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science for a changing world

# Estimating direct fatality impacts at wind farms: How far we've come, where we have yet to go

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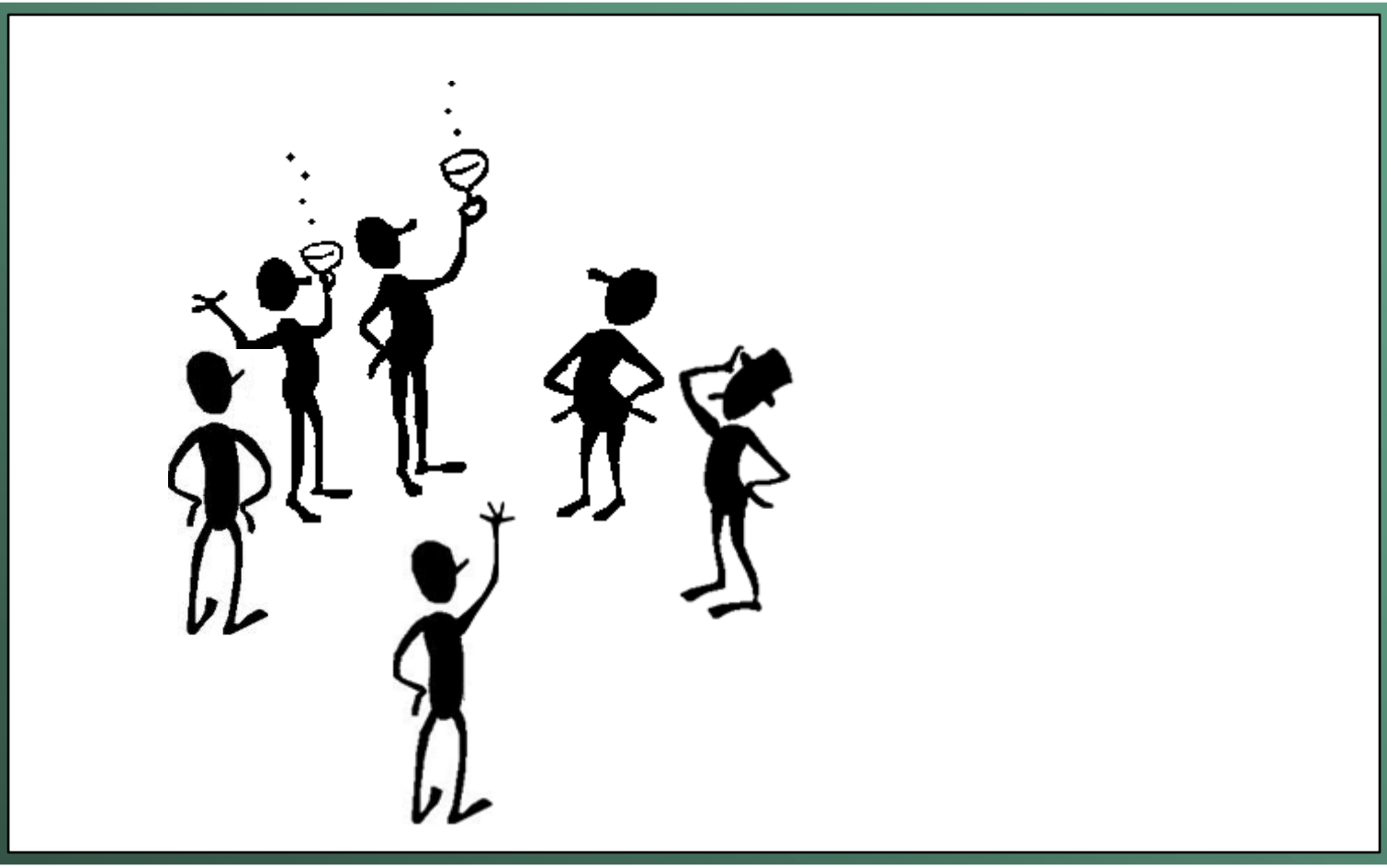
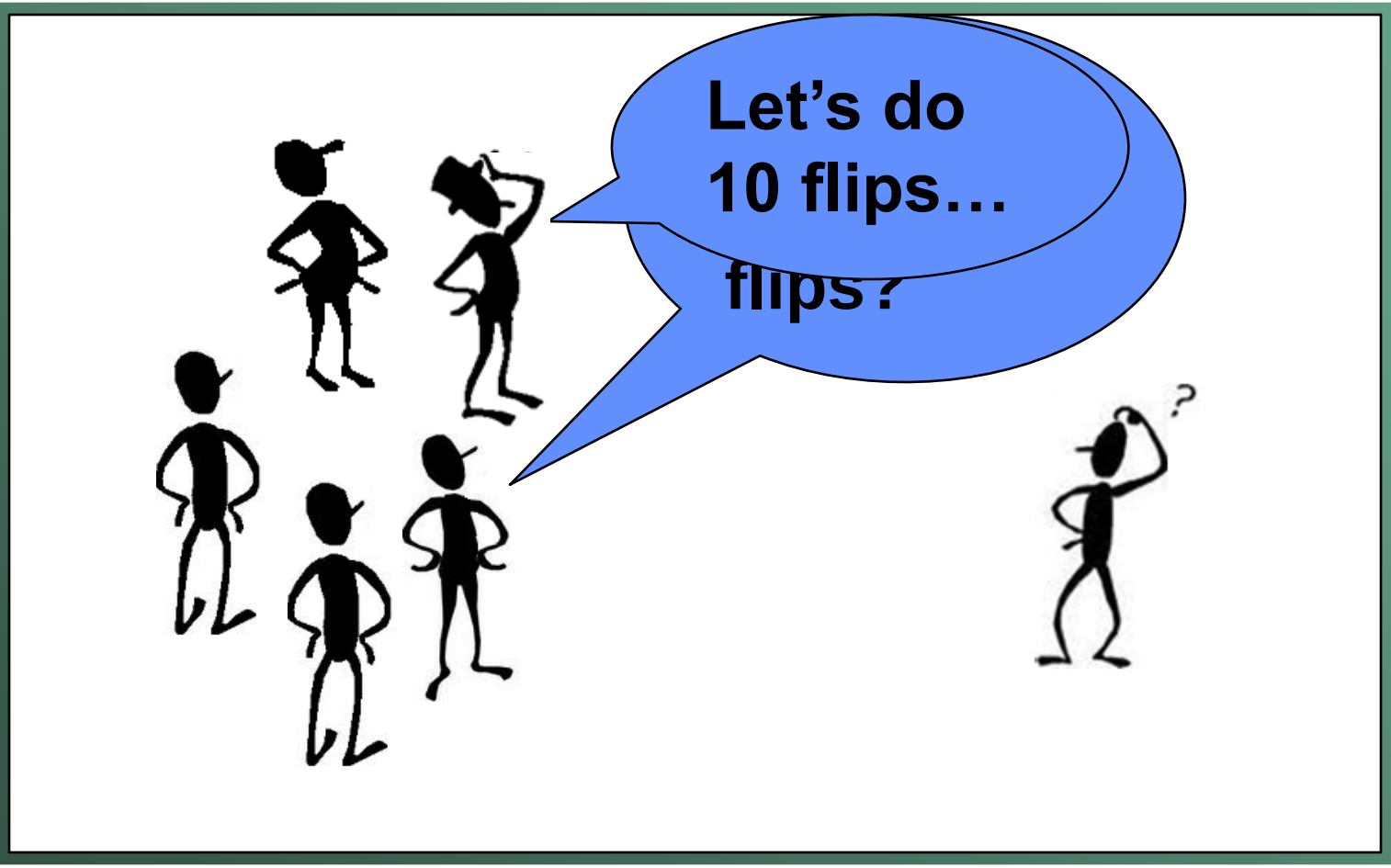
# Estimating fatality is like a parlor game



