Proving Freedom

Development and learnings from wildlife TB management in New Zealand

Bovine tuberculosis bacillus

Landcare Research LINK Seminar 30, Wellington 15 July 2014

Graham Nugent, Landcare Research, P.O. Box 40, New Zealand

Outline

- TB Proof of Freedom model: An introduction and overview of key principle
- Development and application: Hauhungaroa example
- Where to next?
  - Other potential extension and applications

But first: A primer…

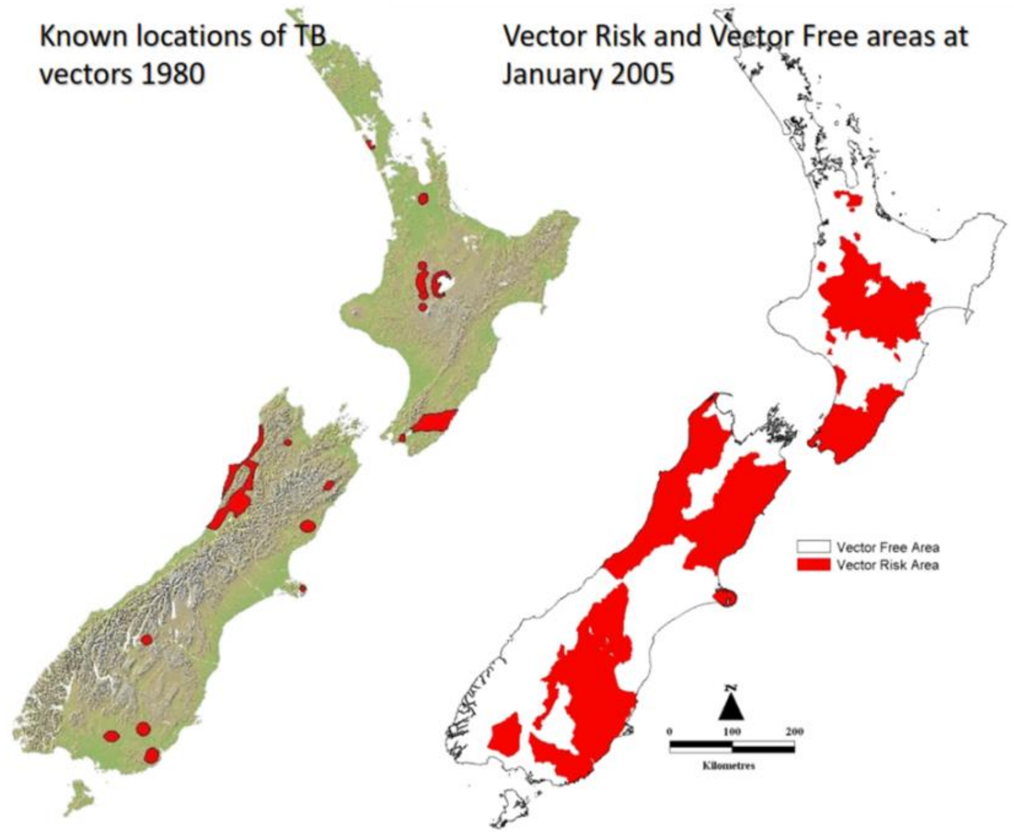
Bovine TB: An ancient zoonosis

- Caused by *Mycobacterium bovis* bacillus, globally widespread
- Closely related to human tuberculosis (*M. tuberculosis*)
  - the white plague of 1700-1800s
- Common ancestor: human disease out of Africa 40,000 years ago
  - Split into animal and human lineages
  - A billion people globally infected with TB (mostly human, mostly latent)
- Slow-moving disease
- Zoonotic effects on human populations almost eliminated by test-and cull, pasteurisation, and meat inspection
- But production and trade impacts still considered important

