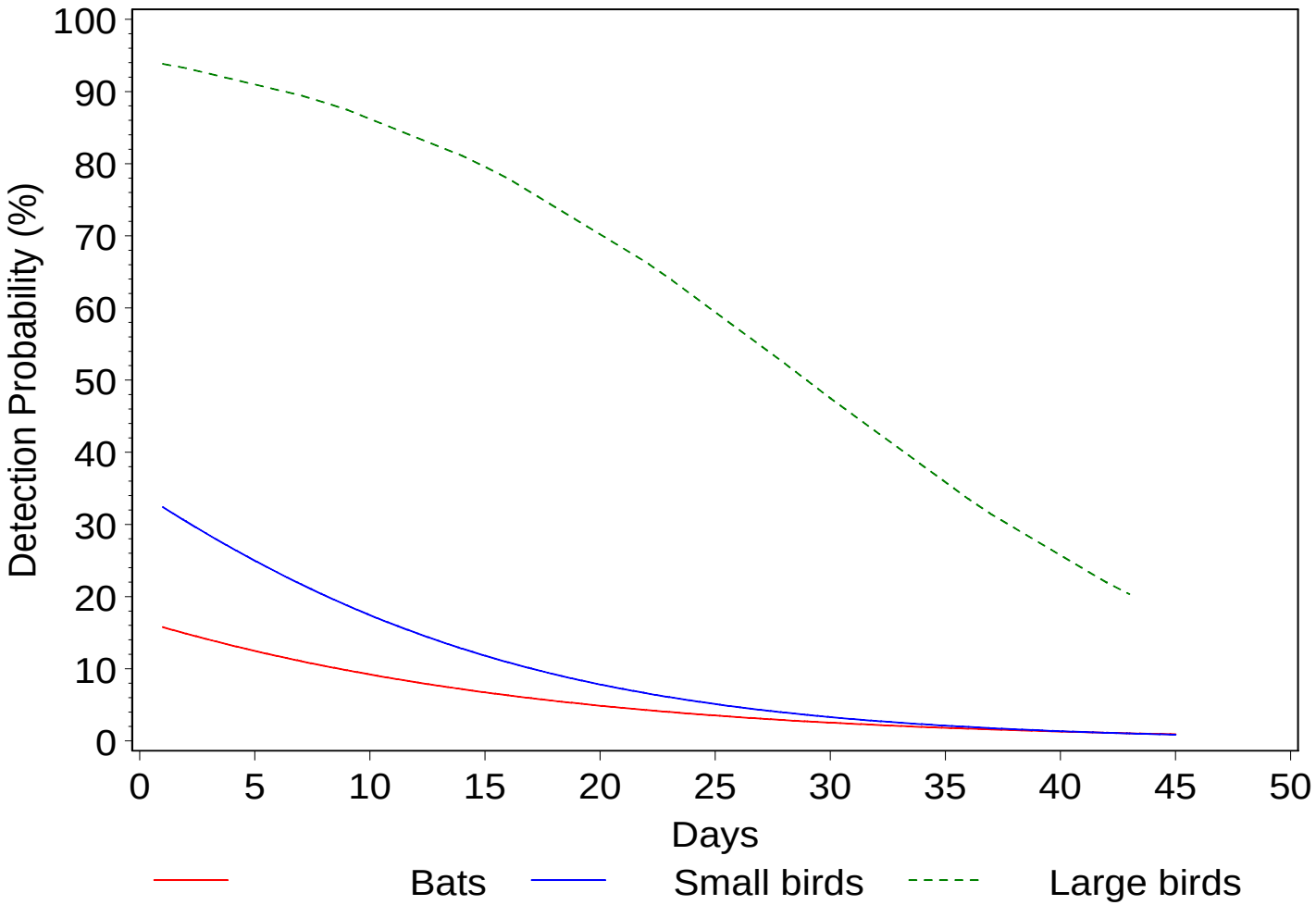
Searching in short grass

PFM Status Check

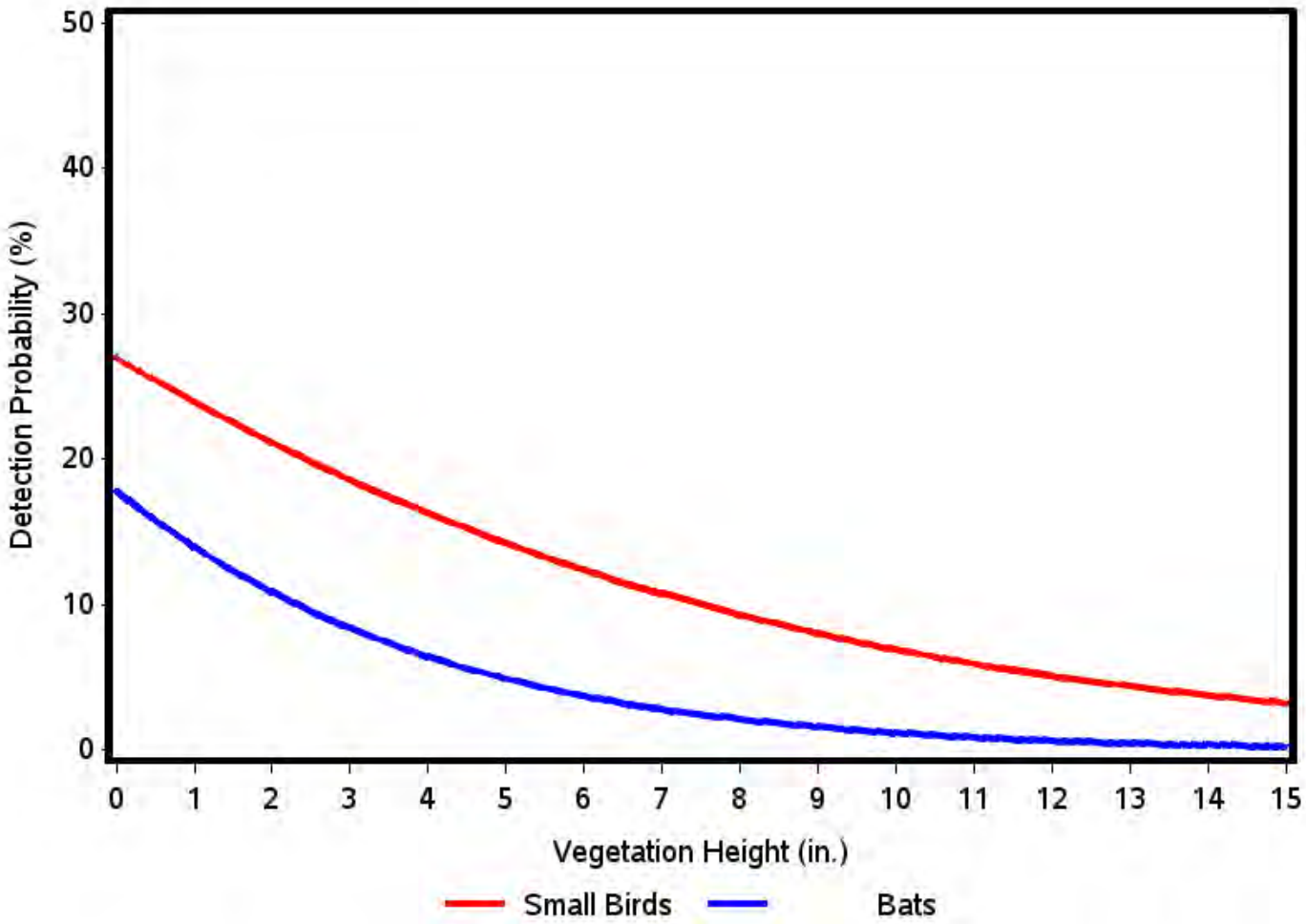
Percent of Birds and Bats Observed

Species	Detected 1st observation	Average detected over all trials for all observers	Unique carcasses detected during study
Bats	14.1%	8.1%	19.2%
Small Birds	22.2%	17.0%	30.8%
Large Birds	83.3%	67.7%	100%