# Estimating fatality is like a parlor game

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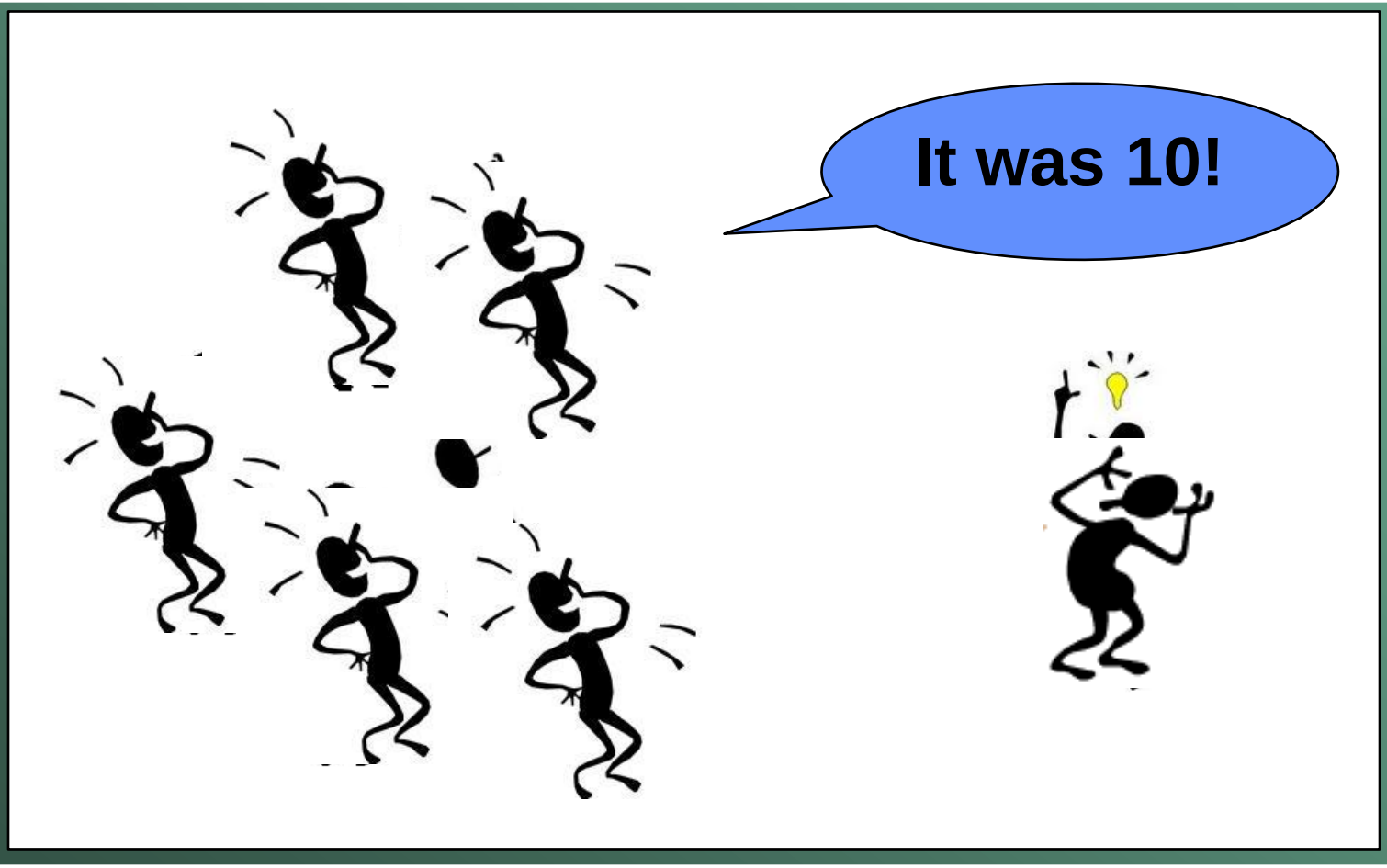
# Estimating fatality is like a parlor game