Bovine TB in NZ: A multi-host disease

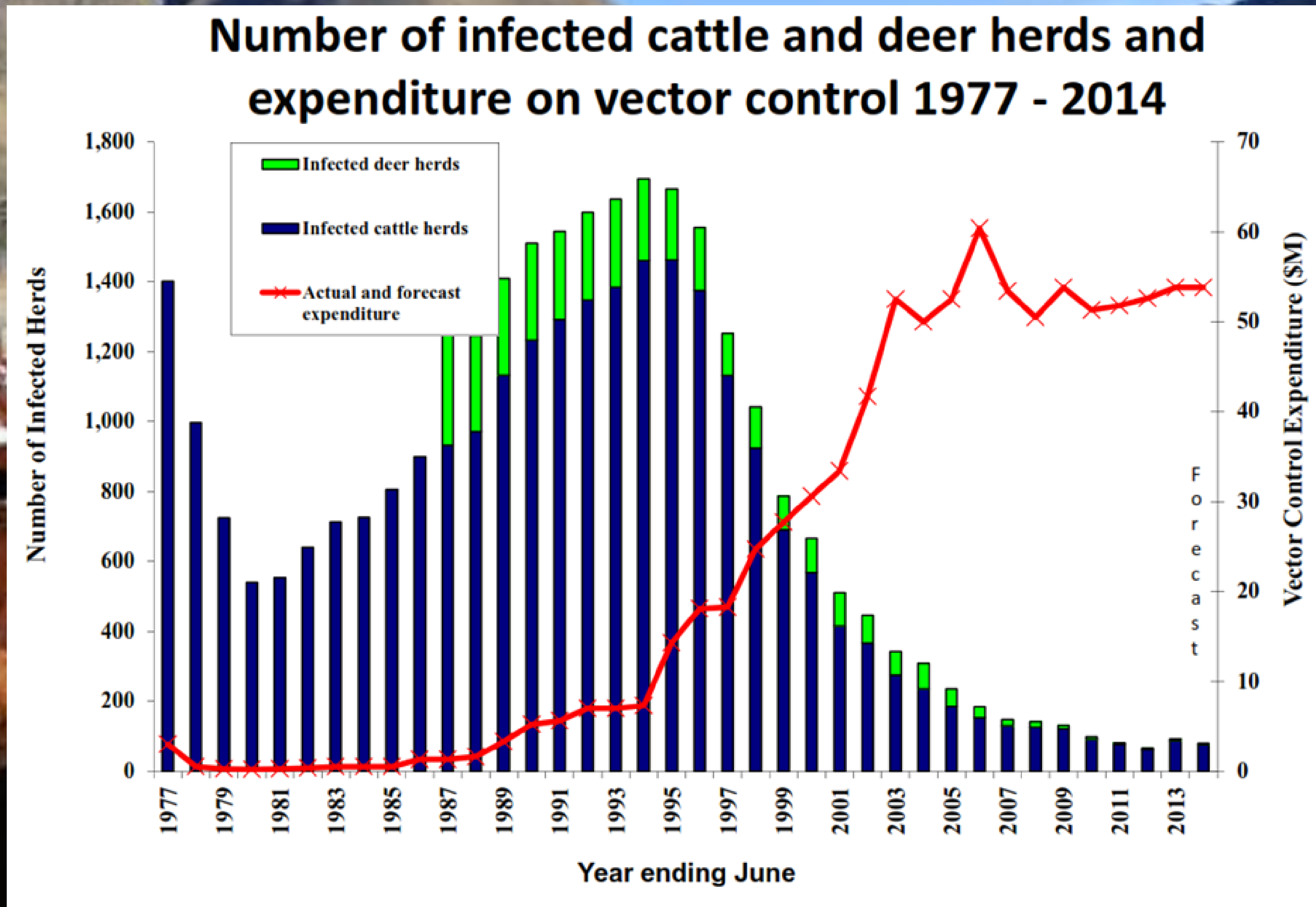
- Introduced w. livestock 1800s
- Spread to wildlife in 1960s
- Possums main host
- Deer/pigs/ferrets spillover hosts

Bovine TB in NZ in wildlife



- Massive spread between 1980 and 2005
- To ~ 10m ha (40% of NZ)
- ~$55mill p.a. spent on possum control/wildlife survey, 8 m ha now controlled for btwn 1-20 yrs

Successful control of TB



- Through test-and cull of livestock **AND** intensive control of possums (>95% reduction since 1994)