Searcher Proficiency: A Time Dependent Process

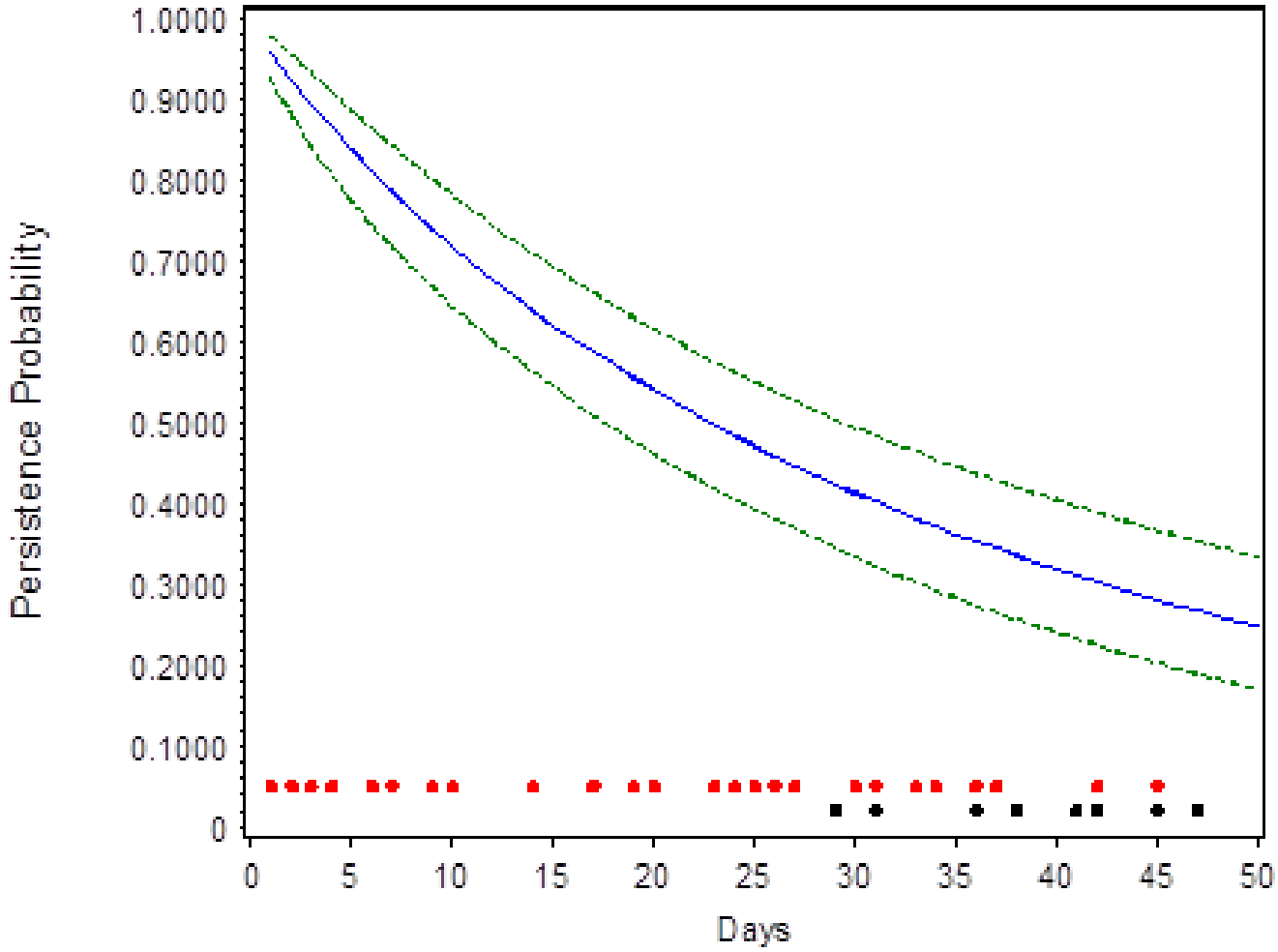


Searcher Proficiency: Dependency on Grass Height



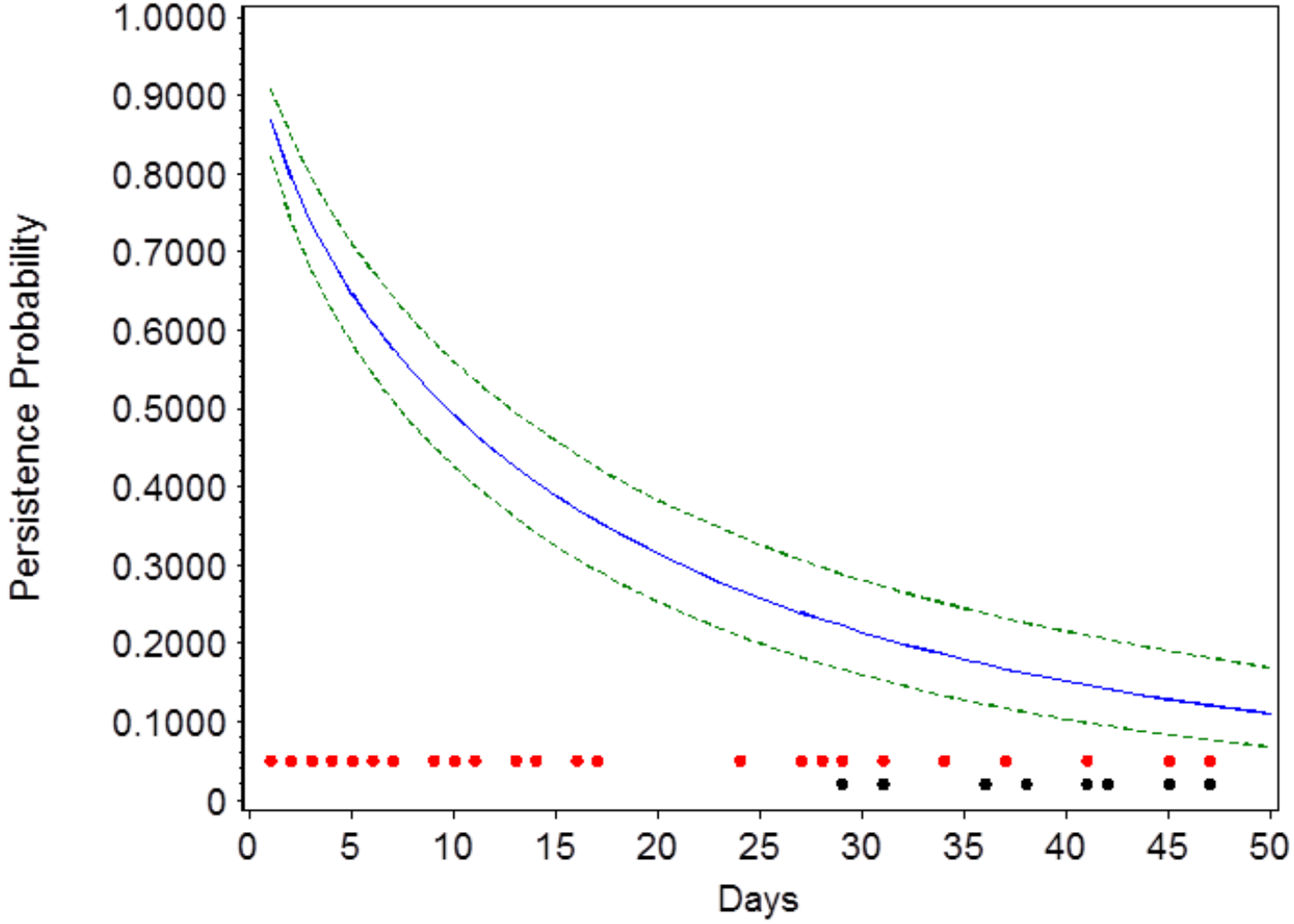
Persistence Probability:

