The Optimal Number of Surveys When Detection Rates Vary

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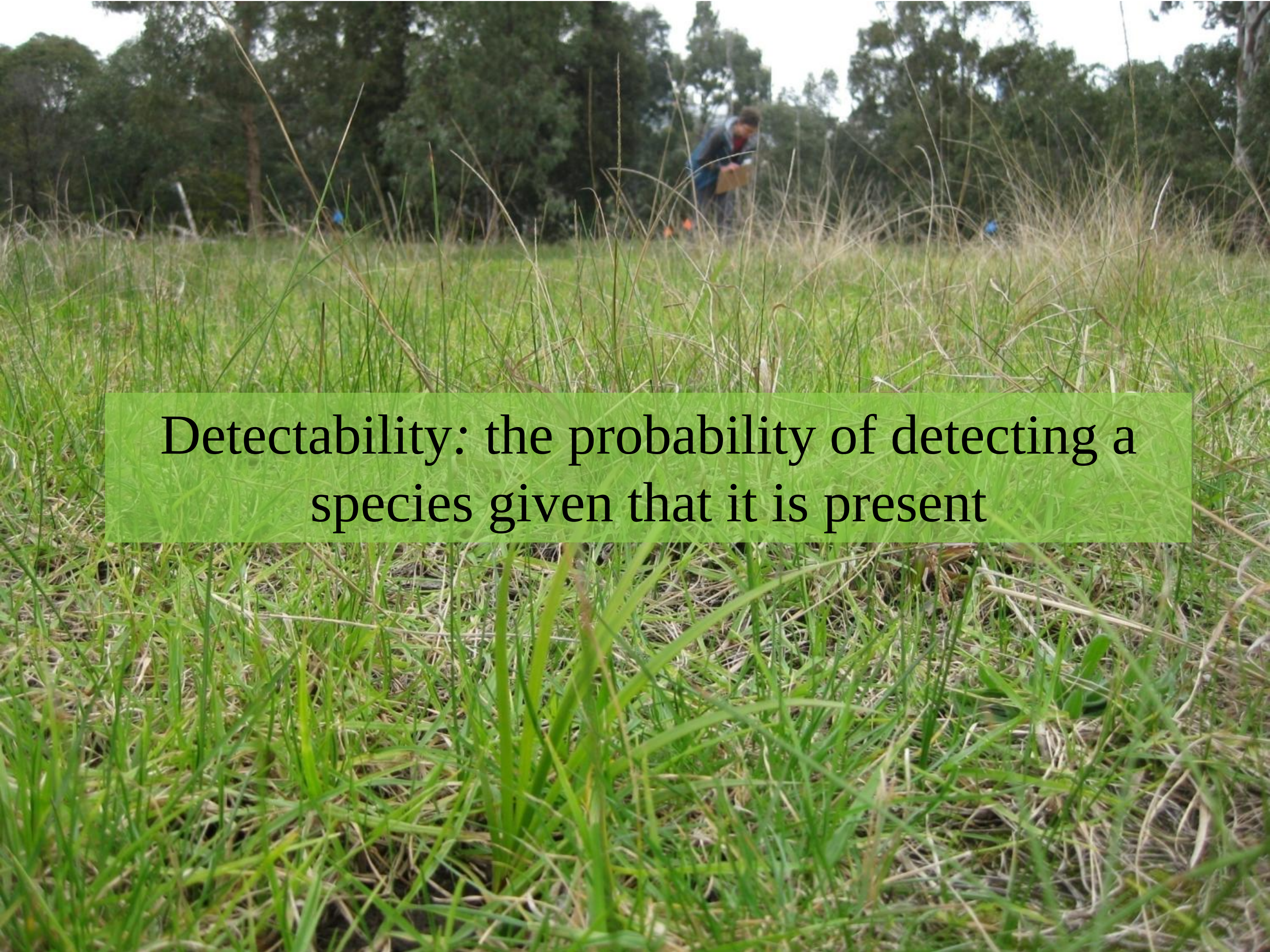
Outline

- Introduction
- Problem description
- Model
- Results
  - An approximate analytic solution
  - Testing the model with data
- Extensions

The optimal number of surveys when detection rates vary


Lomandra


Detectability: the probability of detecting a species given that it is present


Can rarely be sure that a species is truly absent!

Imperfect detection

- Surveys fundamental for ecology
- Imperfect detection is important for a range of ecological studies
  - demographic studies
  - environmental impact assessments
  - species occupancy studies
  - species distribution modelling
  - designing surveys

Diversity and Distributions, (Diversity Distrib.) (2012) **18**, 417–424

BIODIVERSITY RESEARCH

Designing occupancy surveys and interpreting non-detection when observations are imperfect

Brendan A. Wintle*, Terry V. Walshe, Kirsten M. Parris and Michael A. McCarthy

Journal of Applied Ecology 2005
42, 1105–1114

METHODOLOGICAL INSIGHTS

Designing occupancy studies: general advice and allocating survey effort

DARRYL I. MACKENZIE* and J. ANDREW ROYLE†
**Proteus Wildlife Research Consultants, PO Box 5193, Dunedin, New Zealand; †US Geological Survey, Patuxent Wildlife Research Center, 12100 Beech Forest Road, Laurel, MD 20708–4017, USA*

Austral ECOLOGY A Journal of ecology in the Southern Hemisphere
Austral Ecology (2008) **33**, 986–998

When have we looked hard enough? A novel method for setting minimum survey effort protocols for flora surveys

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Ecology Letters, (2009) **12**: 683–692 doi: 10.1111/j.1461-0248.2009.01323.x

LETTER

Streamlining 'search and destroy': cost-effective surveillance for invasive species management

Cindy E. Hauser[1]* and Michael A. McCarthy[2]

Abstract
Invasive species surveillance has typically been targeted to where the species is most likely to occur. However, spatially varying environmental characteristics and land uses