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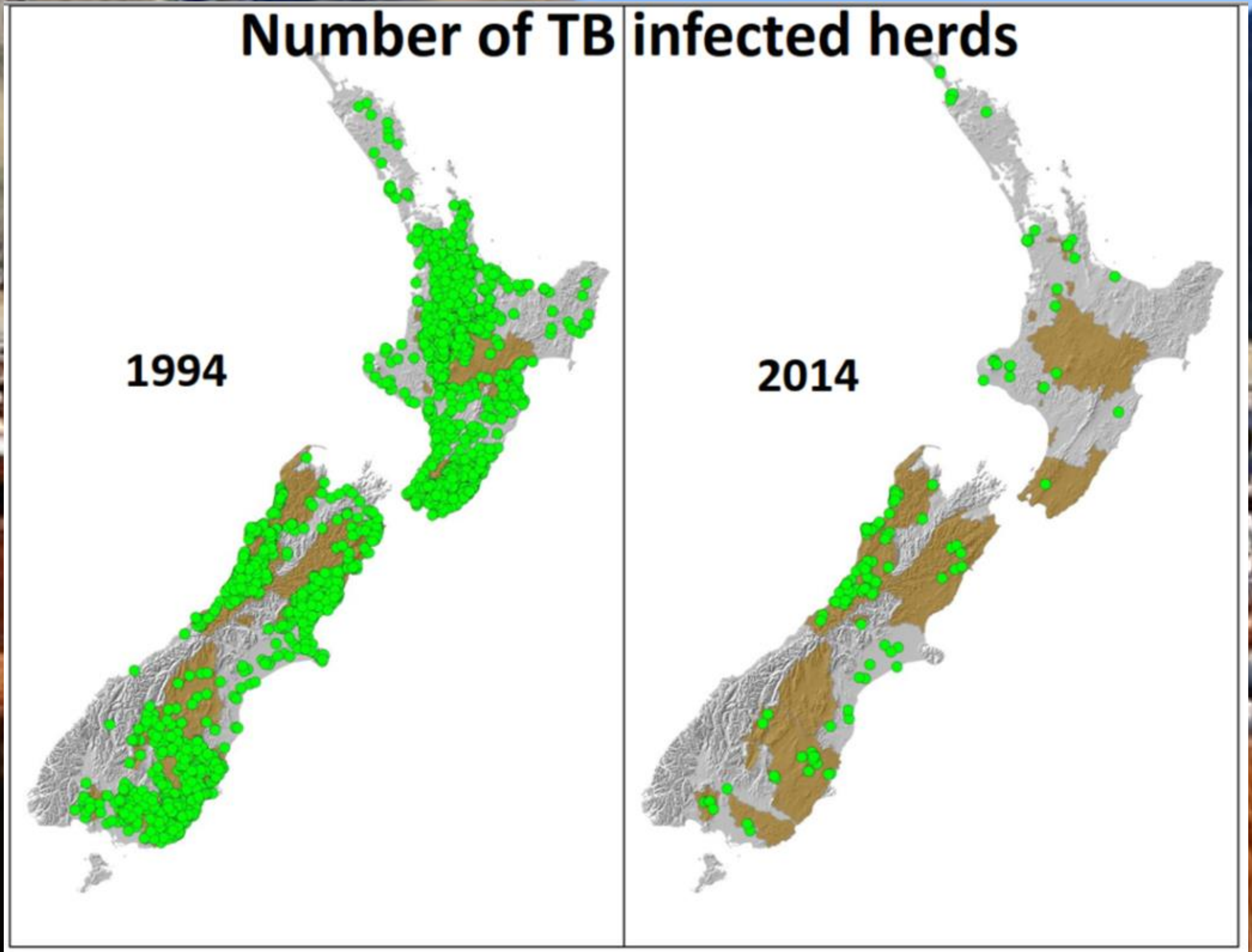
Successful control of TB



- Other than West Coast, as much or more TB now outside Vector Risk Area – esp. North Island