Bats (Weibull Distribution, Mean = 43 days)



Persistence Probability:

Small Birds (Weibull Distribution, Mean = 30 days)



Implications: Field Study

- Carcass persistence is a time-dependent process, fits best with a Weibull distribution
- Searcher proficiency is a function of time
- Ecological conditions impact searcher proficiency (e.g., vegetation height)
- Searcher proficiency for bats is considerably less than for small birds
- Small birds have lower time-dependent persistence than bats
- Above have implications for selection of estimation equation and equation inputs

Partially-Periodic Estimation of Avian Mortality

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CalWEA-CEC Webinar: 2012-09-26

Carcass Counts and Avian Mortality

Let's start with Repeated carcass counts by Field Technicians at regular intervals in specified regions near specific turbines, with:

I_{ij}	(interval)	= days between successive searches,
M_{ij}	(mortality)	= number of carcasses during interval,
C_{ij}	(count)	= number of carcasses counted by FTs,

Naïve estimate "$\hat{M}_{ij} = C_{ij}$" would be okay if:

- A_1: No carcasses at start of interval;
- A_2: Every fatality leads to a carcass;
- A_3: No other carcass sources;
- A_4: Carcasses remain throughout period;
- A_5: Field Technicians find every one.

More realistically...

Several authors have proposed improved estimators to accommodate removal by scavengers and discovery failure, based on one or more of:

p_{ij}	(persistence)	= probability a carcass is unremoved,
r_{ij}	(removal rate)	= probability per day of scavenging,
s_{ij}	(search proficiency)	= discovery probability by FTs,
t_{ij}	(persistence time)	= mean days carcass unremoved.

Each estimator embodies some assumptions.

Erickson & Johnson

Erickson, Strickland, Johnson, Kern (1998):

$$\hat{M}_{ij}^{\mathrm{EJ}} = \frac{C_{ij}\, I_{ij}}{\hat{s}_{ij}\, \hat{t}_{ij}}$$

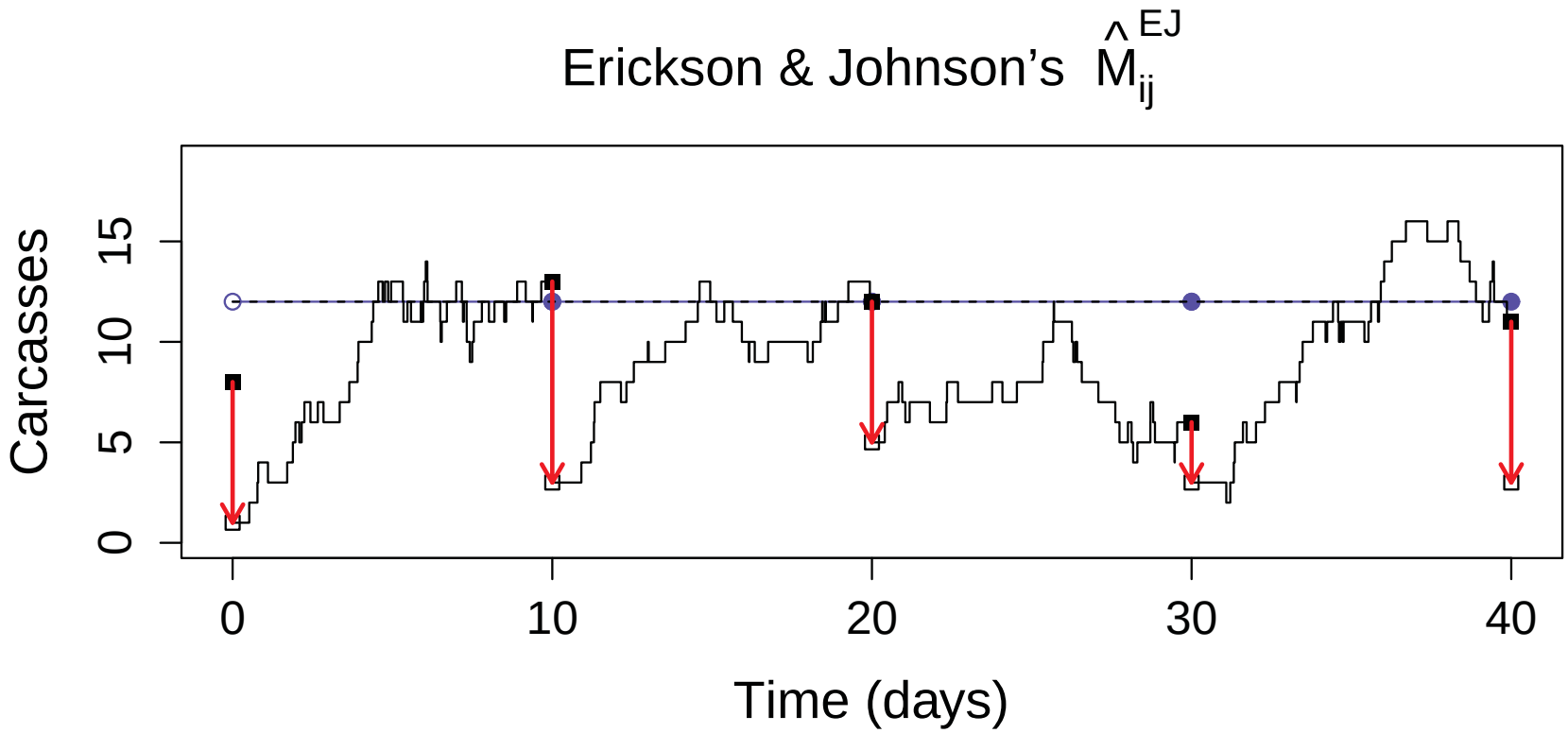
Based on:

$$\mathrm{E}[C_{ij}] = M_{ij}\ (t_{ij}/I_{ij})\ (s_{ij})$$

Assumes:

$\mathrm{A}_1^{\mathrm{EJ}}$: The system is in equilibrium at each search.