Detection rates vary

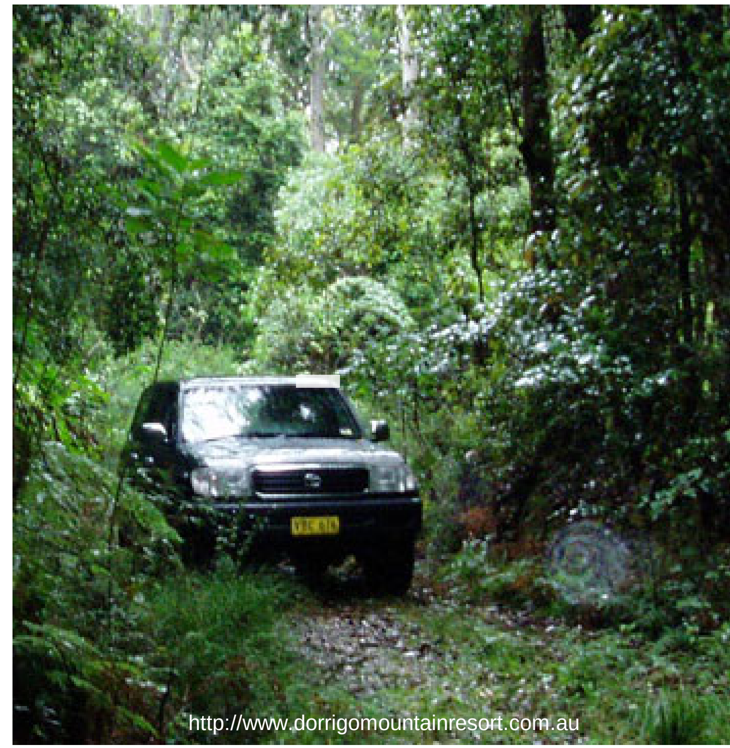
Detection rates vary

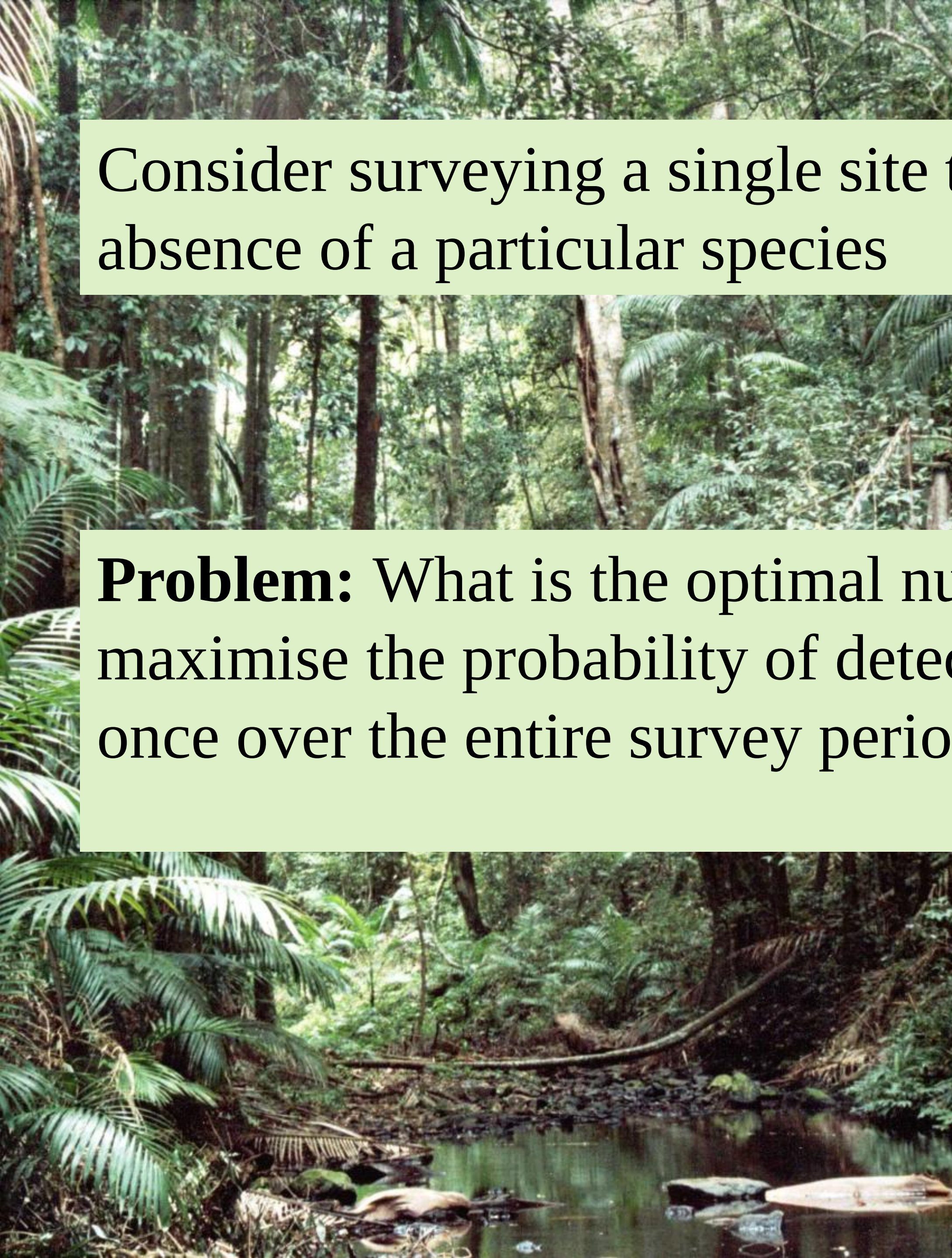
Detection rates vary

Detection rates vary

- Some can be predicted in advance but some cannot: e.g. frogs

Consider surveying a single site to determine presence or absence of a particular species





Consider surveying a single site to determine presence or absence of a particular species

Problem: What is the optimal number of visits to maximise the probability of detecting the species at least once over the entire survey period?

Modeling detection

B, per site budget for searching & travel

c, travel cost of each survey

n surveys

$t = B/n - c$ (time per survey)

Modeling detection

$q_i = \exp(-t\lambda_i)$, probability of failed detection

Assume λ_i iid random variables with mean μ and variance σ^2

$q = \Pi q_i = \exp(-t\Sigma\lambda_i)$ (over n surveys)

$A = \Sigma\lambda_i$ r.v. with mean $n\mu t$ and variance $n\sigma^2 t^2$

Assume $\Sigma\lambda_i$ ~ dlognorm()

Optimisation Model

Minimise E[q] = $\exp(-t\Sigma\lambda_i)$

s.t. $n(t + c) = B$,

where

B, per site budget for searching & travel

c, travel cost of each survey

n surveys

Optimisation Model

Minimise E[q] = $\exp(-t\Sigma\lambda_i)$,

s.t. $n(t + c) = B$

Assume

- $\Sigma\lambda_i$ ~ dlognorm()
- λ_i are iid random variables with known mean μ and variance σ^2