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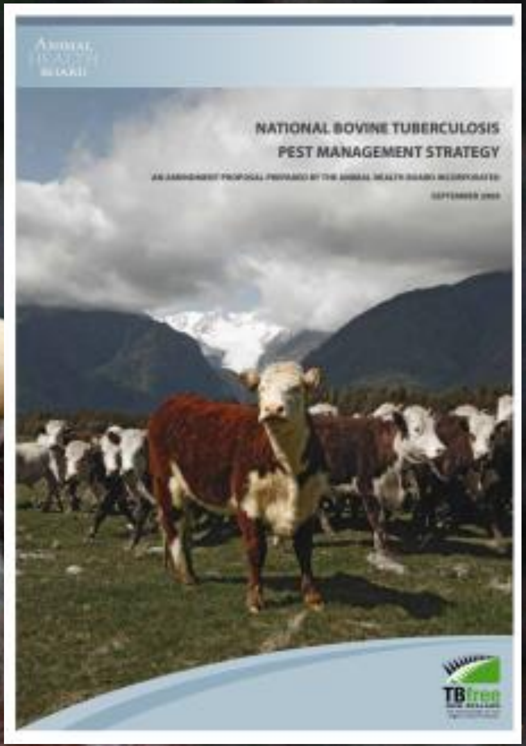
NZ aims to eradicate bovine TB from livestock (by first <u>locally eradicating it from wildlife</u>)



- Eradication target: 2.5m ha TB free by 2026

- Since 2011 ~800,000 ha declared free

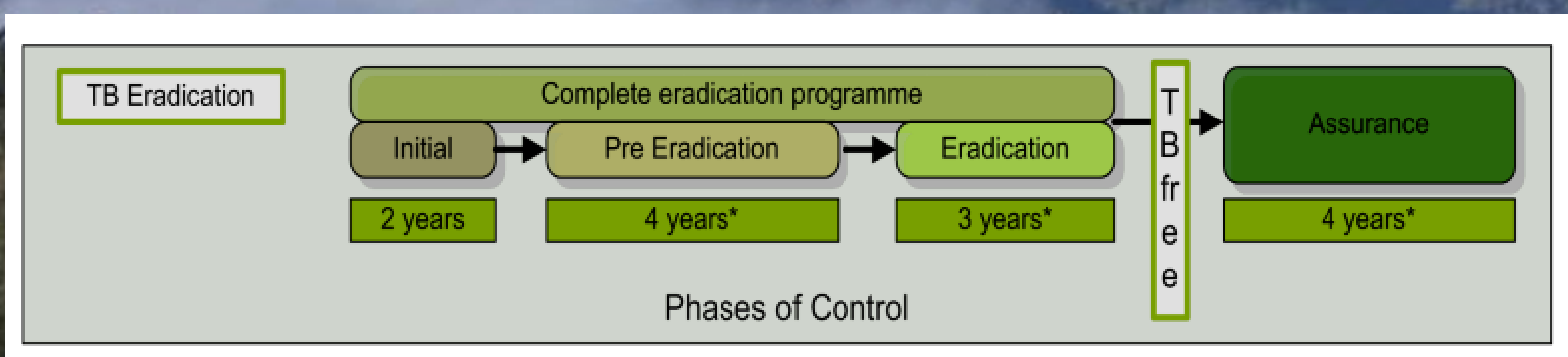
Open question: <u>Can</u> Tb be eradicated from an abundant wildlife host?

- Only one country (Aust.) has ever eliminated TB from a wildlife maintenance host
  - Buffalo - big and easy to see, and muster or shoot – much the same as cattle
- In NZ, the main TB host is the possum
  - Small, abundant (often >10/ha), forest dwelling, nocturnal, widespread

=> Much much more difficult

NZ’s wildlife-TB eradication process

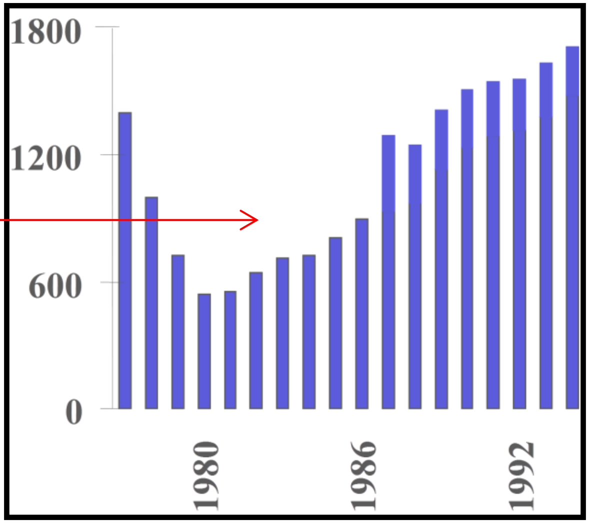
- Reduced possum densities
  - by >90% l to quickly break TB cycle
- Maintain low densities for 4-15 years (to prevent re-establishment from deer or other hosts)
- **Then prove freedom - stop control, start survey to assess TB absence in possums**
- **Declare freedom when confidence of absence is high (but never 100%), stop intensive survey**
- **Maintain low intensity ‘post freedom’ assurance**