Erickson & Johnson in Pictures



Shoenfeld's Periodic Equation

Shoenfeld (2004):

$$\hat{M}^{S}_{ij} = \frac{C_{ij}\, l_{ij}}{\hat{s}_{ij}\, \hat{t}_{ij}} \left[\frac{e^{l_{ij}/\hat{t}_{ij}} - 1 + \hat{s}_{ij}}{e^{l_{ij}/\hat{t}_{ij}} - 1} \right]$$

Based on:

$$\mathrm{E}[C_{ij}] = \underbrace{M_{ij}\ (t_{ij}/l_{ij})(1 - e^{-l_{ij}/t_{ij}})\ s_{ij}}_{\text{New}} + \underbrace{\mathrm{E}[C_{ij}]\ (1 - s_{ij})\ e^{-l_{ij}/t_{ij}}}_{\text{Old}}$$

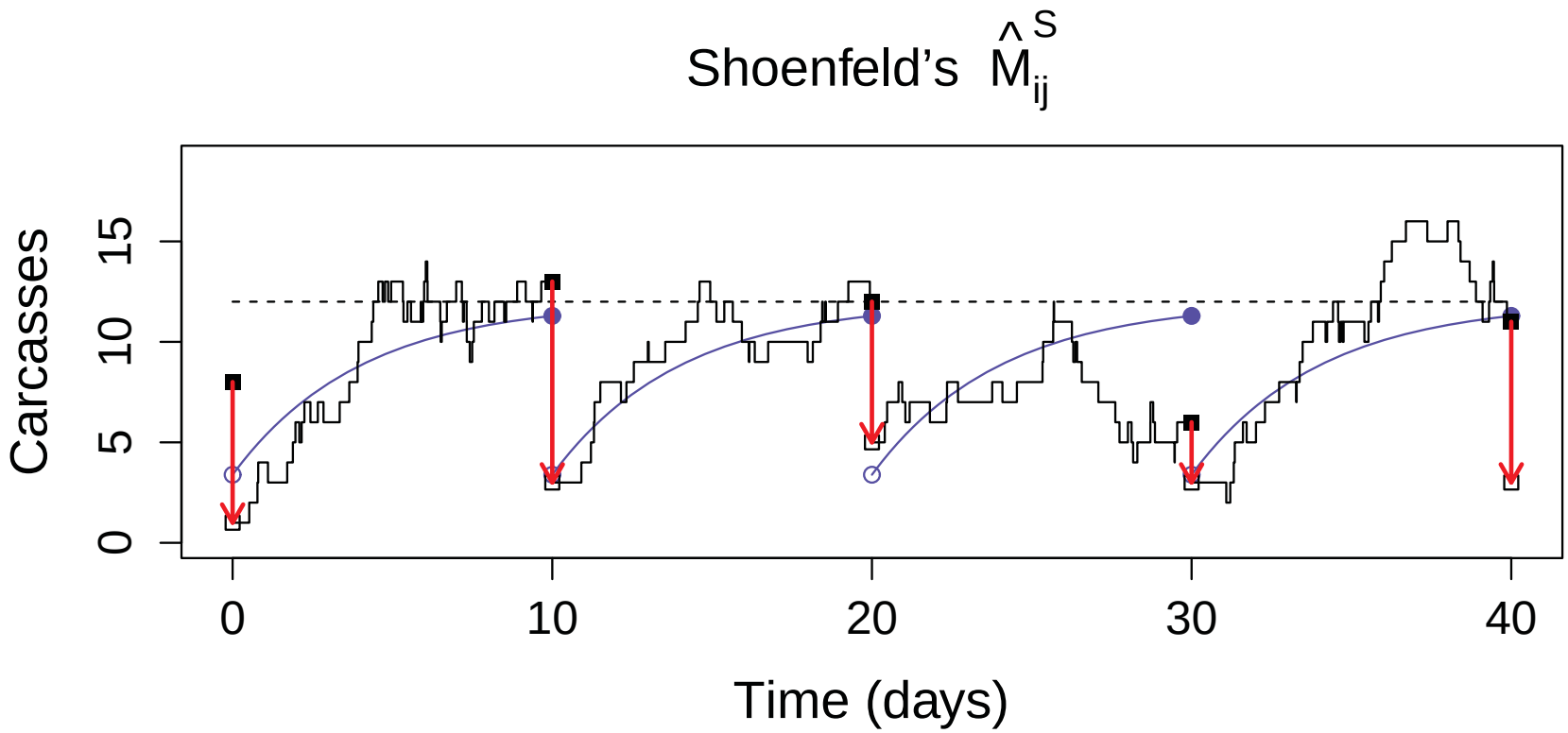
Assumes:

A^{S}_{1}: Carcass persistence times have exponential distributions.

A^{S}_{2}: New & Old carcasses have same discovery probability s_{ij}

A^{S}_{3}: Intervals l_{ij}, mortality and removal rates m_{ij}, r_{ij}, and persistence s_{ij} are similar in consecutive intervals.

Shoenfeld in Pictures



Reflection...

- Both $\hat{M}_{ij}^{\mathrm{EJ}}$ and $\hat{M}_{ij}^{\mathrm{S}}$ assume "100% bleed-through"—Every carcass that is not removed by scavengers, and is not discovered and removed in a search, remains for possible discovery in later searches.
- Shoenfeld also assumes exponential distributions for removal.
- Erickson & Johnson also assume equilibrium, even though FTs remove carcasses discovered in searches.
- Always $\hat{M}_{ij}^{\mathrm{EJ}} < \hat{M}_{ij}^{\mathrm{S}}$, with small differences if $l_{ij} \gg t_{ij}$:

$$\hat{M}_{ij}^{\mathrm{EJ}} < \hat{M}_{ij}^{\mathrm{S}} = \hat{M}_{ij}^{\mathrm{EJ}} \left[1 + \frac{s_{ij}}{e^{l_{ij}/t_{ij}} - 1} \right]$$

Estimators without bleed-through

Perhaps *none* of the "Old" carcasses that were

- Not removed by scavengers, and
- Not discovered & removed by FTs

are ever discovered in subsequent searches.

If so, we can remove the bleed-through part from Shoenfeld's equation to get a new estimator:

Huso's Equation

Huso (2011) proposed:

$$\hat{M}_{ij}^{\mathrm{H}} = \begin{cases} \dfrac{C_{ij}\, l_{ij}}{\hat{s}_{ij}\, \hat{t}_{ij} \left(1 - e^{-l_{ij}/\hat{t}_{ij}}\right)} & l_{ij} < \hat{l}_{ij} \\ \dfrac{C_{ij}\, l_{ij}}{\hat{s}_{ij}\, \hat{t}_{ij} \left(1 - e^{-\hat{l}_{ij}/\hat{t}_{ij}}\right)} & l_{ij} > \hat{l}_{ij} \end{cases}$$

Based on:

$$\mathrm{E}[C_{ij}] = M_{ij}\ (t_{ij}/l_{ij})(1 - e^{-l_{ij}/t_{ij}})\ s_{ij}$$

Assumes:

$\mathrm{A}_1^{\mathrm{H}}$: Each period begins with no discoverable carcasses.

$\mathrm{A}_2^{\mathrm{H}}$: Persistence times have exponential distributions.

Huso's Equation

Huso (2011) proposed:

$$\hat{M}_{ij}^{\mathrm{H}} = \frac{C_{ij}\, I_{ij}}{\hat{s}_{ij}\, \hat{t}_{ij}\, \left[0.99 \wedge (1 - e^{-I_{ij}/\hat{t}_{ij}})\right]}.$$

Based on:

$$\mathrm{E}[C_{ij}] = M_{ij}\, (t_{ij}/I_{ij})(1 - e^{-I_{ij}/t_{ij}})\, s_{ij}$$

Assumes:

$\mathrm{A}_1^{\mathrm{H}}$: Each period begins with no discoverable carcasses.