Model

Expected probability of failed detection…

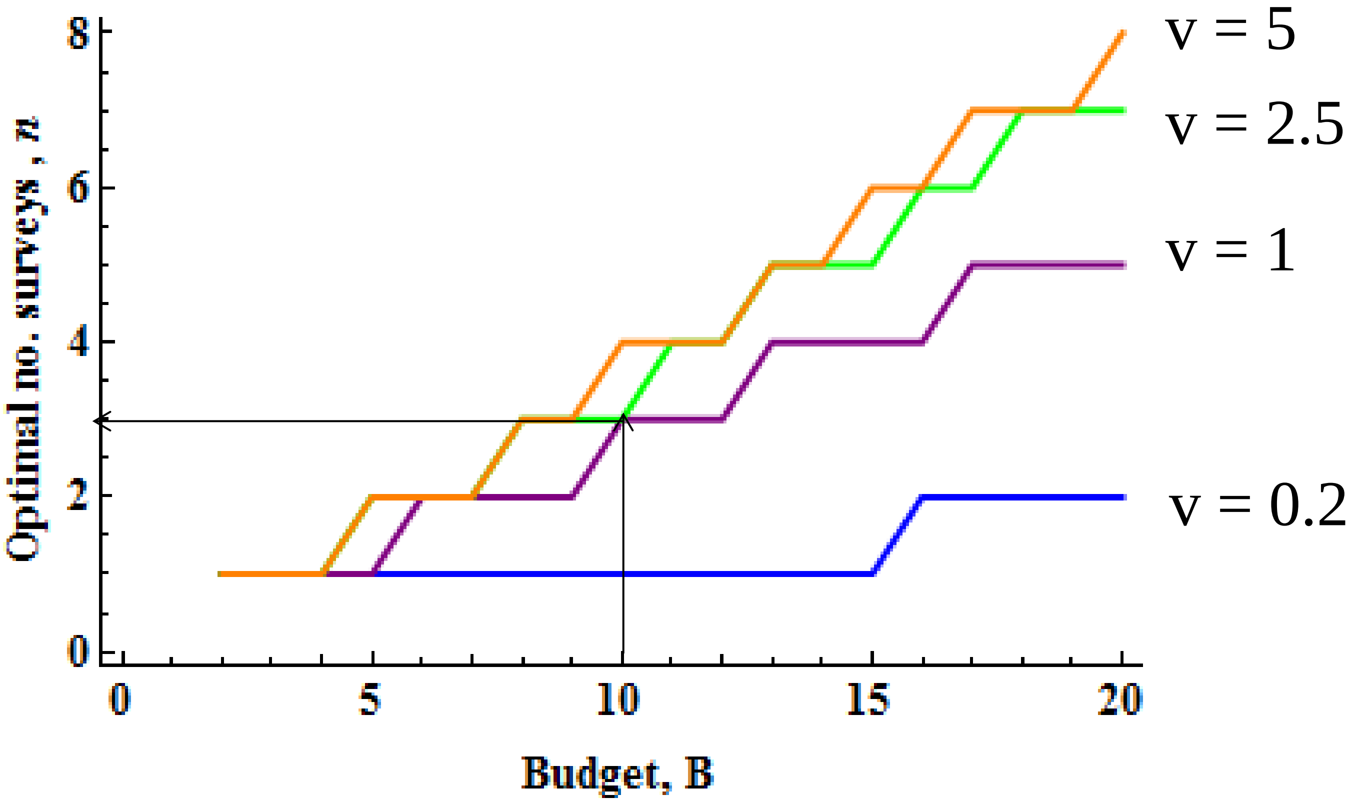
$$E[q] = \int_0^1 -\frac{e^{-\frac{(-\ln[(-c+\frac{B}{n})n\mu]+\frac{1}{2}\ln[1+\frac{\sigma^2}{n\mu^2}]+\ln[-\ln[q]])^2}{2\ln[1+\frac{\sigma^2}{n\mu^2}]}}}{\sqrt{2\pi}\ln[q]\sqrt{\ln[1+\frac{\sigma^2}{n\mu^2}]}}\,dq$$

Model

Expected probability of failed detection…

$$E[q] = \int_0^1 -\frac{e^{-\frac{\left(-\ln[(-c+\frac{B}{n})n\mu]+\frac{1}{2}\ln[1+\frac{\sigma^2}{n\mu^2}]+\ln[-\ln[q]]\right)^2}{2\ln[1+\frac{\sigma^2}{n\mu^2}]}}}{\sqrt{2\pi}\ln[q]\sqrt{\ln[1+\frac{\sigma^2}{n\mu^2}]}}\,dq$$

Results: optimal frog surveys



μ = 0.67 dets/hr
v = 2.5
B = 10 hours
c = 1 hour

Cascade Tree-frog

Parris KM (2001) Distribution, Habitat Requirements And Conservation Of The Cascade Treefrog (Litoria Pearsoniana, Anura: Hylidae). *Biological Conservation* 99: 285–292.

An analytical solution?

- General insights, e.g. key parameter combinations
- Easier for users to implement
- Useful for examining for complicated scenarios, e.g. multiple sites

Approximate solution

Laplace's approximation:

$$\int f(q)dq \approx \exp(h(q^*)) \left(-\frac{2\pi}{h''(q^*)}\right)^{1/2},$$

where *h*(*q*) = ln *f*(*q*) and the global maximum of *h*(*q*) occurs at q^*

Approximate solution

- $E[q] \approx e^{-(B\mu - c\mu n)} \left(\frac{n}{n+v^2}\right)^{3/2} \sqrt{\frac{n}{n+v^2}}$

where v = σ/μ is the coefficient of variation.

Approximate solution

- $E[q] \approx e^{-(B\mu - c\mu n)} \left(\frac{n}{n+v^2}\right)^{3/2} \sqrt{\frac{n}{n+v^2}}$

where v = σ/μ is the coefficient of variation.