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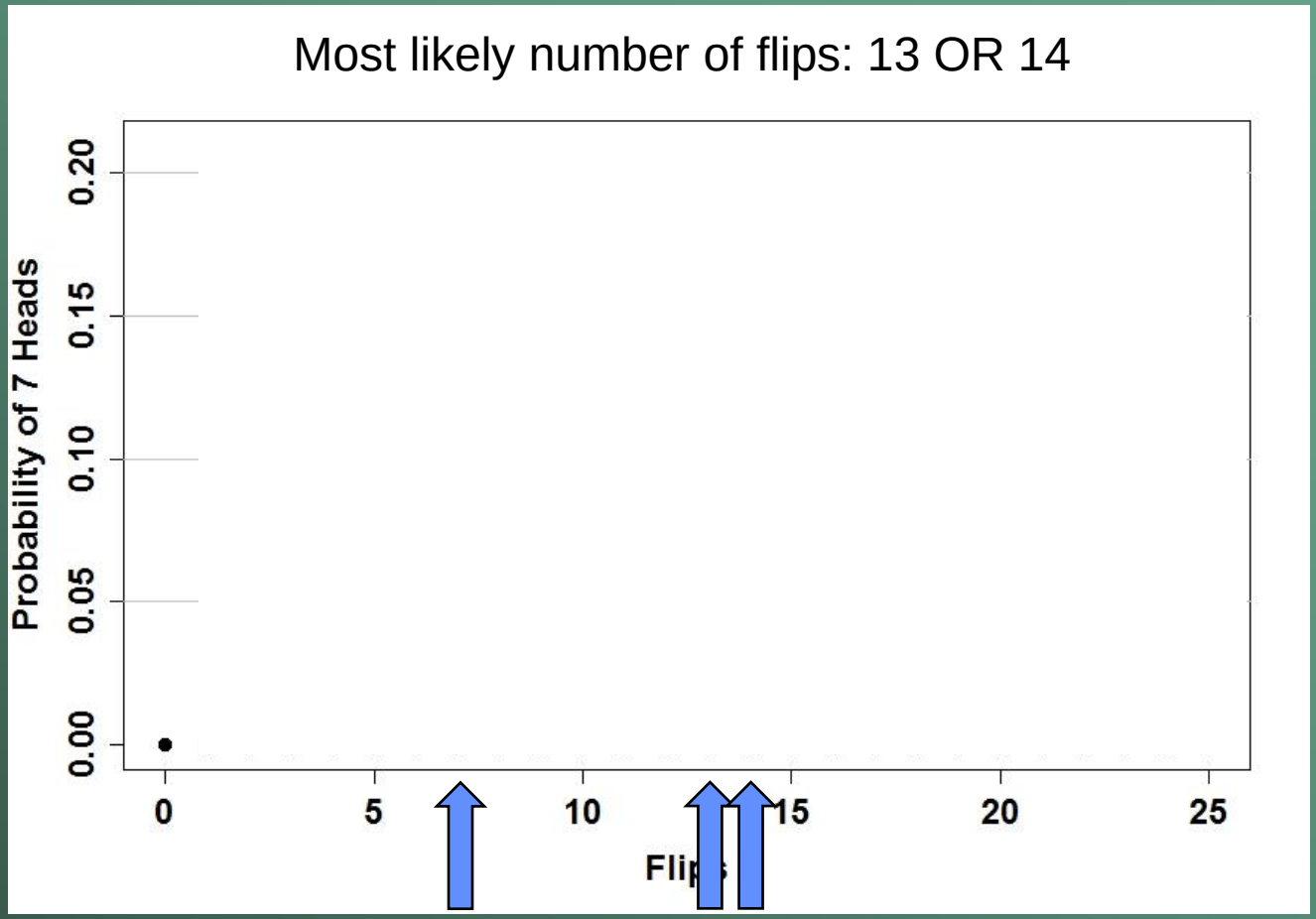
# Probability of 7 Heads with fair coin

$N \geq 7$

$\hat{N}$=13 or 14

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# Probability of 7 Heads with fair coin

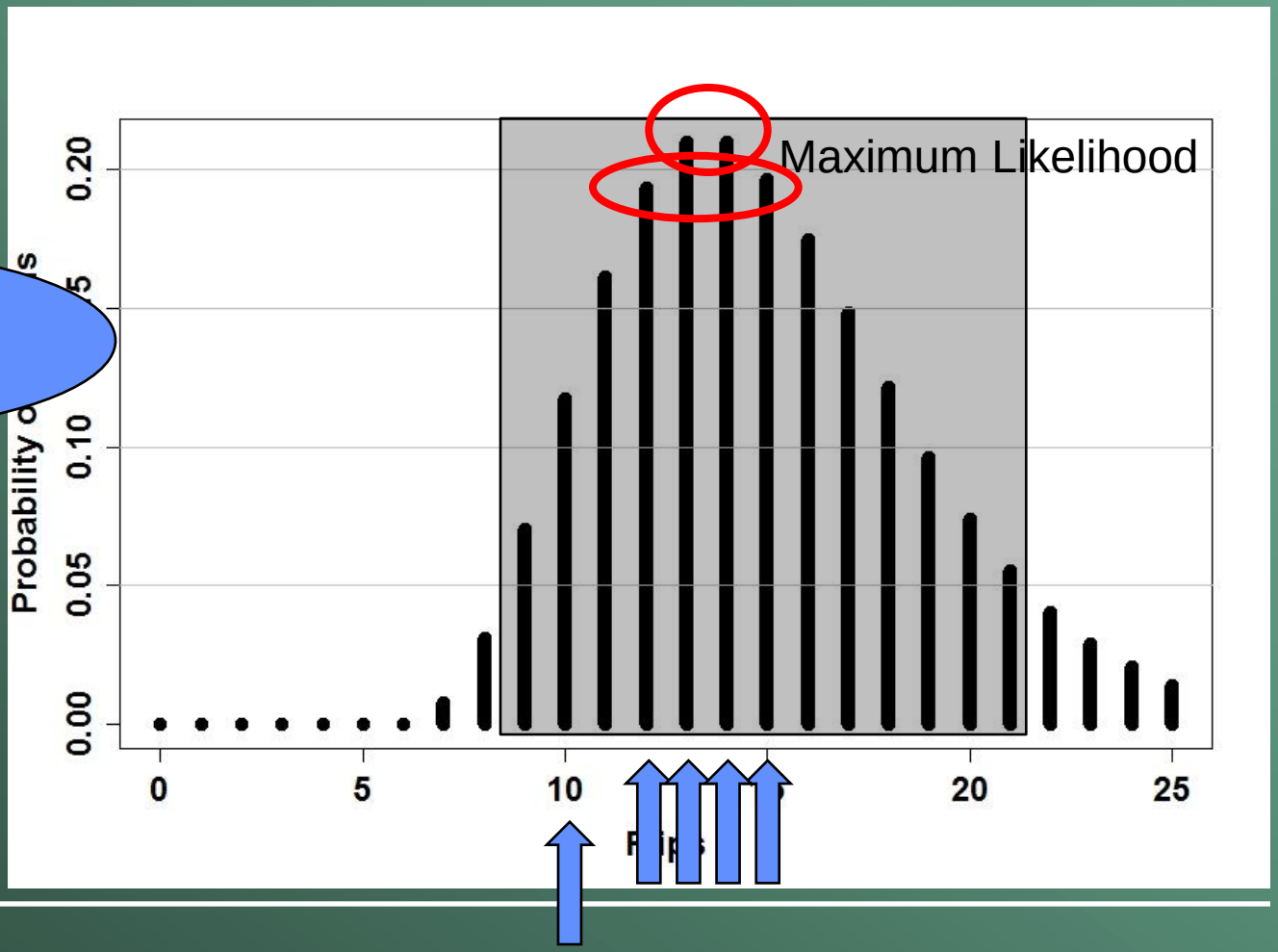
$N \geq 7$

$\hat{N}$=13 or 14

I was right!