$\mathrm{A}_2^{\mathrm{H}}$: Persistence times have exponential distributions.

Huso's Equation

Huso (2011) proposed a slight variation on:

$$\hat{M}_{ij}^{\mathsf{H}} \approx \frac{C_{ij}\, l_{ij}}{\hat{s}_{ij}\, \hat{t}_{ij}\, (1 - e^{-l_{ij}/\hat{t}_{ij}})}.$$

Based on:

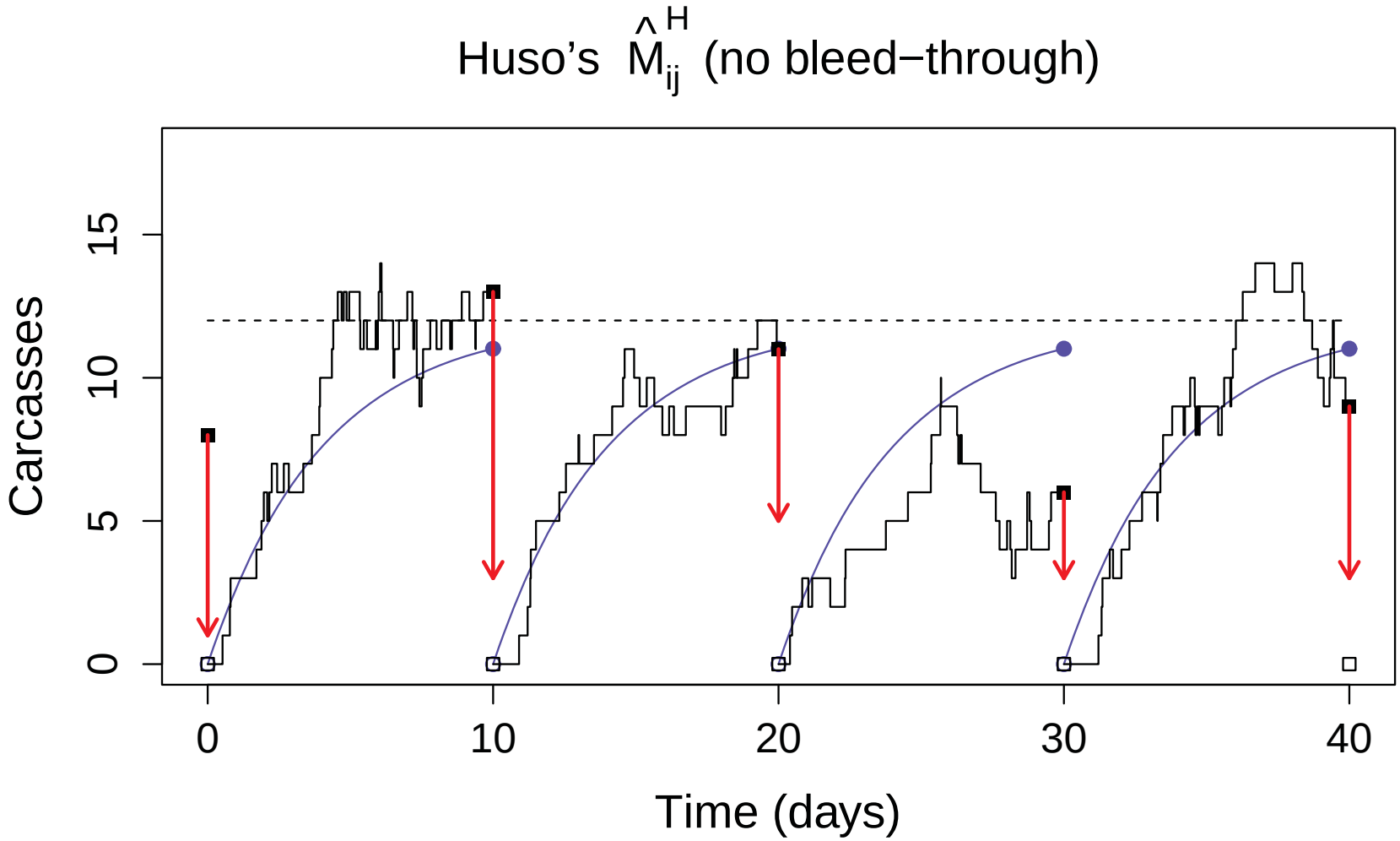
$$\mathrm{E}[C_{ij}] = M_{ij}\ (t_{ij}/l_{ij})(1 - e^{-l_{ij}/t_{ij}})\ s_{ij}$$

Assumes:

$\mathrm{A}_1^{\mathsf{H}}$: Each period begins with no discoverable carcasses.

$\mathrm{A}_2^{\mathsf{H}}$: Persistence times have exponential distributions.

Huso in Pictures



Pollock's Estimator

Pollock (2007) based an estimator on "average probability a carcass is unremoved until the search" p_{ij}, instead of more commonly used mean persistence time t_{ij}:

$$\hat{M}^{\mathrm{P}}_{ij} = \frac{C_{ij}}{\hat{s}_{ij}\,\hat{p}_{ij}} \qquad \text{(any dist'n)}$$

$$= \frac{C_{ij}\,l_{ij}}{\hat{s}_{ij}\,\hat{t}_{ij}}[1 - e^{-l_{ij}/\hat{t}_{ij}}]^{-1} \qquad \text{(w/Expon.)}$$

$$= \frac{C_{ij}\,l_{ij}}{\hat{s}_{ij}\,\hat{t}_{ij}}\,P\left(\tfrac{1}{\alpha},\ [\Gamma(1+\tfrac{1}{\alpha})l_{ij}/\hat{t}_{ij}]^{\alpha}\right)^{-1} \qquad \text{(w/Weibull)}$$

Based on:

$$\mathrm{E}[C_{ij}] = M_{ij} \ \times\ p_{ij} \ \times\ s_{ij}$$

Assumes:

$\mathrm{A}^{\mathrm{P}}_{1}$: Each period begins with no discoverable carcasses.

More reflection...

- Both $\hat{M}_{ij}^{\mathrm{H}}$ and $\hat{M}_{ij}^{\mathrm{P}}$ assume "0% bleed-through"— "Old" carcasses are never discovered.
- Huso also assumes exponential distributions for removal.
- Pollock's equation can be instantiated for any specific removal distribution, or used in "raw" form with direct empirical estimates of $\hat{p}_{ij}$.
- For exponential removal,

$$\hat{M}_{ij}^{\mathrm{EJ}} < \hat{M}_{ij}^{\mathrm{S}} \quad < \quad \hat{M}_{ij}^{\mathrm{P}} = \hat{M}_{ij}^{\mathrm{H}}$$

(unless $l_{ij} > 4.6 t_{ij}$, when $\hat{M}_{ij}^{\mathrm{H}}$ is 1% bigger than $\hat{M}_{ij}^{\mathrm{P}}$)

Do the differences matter?