- n* is the solution to the implicit equation

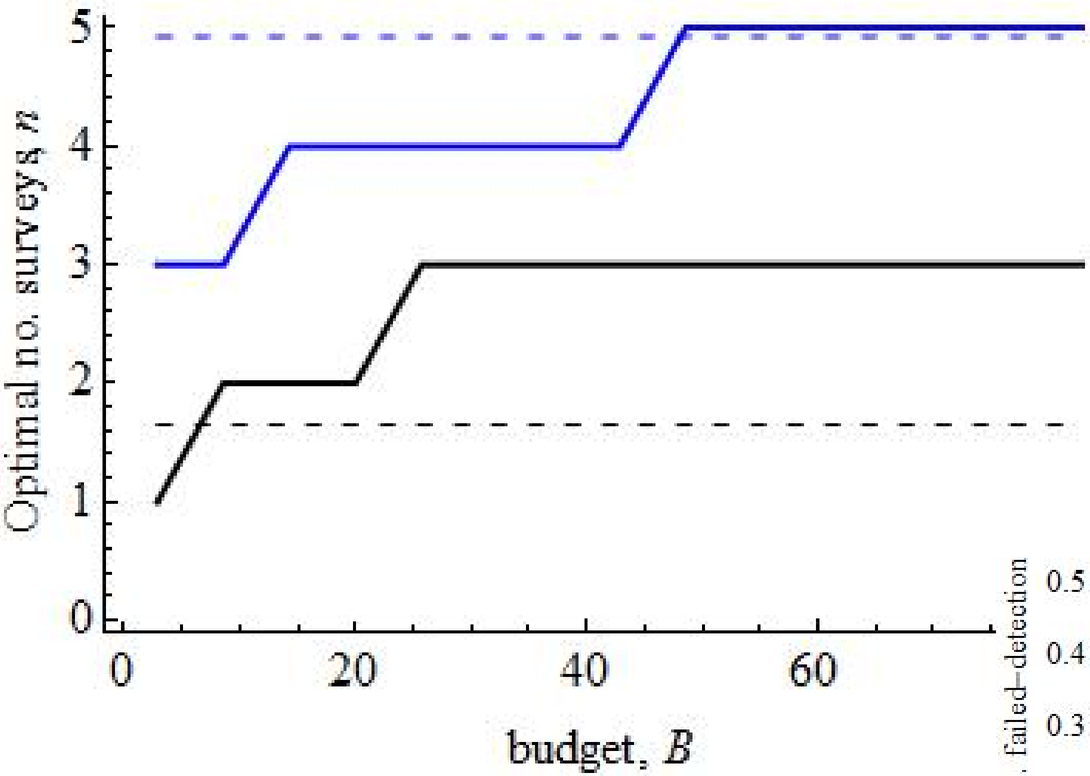
$$3B\mu = c\mu n\left(5 + \frac{2n}{v^2}\right) + \left(1 + \frac{v^2}{n}\right)^{3/2}, \quad \frac{B}{c} \geq n \geq 1$$