$9 \leq \hat{N}$ [illegible]21

10 in[illegible]rval

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# Analogy

- Number of flips = number of dead animals
- Pr(Heads) = Pr(detection)

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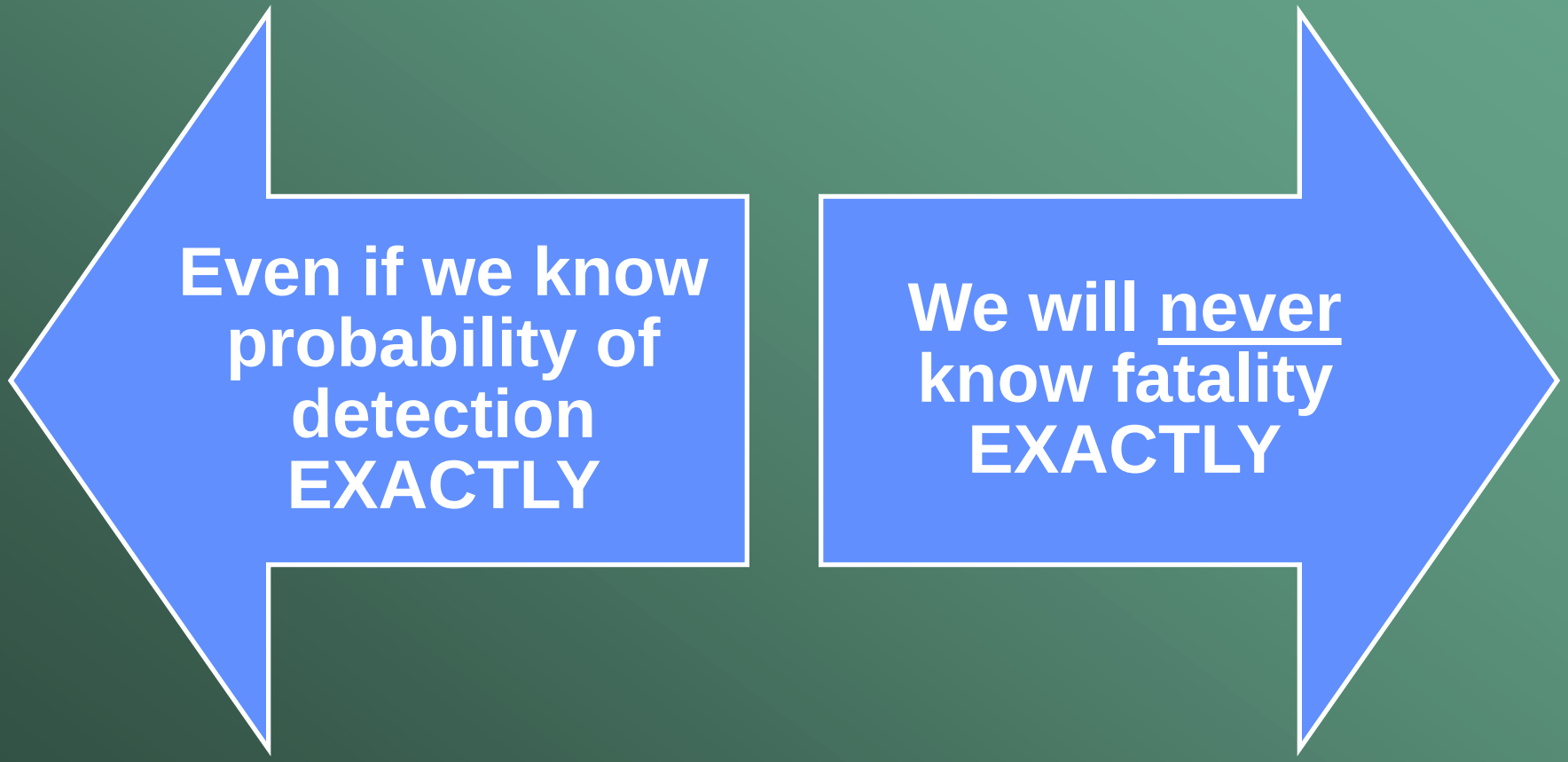
Even if we know probability of detection EXACTLY
We will never know fatality EXACTLY