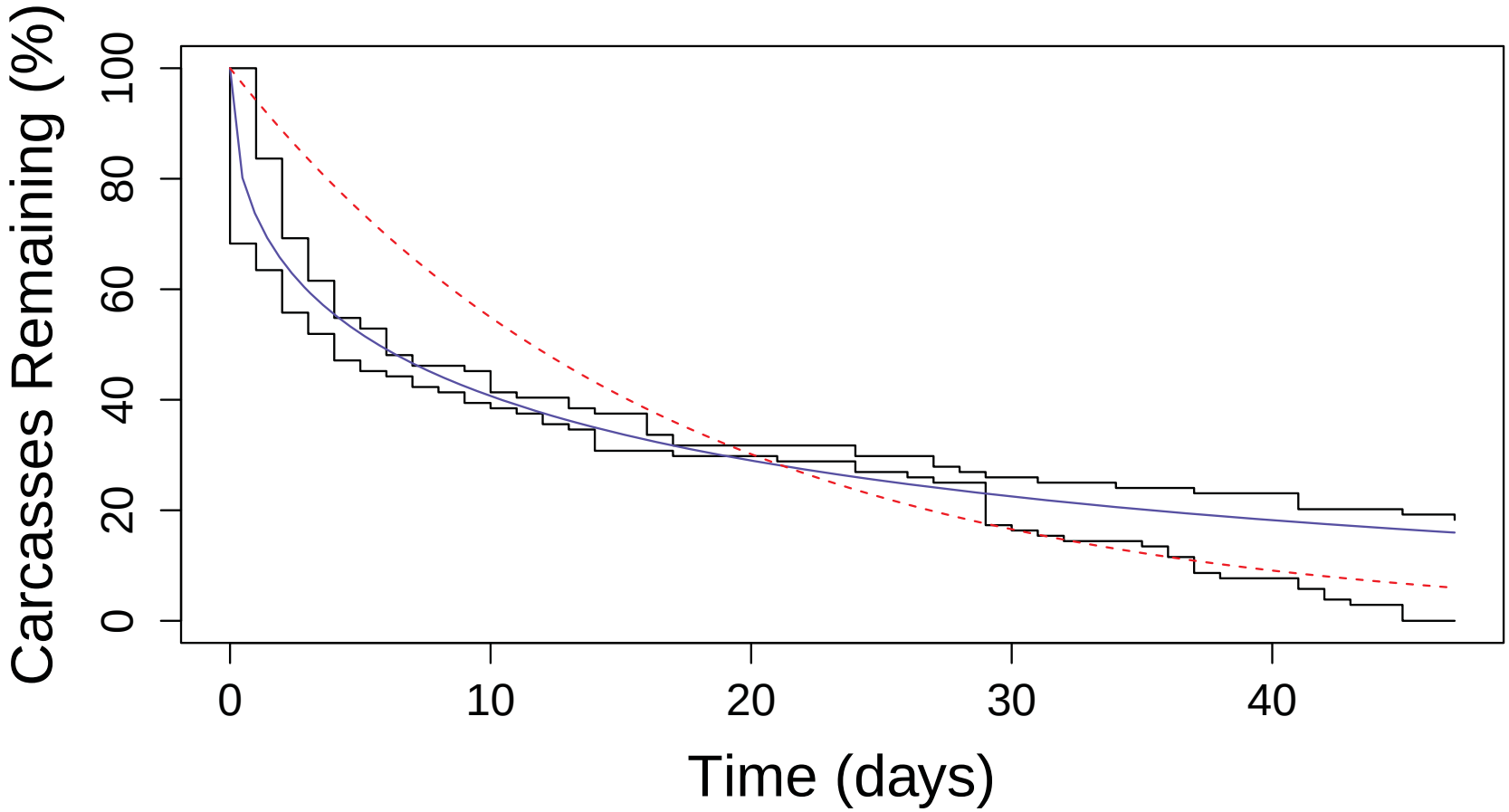
- If $l_{ij} \gg t_{ij}$ (That is, if search intervals are long compared to mean persistence times), Then NO, all four estimators give about the same answers.
- BUT, they differ substantially under more frequent sampling.
- For typical search proficiencies of $25\% < s_{ij} < 60\%$,

If $l_{ij} \approx 2t_{ij}$,	$\hat{M}_{ij}^{\mathrm{EJ}}$	is 4– 9% lower than $\hat{M}_{ij}^{\mathrm{S}}$
	$\hat{M}_{ij}^{\mathrm{H}} = \hat{M}_{ij}^{\mathrm{P}}$	is 6–11% higher;
If $l_{ij} \approx t_{ij}$,	$\hat{M}_{ij}^{\mathrm{EJ}}$	is 13–26% lower than $\hat{M}_{ij}^{\mathrm{S}}$
	$\hat{M}_{ij}^{\mathrm{H}} = \hat{M}_{ij}^{\mathrm{P}}$	is 17–38% higher;
If $l_{ij} \approx \frac{1}{2}t_{ij}$,	$\hat{M}_{ij}^{\mathrm{EJ}}$	is 28–48% lower than $\hat{M}_{ij}^{\mathrm{S}}$
	$\hat{M}_{ij}^{\mathrm{H}} = \hat{M}_{ij}^{\mathrm{P}}$	is 32–83% higher

- No matter how short l_{ij} is, $\hat{M}_{ij}^{\mathrm{S}}$ is never more than s_{ij} times smaller than $\hat{M}_{ij}^{\mathrm{H}} = \hat{M}_{ij}^{\mathrm{P}}$ (at most a factor of 3 or 4).

Are the Assumptions True?

Exponential persistence?



Are the Assumptions True?

Exponential persistence?

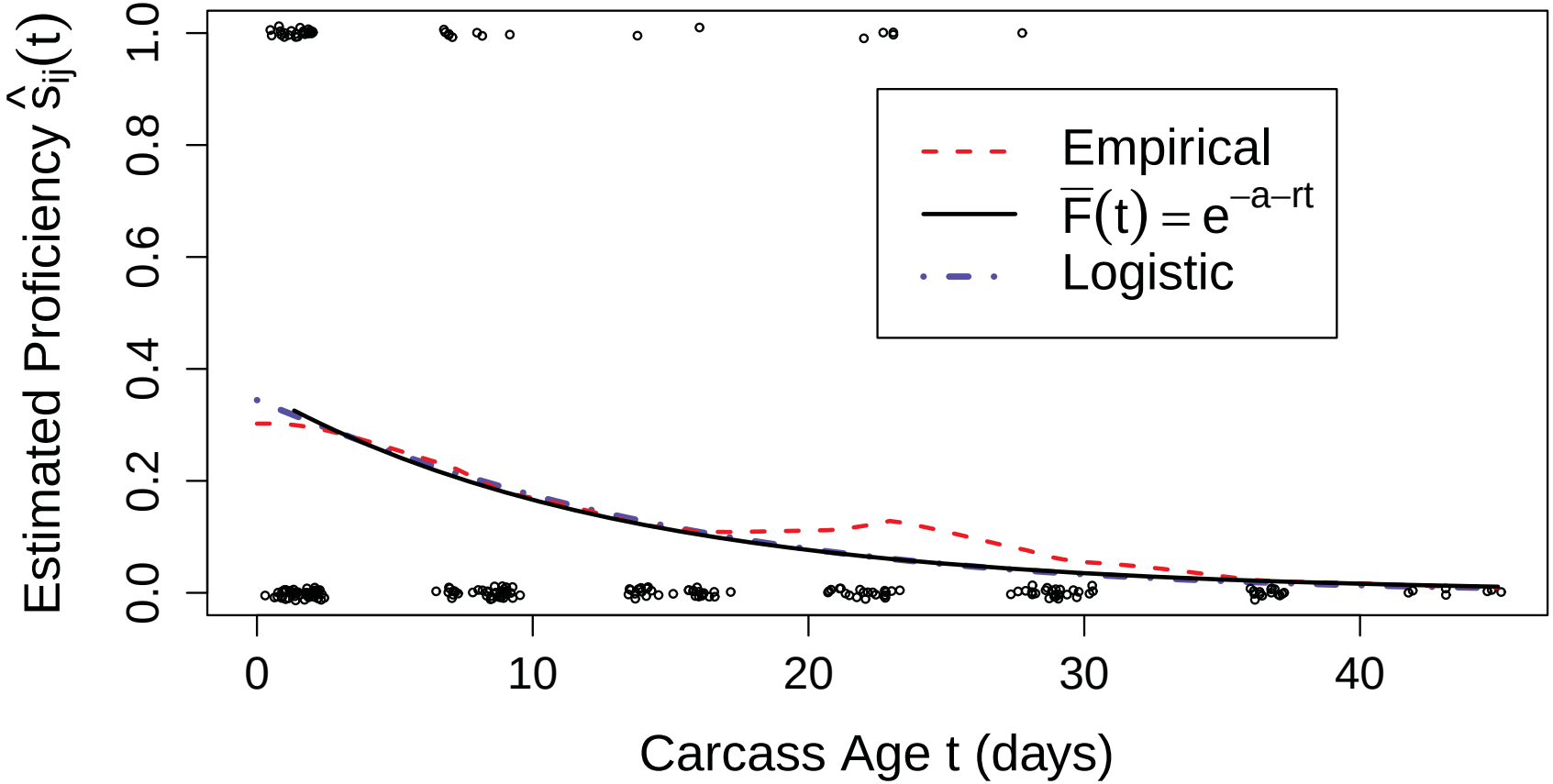
- Weibull, Lognormal, Fisk (Log-logistic) distributions *all* fit data far better than Exponential.
- Ex(λ) is the special case "$\alpha = 1$" of We(α, λ)
- Maximum Likelihood Estimate of α for small birds was