Approximate solution

$$n^* \approx \frac{1}{4} v \sqrt{24 \frac{B}{c} + 25v^2} - 5v^2$$

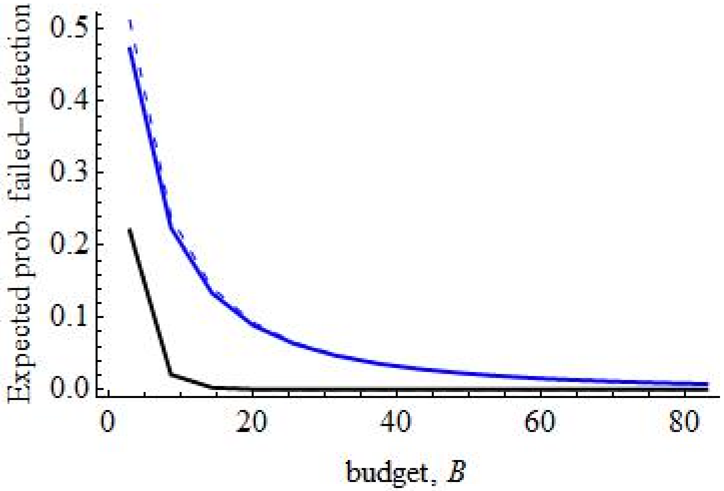
where $v = \sigma / \mu$

Approximate solution



v = 3

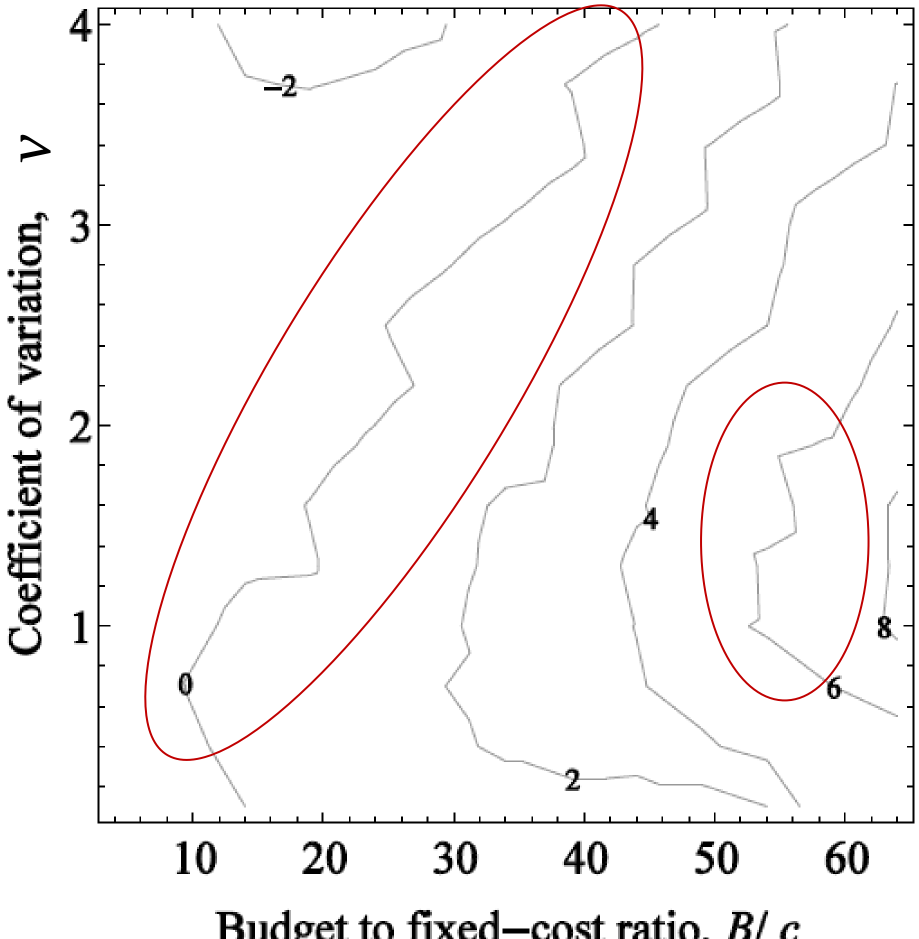
v = 0.5



B/c = 10, μ=0.7

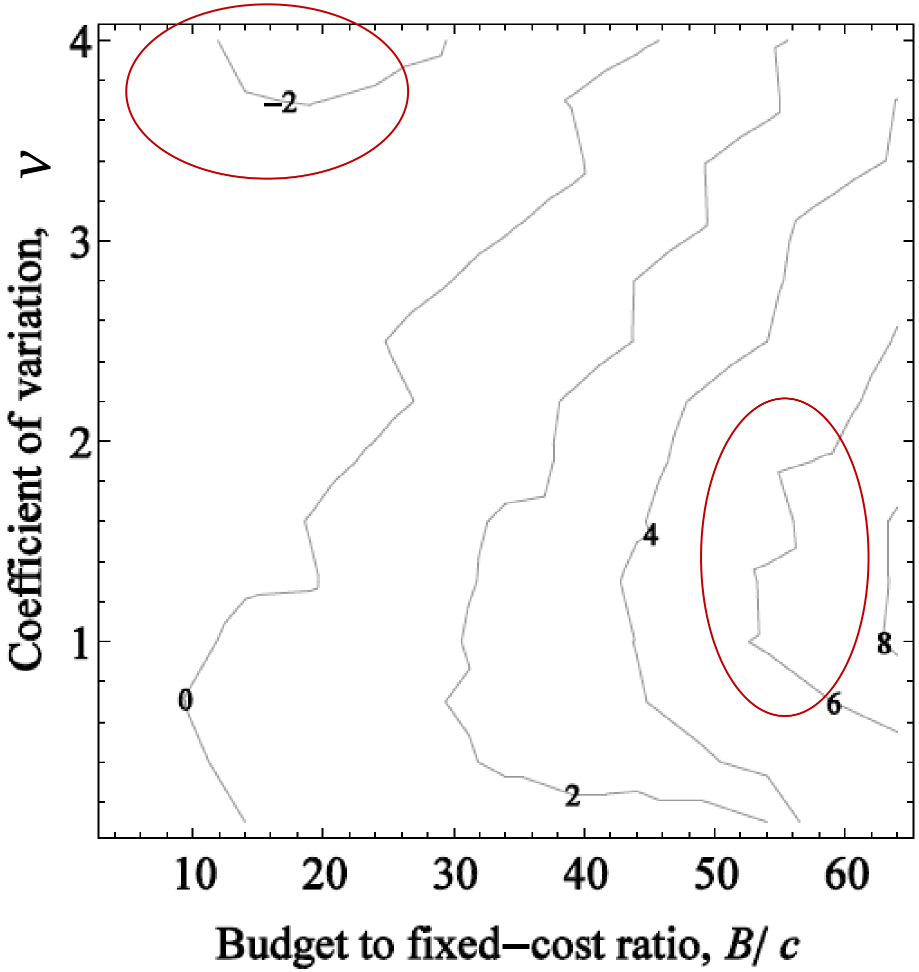
Approximate solution

Approx n* - numerical n*

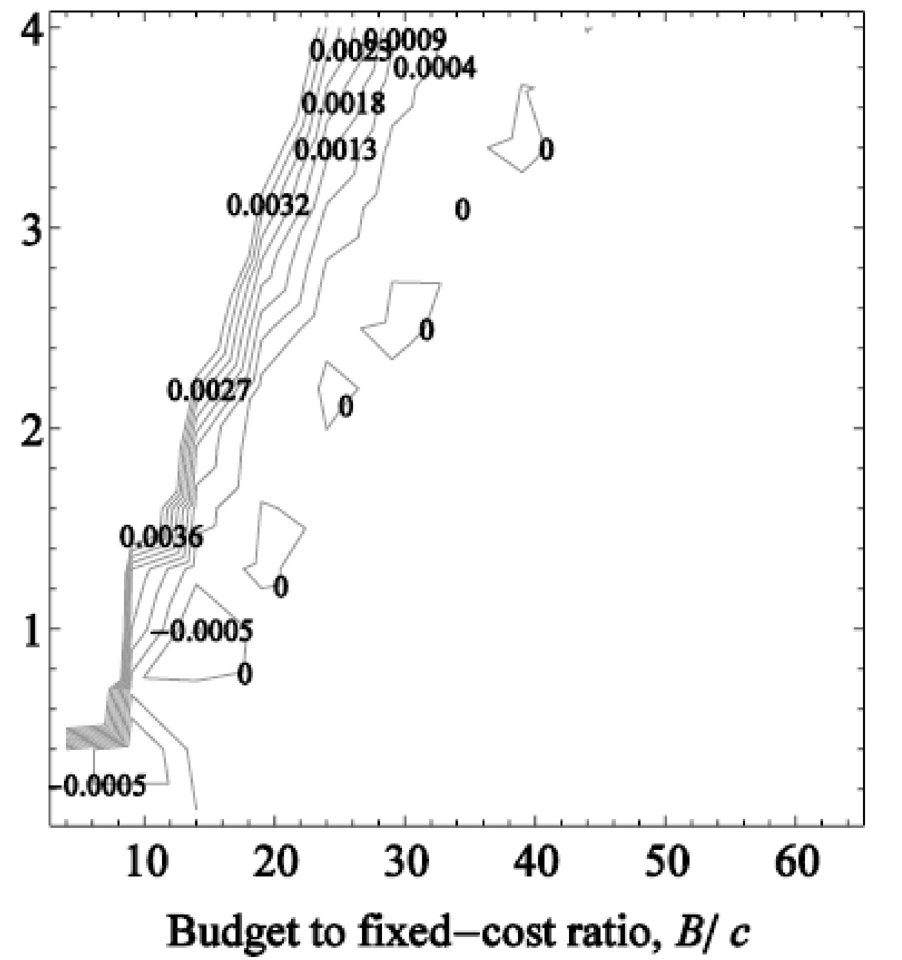


Approximate solution

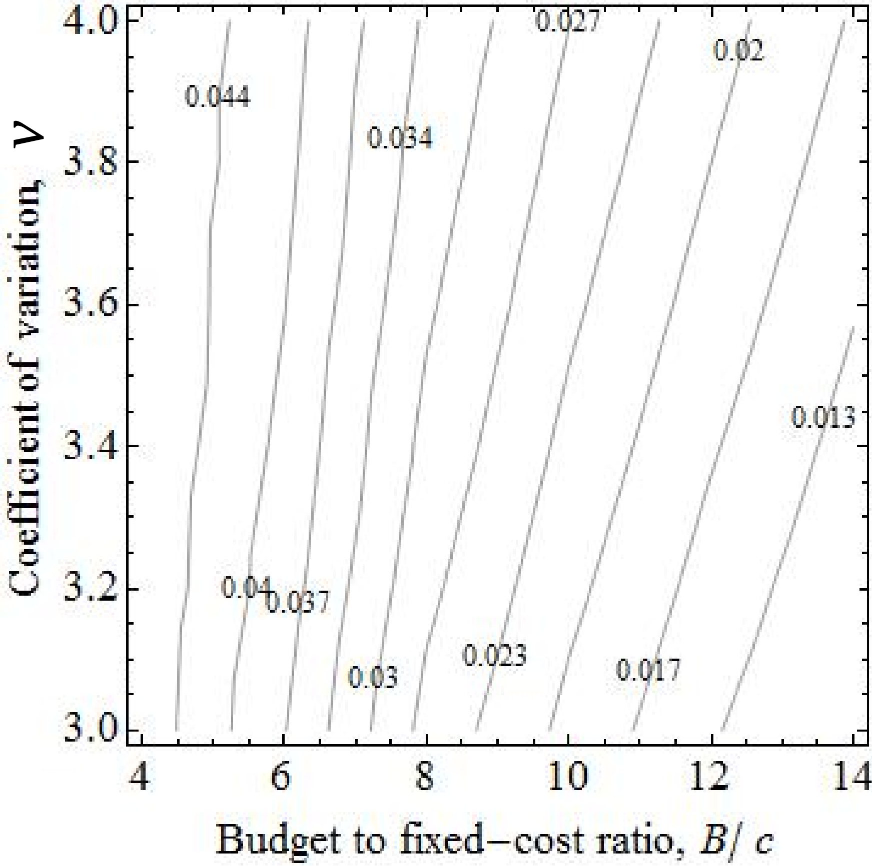
Approx n* - numerical n*



E[Q|approx n*]-E[Q|numerical n*]

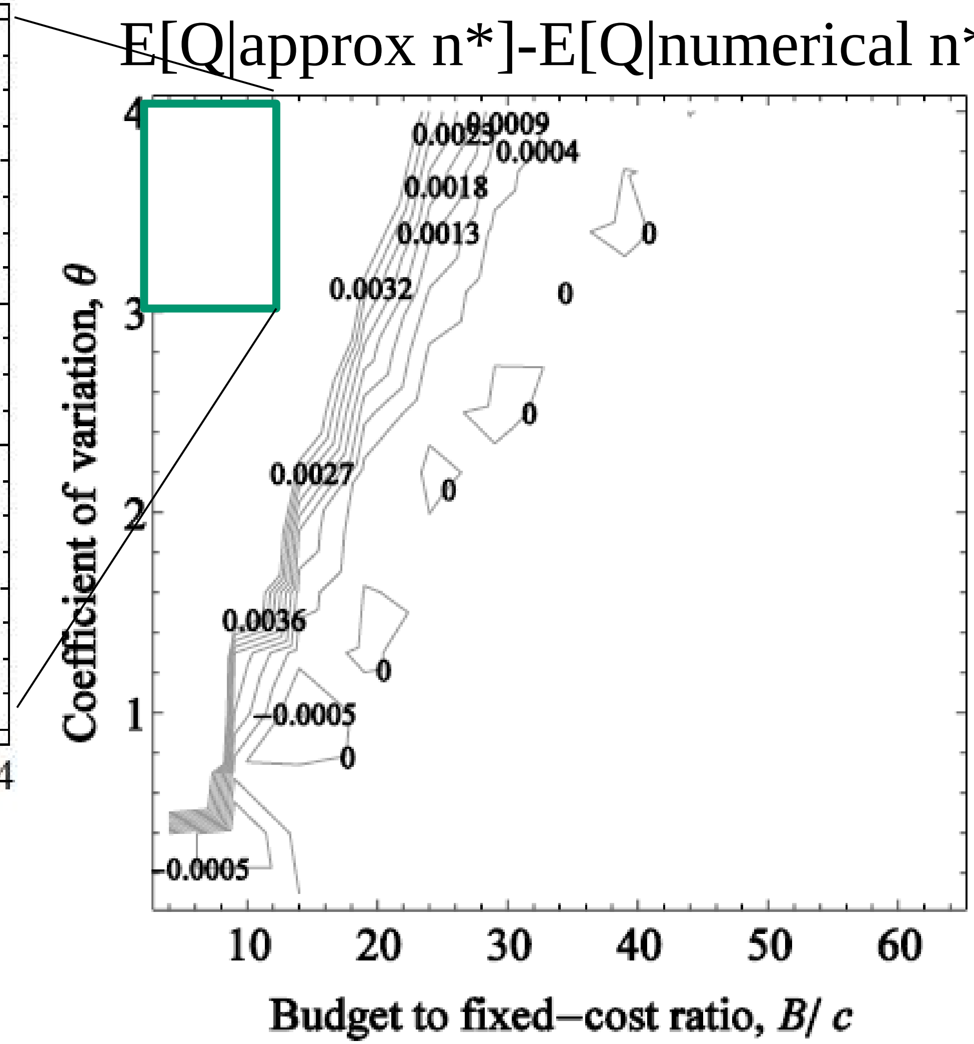


Approximate solution



up 8% difference

E[Q|approx n*]-E[Q|numerical n*]



Approximate solution

- Generally performs well, except when B/c small and $v = \sigma/\mu$ is large

- Provided insight into important parameter combinations

Testing the model with data

Key model assumptions:

- $\Sigma\lambda_i$ ~ dlognorm()
- Mean and standard deviation of that distribution are known

Plant survey experiment

- Variation in detectability over space
- **Problem**: What number of quadrats will maximise the probability of detecting the species, at least once, at the site?

Plant survey experiment

Nine square
(15 × 15 m)
quadrats were planted with thirty, ten, four or two individuals of 5 different species

McCarthy MA, Moore JL, Morris WK, Parris KM, Garrard GE, et al. (2013) The Influence Of Abundance On Detectability. *Oikos* 122: 717–726.

Plant survey experiment


Lomandra


Atriplex

McCarthy MA, Moore JL, Morris WK, Parris KM, Garrard GE, et al. (2013) The Influence Of Abundance On Detectability. *Oikos* 122: 717–726.

Plant survey experiment

Lomandra

Atriplex

Plant survey experiment

Predicted optimal number of quadrats

A failure time model was fitted to the time to detection data from 2010 to estimate the rate of detection of each species within each quadrat by each observer.