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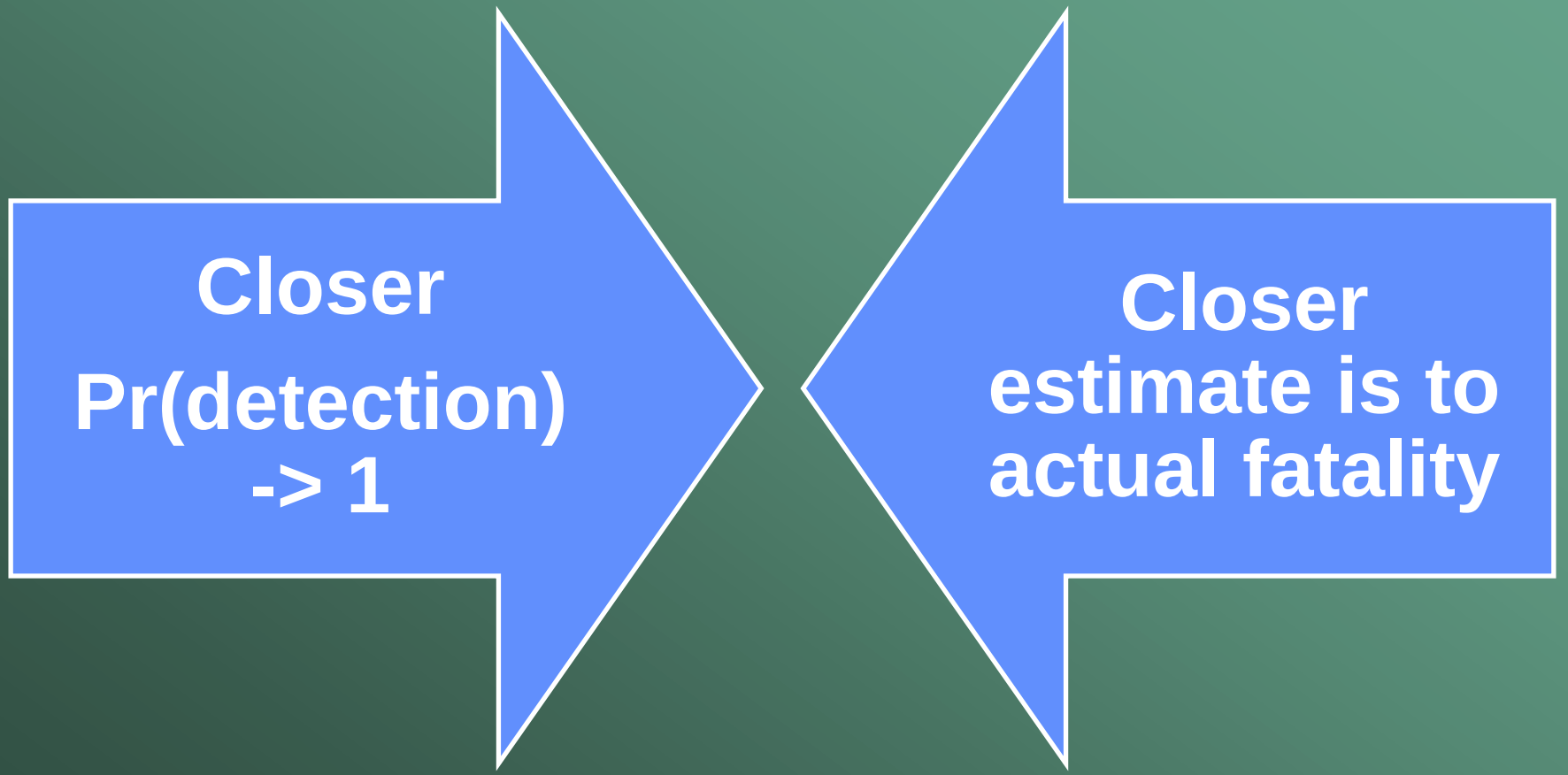
Closer
Pr(detection)
-> 1
Closer
estimate is to
actual fatality

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# Major sources of imperfect detection

$$\hat{F} = \sum_{i=1}^{k} \frac{c_i}{f\,\hat{r}_i\,\hat{p}_i\,\hat{a}_i} = \sum_{i=1}^{k} \frac{c_i}{\hat{g}_i}$$

- *f* = fraction of turbines sampled
- *r* = probability of persisting (~CP)
- *p* = probability of observing a carcass (SE)
- *a* = fraction of carcasses in searched area

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# History

$$\hat{F} = \sum_{i=1}^{k} \frac{c_i}{f\,\hat{r}_i\,\hat{p}_i\,\hat{a}_i} = \sum_{i=1}^{k} \frac{c_i}{\hat{g}_i}$$

- **Pre-Altamont**
  - **Observed fatality but no adjustments made for imperfect detection**
    - **Rogers et al. 1977, 1980; McCrary et al. 1983, 1984, 1986; Estep 1989; Howell et al. 1991**

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# Persistence prob

$$\hat{F} = \sum_{i=1}^{k} \frac{c_i}{f \hat{r}_i \hat{p}_i \hat{a}_i} = \sum_{i=1}^{k} \frac{c_i}{\hat{g}_i}$$

- Altamont
  - CP trials to adjust observed counts
  - Simple proportion persisting 7 d = search interval
    - Assumes all carcasses found died 7 days ago
    - Not flexible to changing search interval

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# Persistence prob

$$\hat{F} = \sum_{i=1}^{k} \frac{c_i}{f \hat{r}_i \hat{p}_i \hat{a}_i} = \sum_{i=1}^{k} \frac{c_i}{\hat{g}_i}$$

- **Recent variations:**
  - **Proportion persisting ½ * I days**
    - **not flexible to changing interval**
  - **Model persistence time with best-fit distribution**
    - **exponential, Weibull, loglogistic, lognormal,…**
    - **calculate r for <u>any</u> period (Huso, 2010; Bispo 2011)**
  - **Model persistence time with Weibull (Wolpert & Warren-Hicks 2012)**

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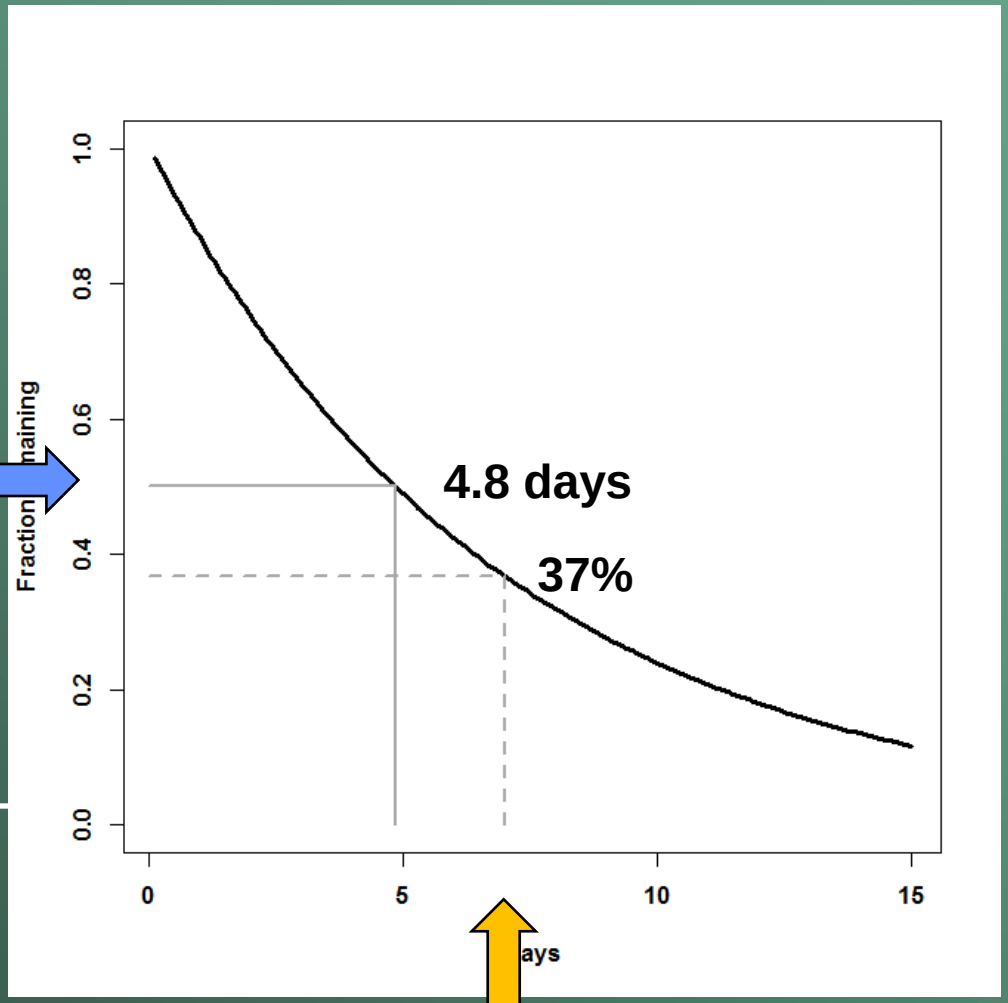
# Carcass persistence: Exponential