$$\hat{\alpha} = 0.4606, \text{ Standard Error} = 0.0532$$

- MLE is 10.14 SEs away from Exponential Dist'n ($\alpha = 1$)... P-value is 1.8×10^{-24}, far below 0.05.
- Higgs Boson discovery claim was based on 5 SE difference.

Are the Assumptions True?

Constant Proficiency s_{ij}?



Zero bleed-through? 100% bleed-through?

- For long search intervals, bleed-through doesn't matter.
- For short search intervals, probably some old carcasses are discovered.
- Falling search proficiency with carcass age ameliorates this—old carcasses are less likely to be found.
- None of the existing estimators reflects falling s_{ij}.

A note about "Mean Persistence Time" t_{ij}

- Most estimators depend on estimates of average time t_{ij} until removal by scavengers.
- This is a hard thing to estimate, because of censored observations and heavy tails.
- If persistence really had exponential distributions it wouldn't matter... but evidence shows that's wrong.
- Methods recommended in the literature systematically underestimate t_{ij}.
- The relation between daily removal rates and t_{ij} is highly model-dependent.

Something New: A Unified Partially-Periodic Estimator

$$\hat{M}^{\star}_{ij} = \frac{C_{ij}\, l_{ij}}{\hat{s}_{ij}\ \hat{t}_{ij}} \left\{ \frac{e^{l_{ij}/\hat{t}_{ij}} - \theta(1-\hat{s}_{ij})}{e^{l_{ij}/\hat{t}_{ij}} - 1} \right\},$$

with "bleed-through" parameter $0 \leq \theta \leq 1$. Special cases:

- $\theta = \mathbf{0}$: Identical to estimator of Huso and Pollock
- $\theta = \mathbf{1}$: Identical to estimator of Shoenfeld
- $\theta = \frac{\mathbf{1}}{\mathbf{1-s_{ij}}}$: Identical to estimator of Erickson & Johnson

For values $0 < \theta < 1$, this interpolates among them.

Based on:

$$\mathrm{E}[C_{ij}] = M_{ij}\ (t_{ij}/l_{ij})(1 - e^{-l_{ij}/t_{ij}})\ s_{ij} + \quad \theta \quad \mathrm{E}[C_{ij}]\ (1 - s_{ij})\ e^{-l_{ij}/t_{ij}}$$

But...

- This form of the Partially Periodic Estimator allows one to overcome the bleed-through problem, but
- It still assumes exponential distributions (as do Shoenfeld's and Huso's estimators)
- It still assumes constant search proficiency (as do all four previous estimators)

- Something better is needed.

Something Better

A new estimator based on the assumptions:

- Declining removal rate achieved through Weibull We(α, r) persistence distribution

$$\mathrm{P}[\tau > t] = e^{-(r\,t)^{\alpha}}$$

  for some parameters $0 < \alpha \leq 1$, $r > 0$;

- Diminishing proficiency

$$s_{ij}\left(t_k\right) = e^{-a-b\,t_k}$$

  where t_k denotes the "age" of kth carcass

- Partial periodicity, with a fraction $0 \leq \theta \leq 1$ of remaining carcasses still discoverable
- Parameters (α, r), (a, b), θ are estimated in Detection Probability Trials designed to accommodate censoring.

The New Estimator:

$$\hat{M}^{\star}_{ij} = \frac{C_{ij}\, l_{ij}}{R^{\star}_{ij}}$$

where C_{ij} is the Carcass Count, l_{ij} is Interval Length and, for $\theta = 0$ (no bleed-through, as in Huso and Pollock), and $R^{\star}_{ij}$ is the *adjusted* (for diminished search proficiency) *remainder factor*:

$$R^{\star}_{ij} = \int_0^{l_{ij}} \exp\Big(-(r_{ij}\, x)^{\alpha} - a - bx \Big)\, dx$$

Easily calculated on a computer— or, for $\alpha \approx 1/2$ as in our small bird data, available explicitly as

$$\begin{aligned} R^{\star}_{ij} &= Q^{\star}(0; a, b, r_{ij}) - Q^{\star}(l_{ij}; a, b, r_{ij}), \quad \text{where} \\ Q^{\star}(x; a, b, r) &= \exp\big(-a - bx - \sqrt{rx} \big)/b \\ &\quad - e^{-a+r/4b}\, \Phi\Big(-\sqrt{2bx} - \sqrt{r/2b} \Big) \sqrt{\pi r/b^3}. \end{aligned}$$

Summary

New estimator:

- Includes as special cases those of Erickson & Johnson, Shoenfeld, Huso, and Pollock,
- Extends to **Partially Periodic** case of $\theta > 0$,
- Allows exponential or more realistic **Weibull** persistence times with **declining removal rate**,
- Allows constant or more realistic **dimishing proficiency**,
- Is not much harder to use than existing ones, after an **integrated detection trial** to estimate the five parameters

(α, r)	(for persistence distribution),
(a, b)	(for proficiency), and
θ	(for bleed-through).

Suggestions:

- For short intervals $I_{ij} \ll t_{ij}$, bleed-through θ is important—getting it wrong will distort estimates (up *or* down).
- For long intervals $I_{ij} \gg t_{ij}$, diminishing proficiency $s_{ij}(t)$ is important. So is declining removal rate: use Weibull or Log Normal or Log Logistic removal distributions, *not* exponential.
- For moderate intervals $I_{ij} \approx t_{ij}$ and search proficiencies s_{ij}, ratios among estimators are no worse than about 3:2.
- All these issues (bleed-through, diminishing proficiency, declining removal rate) can be addressed with a modest increase in complexity with a **partially periodic estimator** and a suitable **integrated detection probability trial**.