Calculated average and SD of the detection rates:

$$\mu_{Atriplex} = 0.55,\ \sigma_{\text{Atriplex}} = 0.60 \rightarrow\ v_{\text{Atriplex}} =\ 1.09$$
$$\mu_{Lom} = 0.56,\ \sigma_{\text{Lom}} = 0.64 \rightarrow\ v_{\text{Lom}} =\ 1.14$$

Plant survey experiment

Predicted optimal number of quadrats

Predicted the optimal number of quadrats in 2011 for 9 scenarios:

B = 5, 10 or 15 minutes, and

c = 0.25, 0.5 or 1 minute

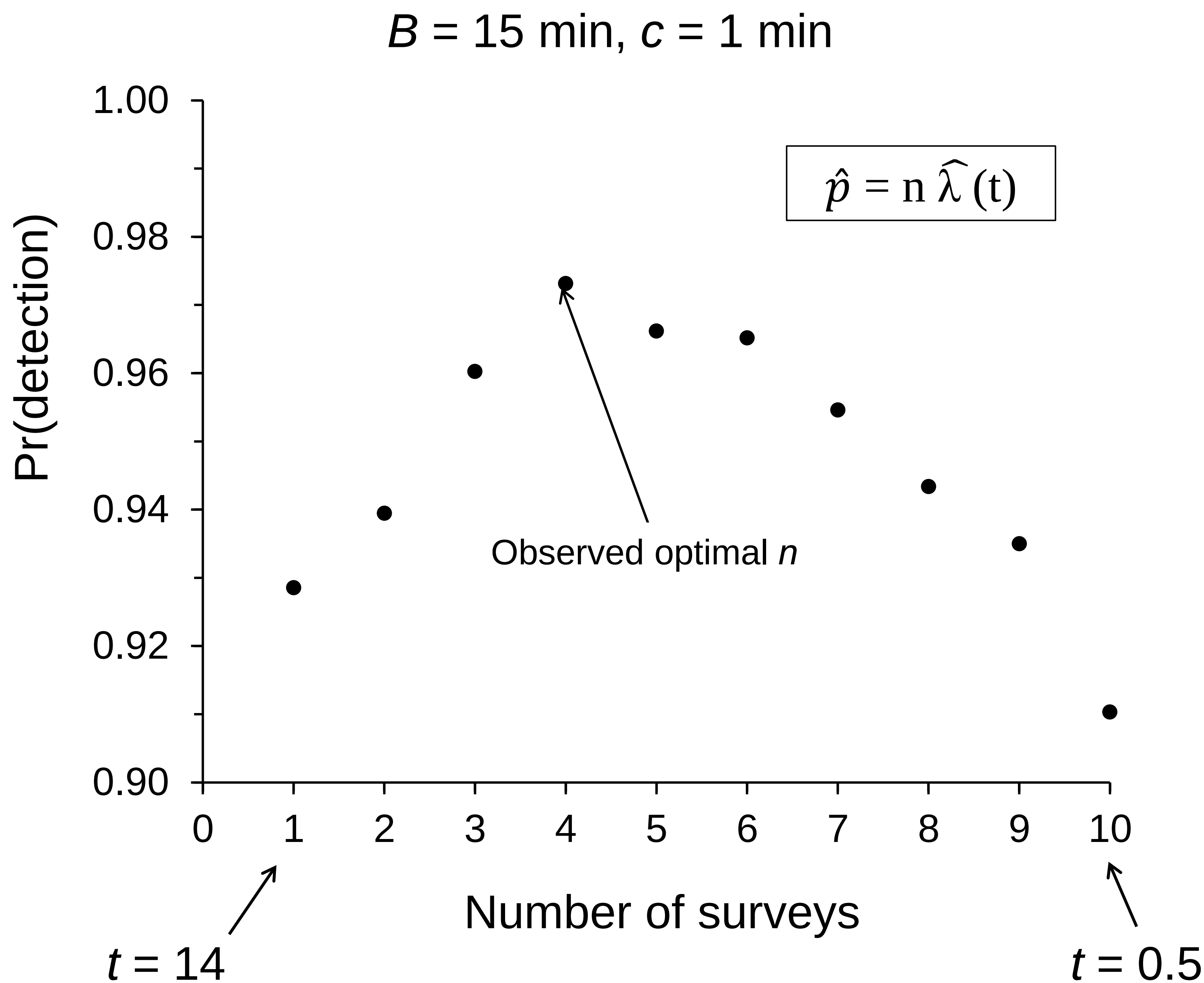
Plant survey experiment

Observed optimal number of quadrats

For a given survey of length t minutes, the "observed" mean probability of detection was estimated by

$$\widehat{\lambda}(t) = \frac{number\ of\ times\ sp.\ detected\ in < t\ mins}{total\ number\ of\ quadrat\ visits\ (14x9 = 126)}$$

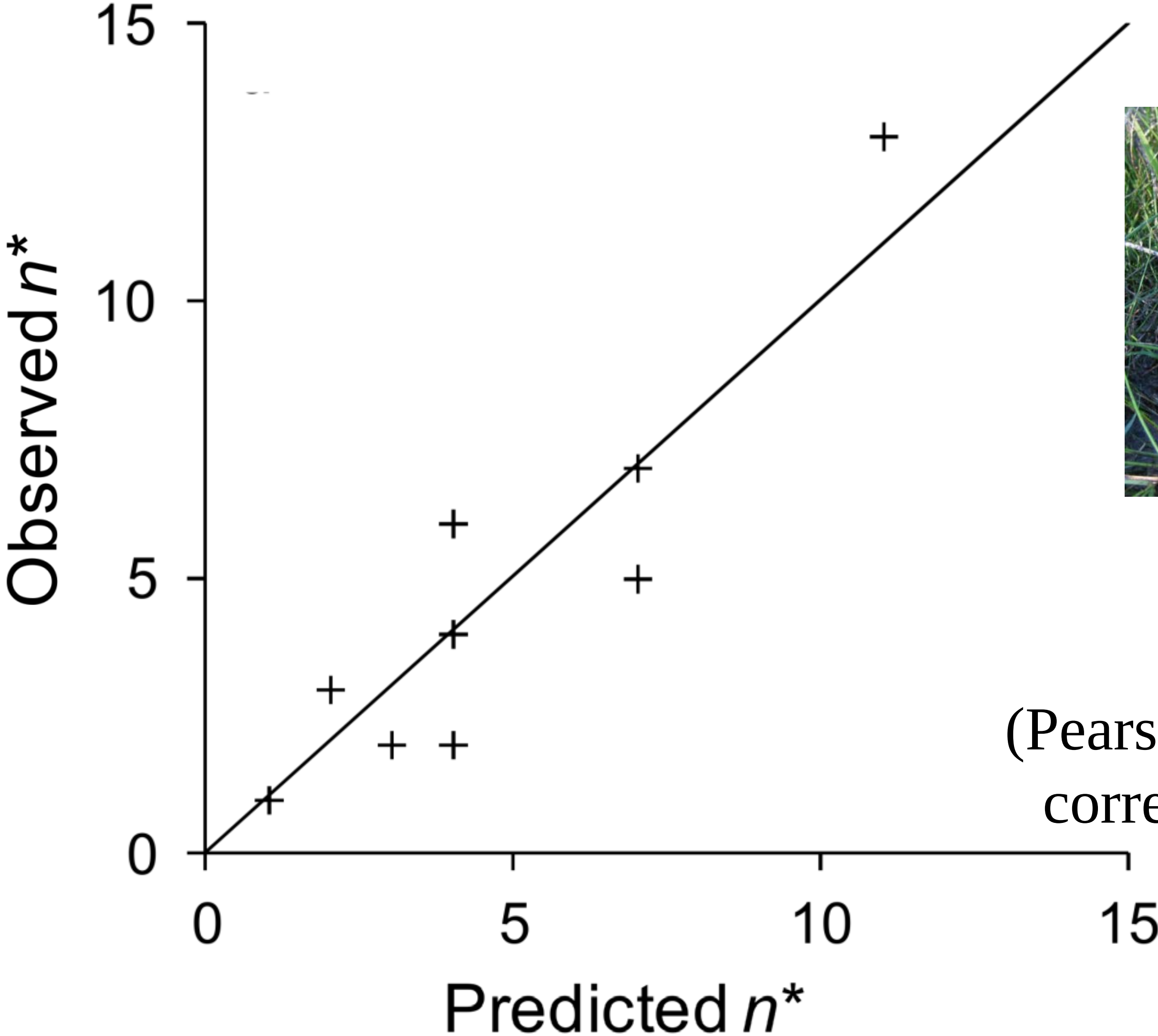
$\hat{p} = \mathrm{n}\,\widehat{\lambda}(\mathrm{t}), \quad \mathrm{t} = \mathrm{B/n} - \mathrm{c}.$