- **Average persistence time = 7 days**

  **scale = 1/7**

**How long before ½ are gone?**

**What % remain after 7 days?**

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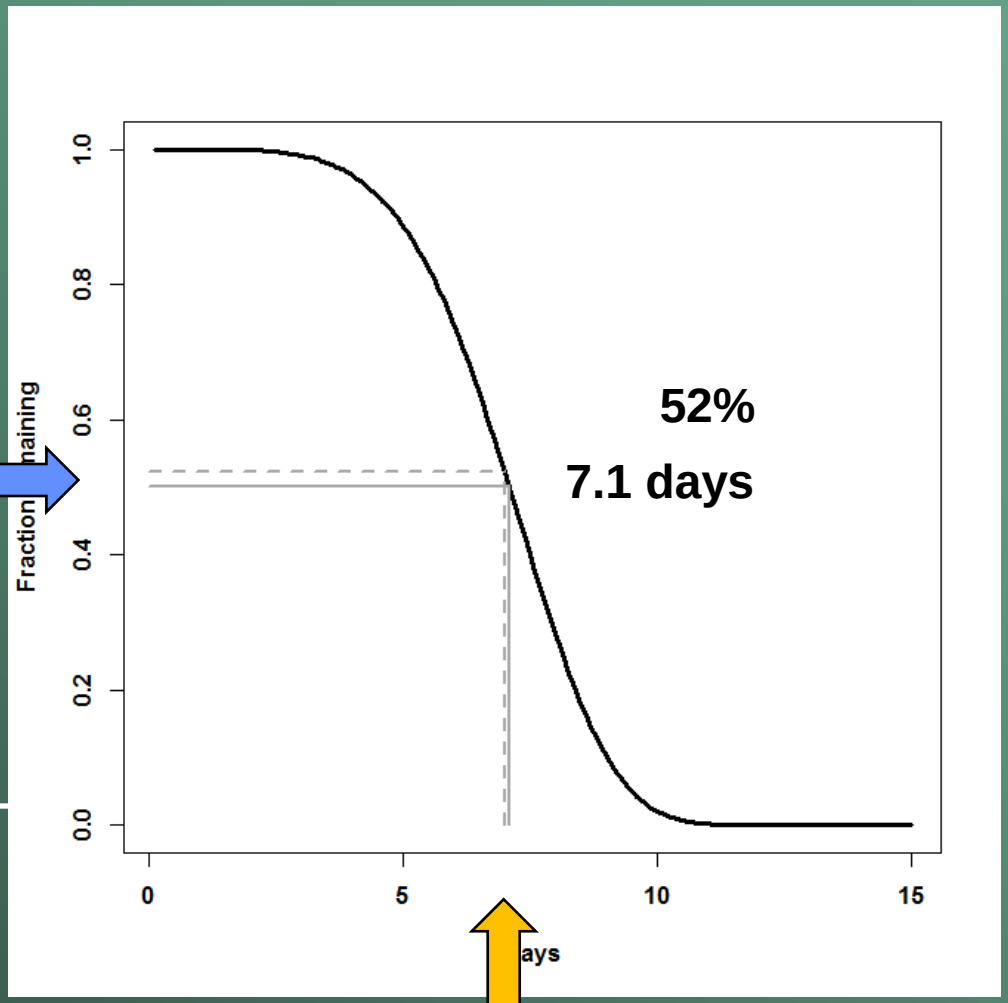
# Carcass persistence: Weibull (1)