Summary: Model Comparison

Model Characteristics

- Contrasting with lessons from the field work:
  - All models assume constant searcher proficiency
  - Some models assume an exponential distribution (fresh and older carcasses equally attractive to scavengers)
- Some models assume bleed-through (Shoenfeld), some don't (Huso, Pollock), and E&J assume equilibrium

Summary: Model Comparison

- For exponential removal:

  Erickson & Johnson < Shoenfeld < Pollock < Huso

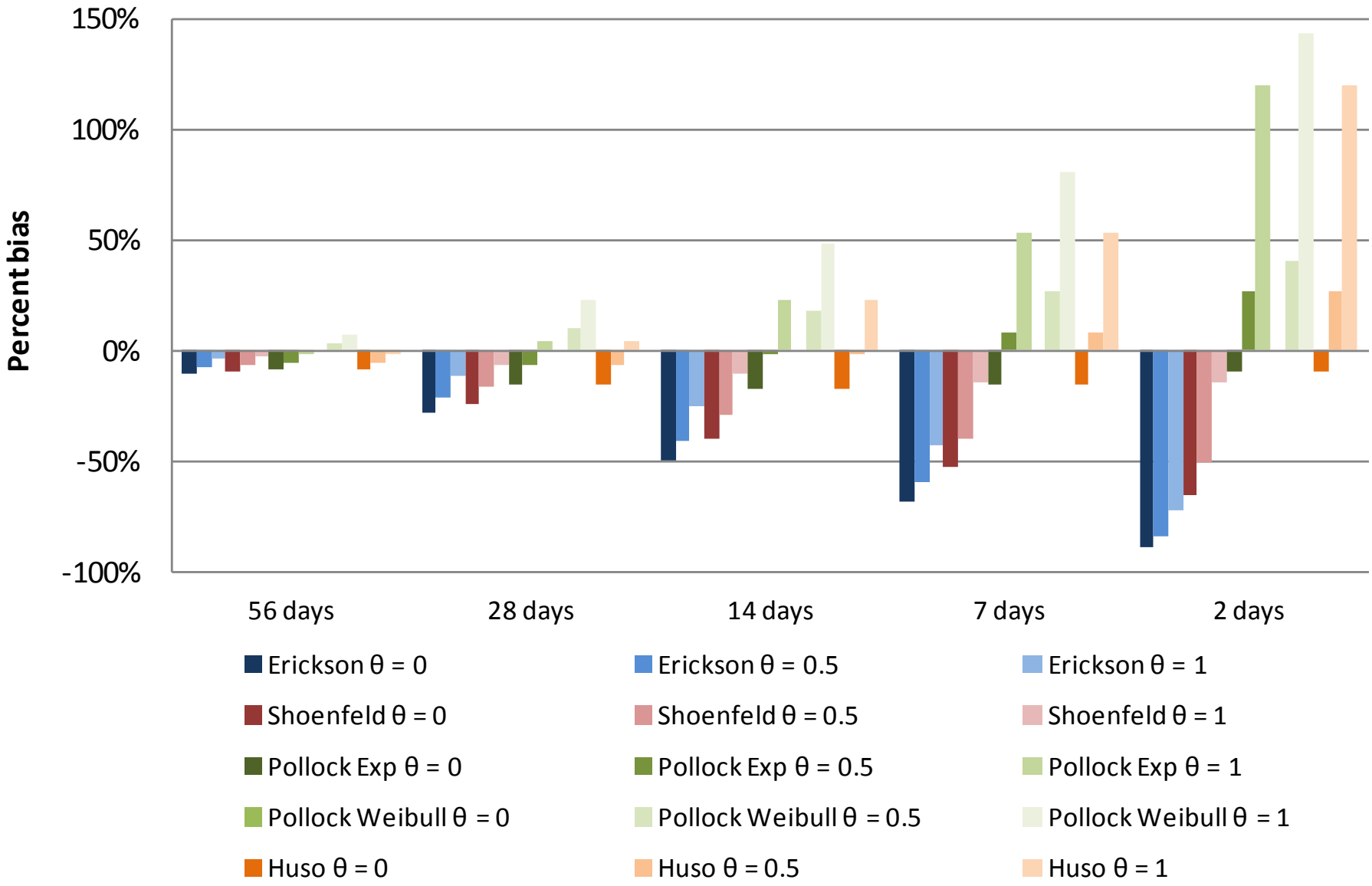
- Even though biased, if search interval is long compared to mean persistence time:
  - **All 4 estimators give about the same results**

- But, if search interval is short relative to persistence:
  - **Differences among equations increase**

Are Short Search Intervals Useful?

- Short search intervals increase chance of bias
  - Short intervals do not allow system to reach equilibrium, inconsistent with E&J assumption
  - Huso and Pollock assume 0% bleed-through, therefore bias will occur if bleed-through is more
  - Shoenfeld assumes 100% bleed-through, therefore bias will occur if bleed-through is less
- New partially-periodic equation allows for any bleed-through, therefore works very well with short or long intervals

Comparison of Bias in Estimators at Various Search Intervals and "Bleed-Through" θ Assumptions with Removal Distribution α = 0.7



Recommendations

Given the shortcomings of traditional estimators …

Traditional fatality estimators do not sufficiently account for

- Time-dependent processes of carcass persistence and searcher proficiency, and
- "Bleed-through" (the portion of carcasses persisting through a search interval that can be detected in subsequent search interval)

… CalWEA's Research Team developed and recommends:

- New fatality estimator ("partially-periodic" presented above), and
- Integrated detection probability trial methodology

Why Traditional Detection Trials Won't Work

- Traditional Searcher Proficiency Trials
  - Only fresh carcass detection events
  - One day trials
- Traditional Carcass Persistence Trials
  - No way of measuring bleed-through

Requirements for a New Integrated Detection Probability Trial

1. A preliminary traditional carcass persistence trial
2. Strategic placement of trial carcasses
3. Traditional schedule of carcass checks, with additional checks on the same day as scheduled searches
4. Searchers record detected trial carcasses over multiple search intervals
5. Measure the proportion of carcasses that persist (bleed-through) from one search interval to the next to derive the term theta

Analytical Products Gained From New Integrated Detection Trial

1. Time dependent probabilities for carcass persistence and searcher proficiency

2. A measurement of theta (bleed-through)

3. Traditional fatality estimator parameters are conserved

Conclusions
Policy Decision Implications

- Potentially faulty fatality estimates are being used in decision-making
- Are the errors of consequence?
  - Accuracy vs. precision
- Caution is required …

Conclusions
Policy Decision Implications

- Caution needed in determining:
  - National avian and bat mortality values
  - Industry averages
  - Regulatory standards for monitoring
  - Numerical “thresholds” for additional actions
    - HCP and IT Permit numbers for endangered species
    - Post-construction monitoring
    - Adaptive management requirements
- Caution needed when comparing:
  - Specific project results to national industry averages
  - Intra-project results where study approaches have differed
  - Results among wind facilities

Conclusions
Study Design Implications

- To generate accurate and comparable fatality detection probabilities and fatality estimates
  - Uniform, standardized methods are needed
  - Partially periodic equation produces unbiased results
  - New equation requires new field study protocols

Final Thoughts & Questions

This webinar will be posted (early October)
and the final report by (November)

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