B = 15 min, c = 1 min
$\hat{p} = n\,\widehat{\lambda}(t)$
Pr(detection)
1.00
0.98
0.96
0.94
0.92
0.90
Observed optimal n
0
1
2
3
4
5
6
7
8
9
10
Number of surveys
t = 14
t = 0.5

B = 5, 10, 15 min; c = 0.25, 0.5, 1 min

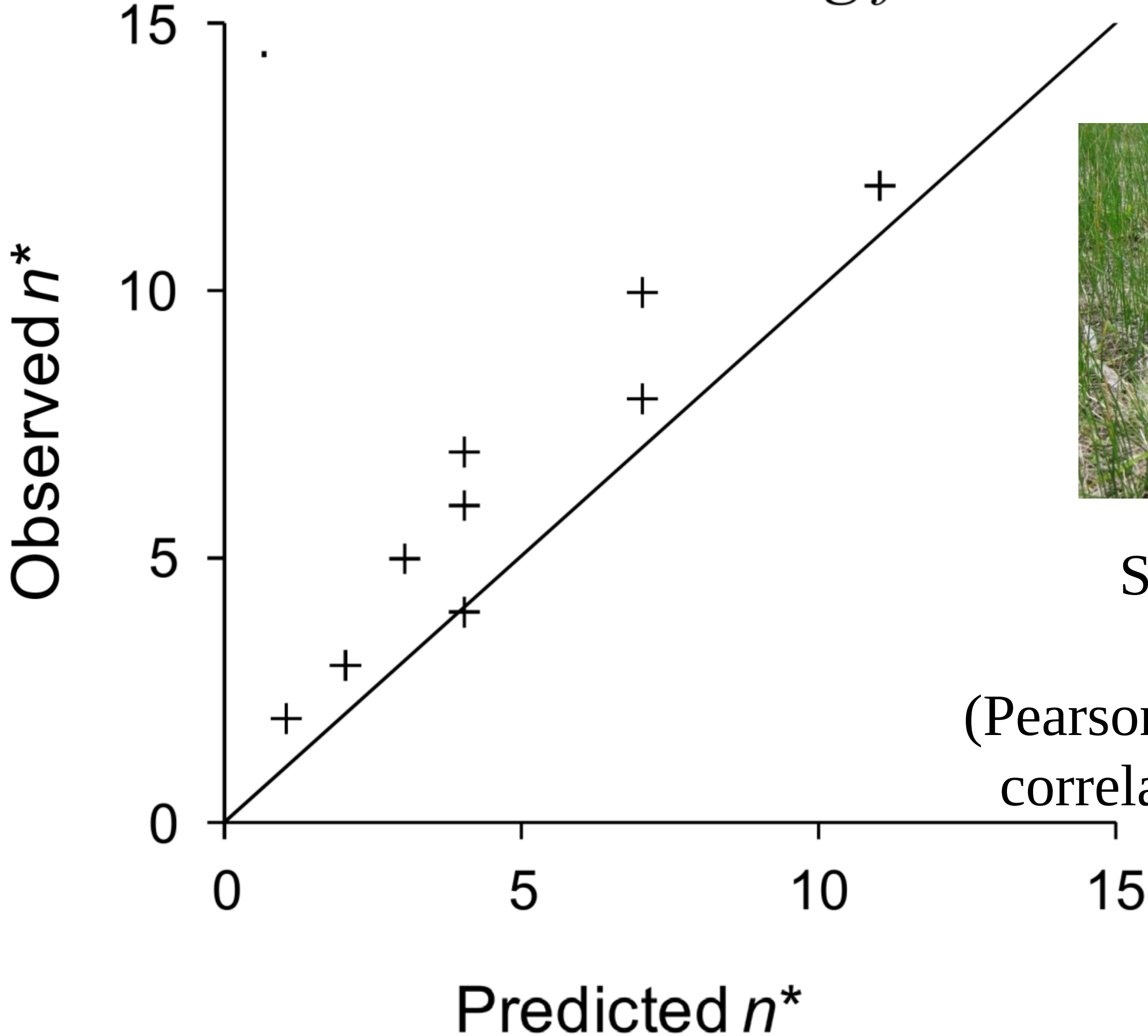
Atriplex semibaccata



Slope = 1.09
r = 0.93
(Pearson product-moment correlation coefficient)

B = 5, 10, 15 min;   *c* = 0.25, 0.5, 1 min

Lomandra longifolia



Slope = 1.04

r = 0.95

(Pearson product-moment correlation coefficient)

Extensions

- Temporal correlation
  - small effect on n^* unless large correlation

Extensions

- Temporal correlation
  - small effect on n^* unless large correlation
- Objective: maximise the chance of achieving an acceptable probability of detection
  - solution is insensitive the coefficient of variation, instead depends on the acceptable probability of detection

Recent Applications

- Surveying for an invasive Newt species
  - A. Smart, R. Tingley, et al. (In prep). *Cost efficiency of environmental DNA sampling*
  - Compare cost-efficiency of eDNA and bottle-trapping

Future research

- Multiple survey techniques
  - Two (or more) survey techniques, when should you use both?

Thank you

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alanamooreresearch.wordpress.com

Moore, A.L., McCarthy, M.A., Parris, K.M., Moore, J.L. (2014). The optimal number of surveys when detectability varies. *PLoS One* 9(12)

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Does it make a difference?