- **Average persistence time = 7 days**

  **scale = 1/7.63, shape=5**

**How long before ½ are gone?**

**What % remain after 7 days?**

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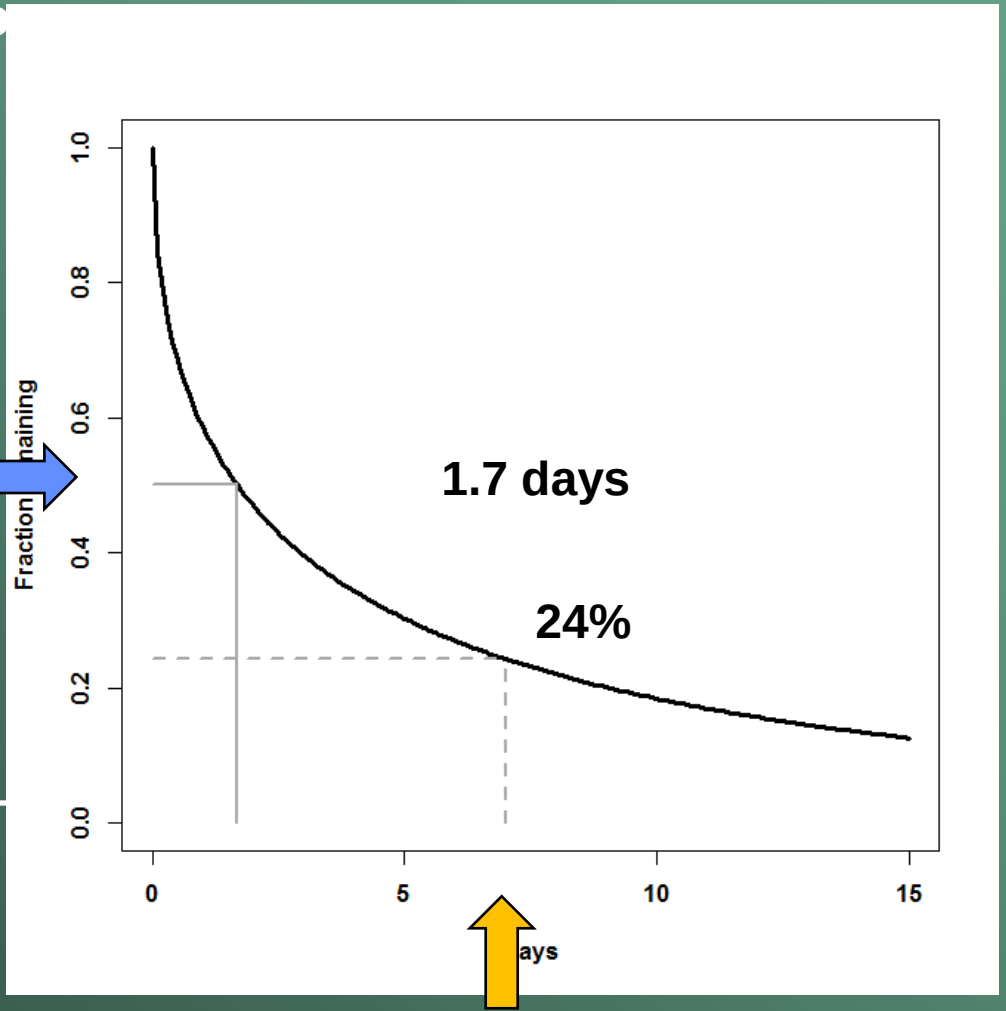
# Carcass persistence: Weibull (2)

- **Average persistence time = 7 days**

  **scale = 1/3.5, shape=0.5**

**How long before ½ are gone?**

**What % remain after 7 days?**

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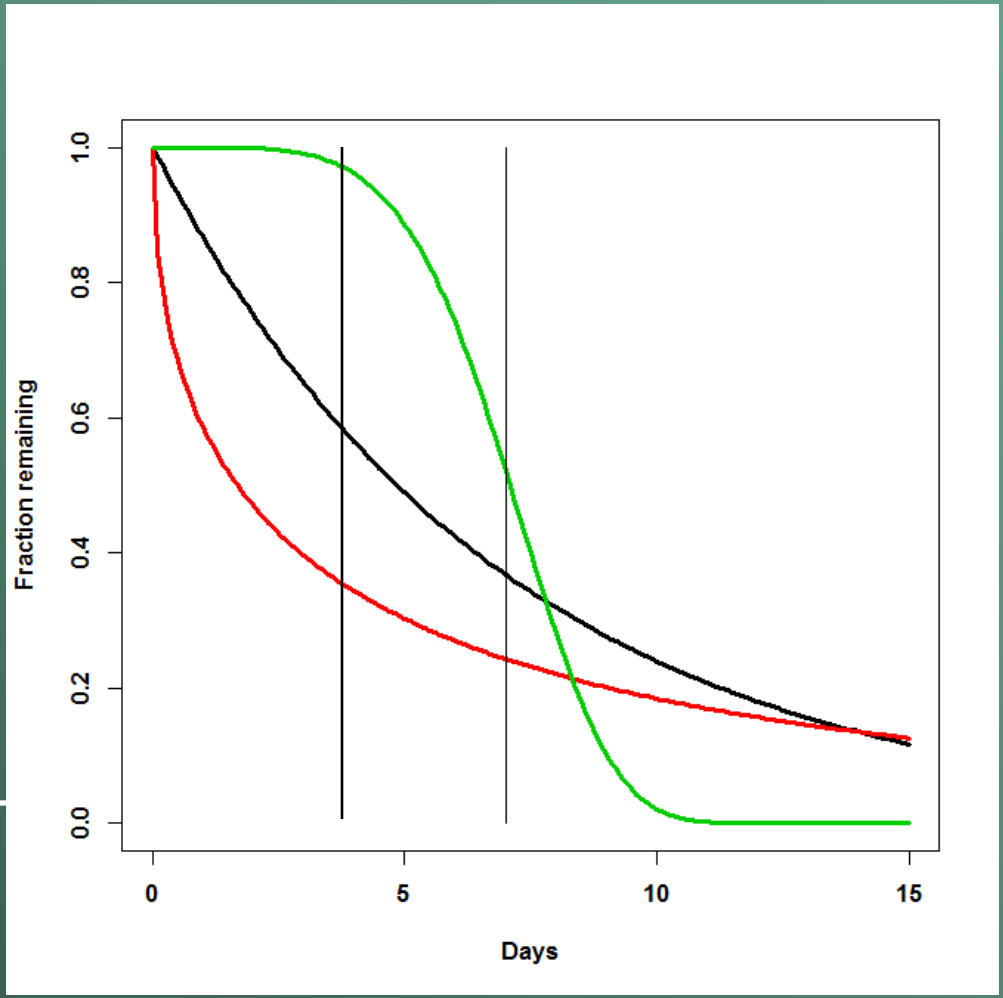
# Carcass persistence

- Average persistence time = 7 days

- Prop$^{tn}$ persisting
  VERY DIFFERENT

Knowing average is
not enough…
need distribution

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# Searcher Efficiency

$$\hat{F} = \sum_{i=1}^{k} \frac{c_i}{f\, \hat{r}_i \hat{p}_i \hat{a}_i} = \sum_{i=1}^{k} \frac{c_i}{\hat{g}_i}$$

- **SE = # found / #placed**

**Assumptions:**

- **SE constant and independent (Schoenfeld 2004)**
  ***overestimate SE ►underestimate F***
- **SE not constant nor independent (Huso 2010)**
  ***underestimate SE ►overestimate F***
- **SE not constant but independent (Wolpert & Warren-Hicks 2012)**

  ***just right…***

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# Area searched

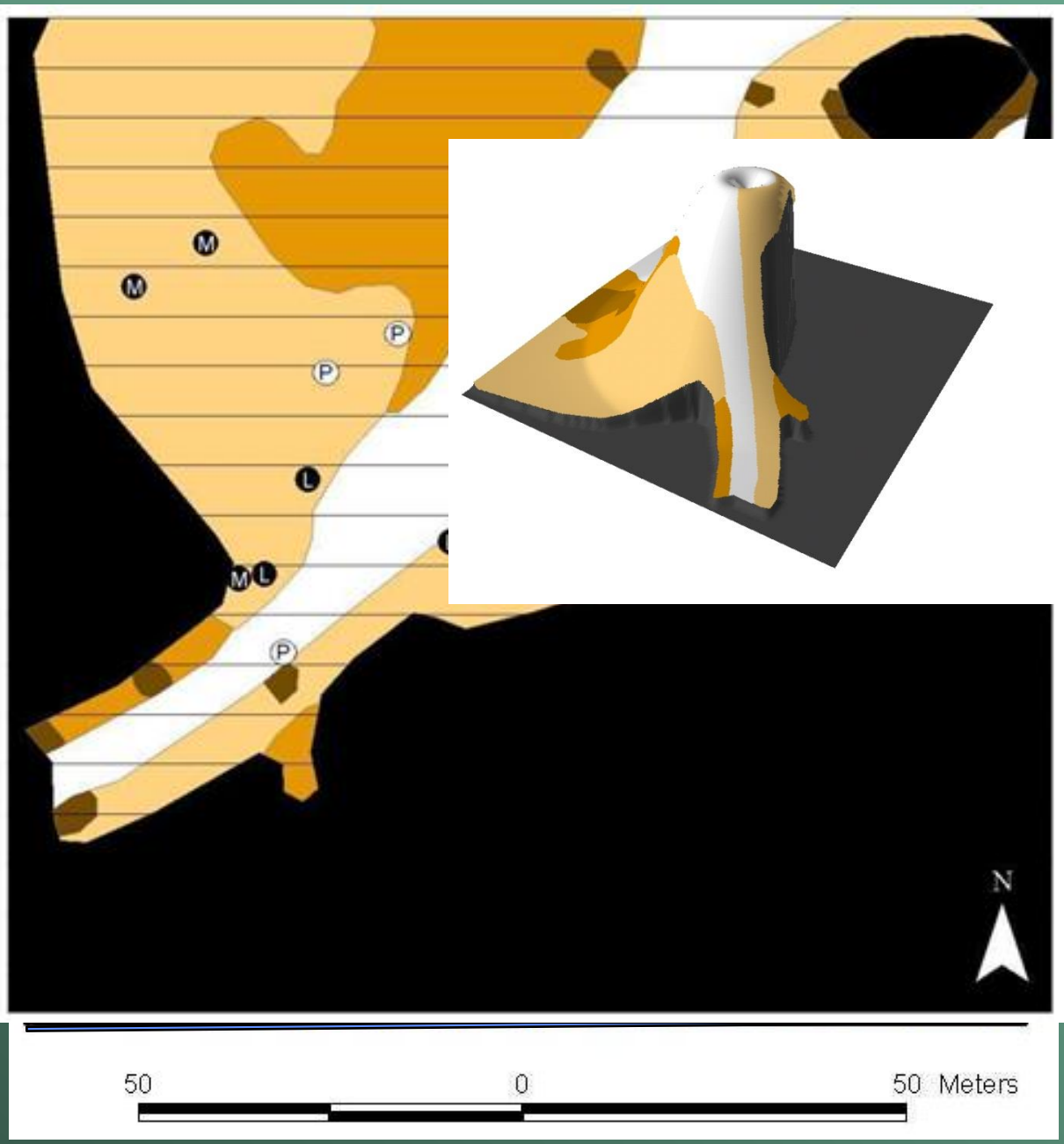
Carcass density not constant

Ratio

R&P/Total

Model

density ~ dist

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From Arnett et al. 2005 BWEC Report

# Variance

$$Var(\hat{F}) = Var\left(\sum_{i=1}^{k} \frac{c_i}{f\ \hat{r}_i \hat{p}_i \hat{a}_i}\right) = ??$$

- What about confidence interval?

  Altamont

  182 birds, 119 raptors over 6 spr/fall

| | | |
|---|---|---|
| 1989: | Large Raptors | 81 ± 112 |
| | Small Raptors | 227 ± 416 |
| 1990: | Large Raptors | 0 ± 112 |
| | Small Raptors | 82 ± 451 |

No information on how variance was calculated

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# Variance

$$Var(\hat{F}) = Var\left(\sum_{i=1}^{k} \frac{c_i}{f\ \hat{r}_i \hat{p}_i \hat{a}_i}\right) = ??$$

- Difficult
- Recent variations:
  - Bootstrap (Erickson et al.; Huso et al.)
  - Closed-form (Wolpert & Warren-Hicks 2012)
  - Other closed-form solutions – negative limits
- No estimate without measure of uncertainty
- Use common sense
  - Model says 150 might have been killed

send it back!

send it back!

# Next Steps: Analysis

- Reanalysis of existing data for cumulative impacts, regional patterns (Sonnenberg et al.)
- Critical evaluation of assumptions
  - Surrogate species?
  - Nearby sites' SE & CP? Previous years' SE & CP?
- Predictive models of activity and/or fatality
  - Confidence Interval ≠ Prediction Interval

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# Next Steps: Estimators

- Improve current H-T estimators to reflect more realistic assumptions
  - Wolpert & Warren-Hicks — SE
  - Bispo et al. — r (~ CP)
  - Erickson et al. — SE and r combined
  - Hull & Muir; Huso & Dalthorp — a

    Sonnenberg et al.; Ong et al.; Kosciuch et al.
- New (not H-T) estimators for rare events,
  - e.g. GOEA, Ibat, …
  - (Peron & Nichols; Huso & Dail; Dalthorp & Huso)

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# Next Steps: Protocol

- Monitoring design tools
  - What fraction of turbines? What search interval?
  - Trial sample size needs
- Increase efficiency, reduce cost
  - Search high probability/high density areas, extrapolate to rest
    - Sonnenberg et al.; Huso & Dalthorp; Roppe et al.
- Develop completely different approach
  - Impact sensors — Delprat et al.; Suryan et al.
  - Cameras — Cryan & Gorreson; Bart et al.

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# THANK YOU!

Statistics means never being able to say you're certain

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