Proof of freedom goal:
Optimal and objective decisions about when to stop expensive possum management

Risk 1: Stopping too soon

- Tb is still present and after 5, or 10, or 20 years remerges - as in 1980s



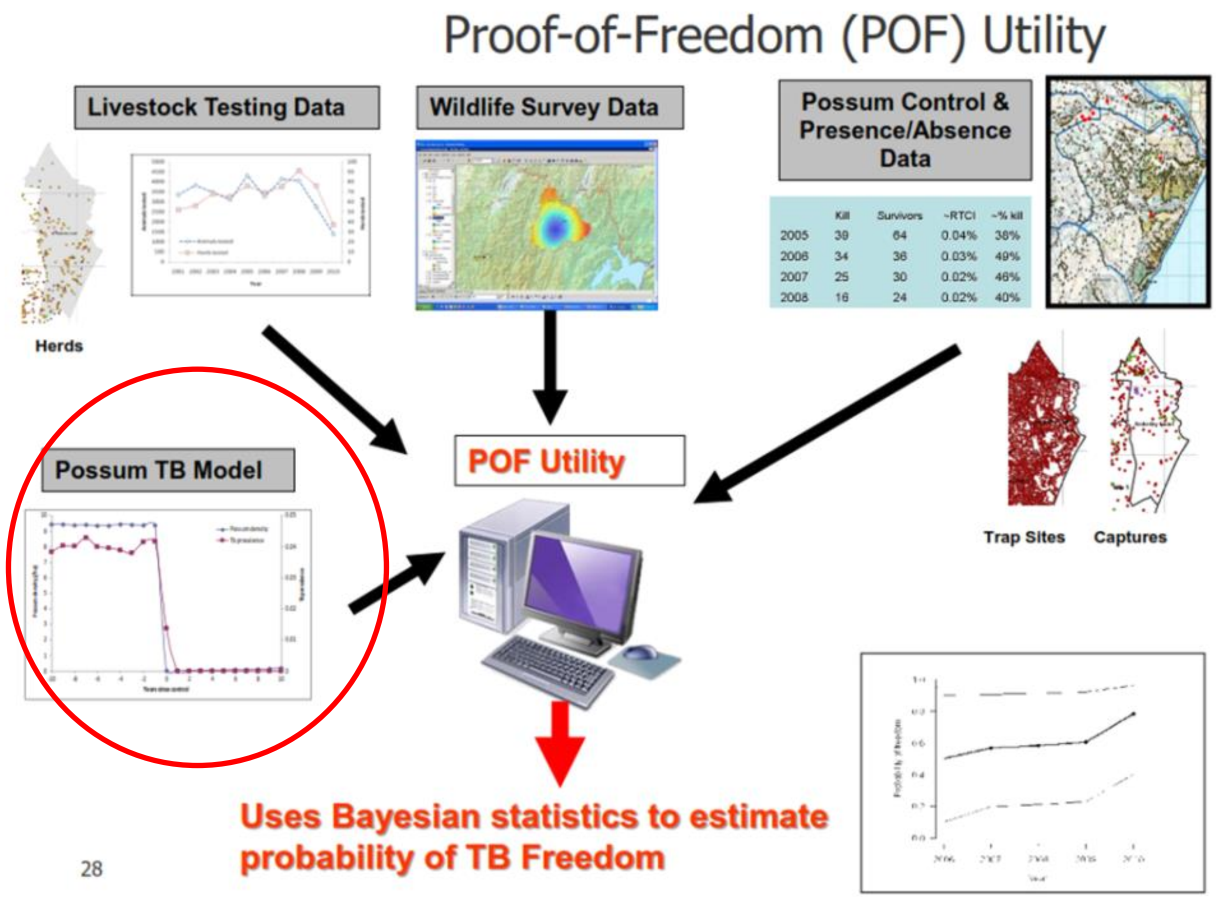
Risk 2: Stopping too late

- Needless possum control continued for many years
- Money down the drain

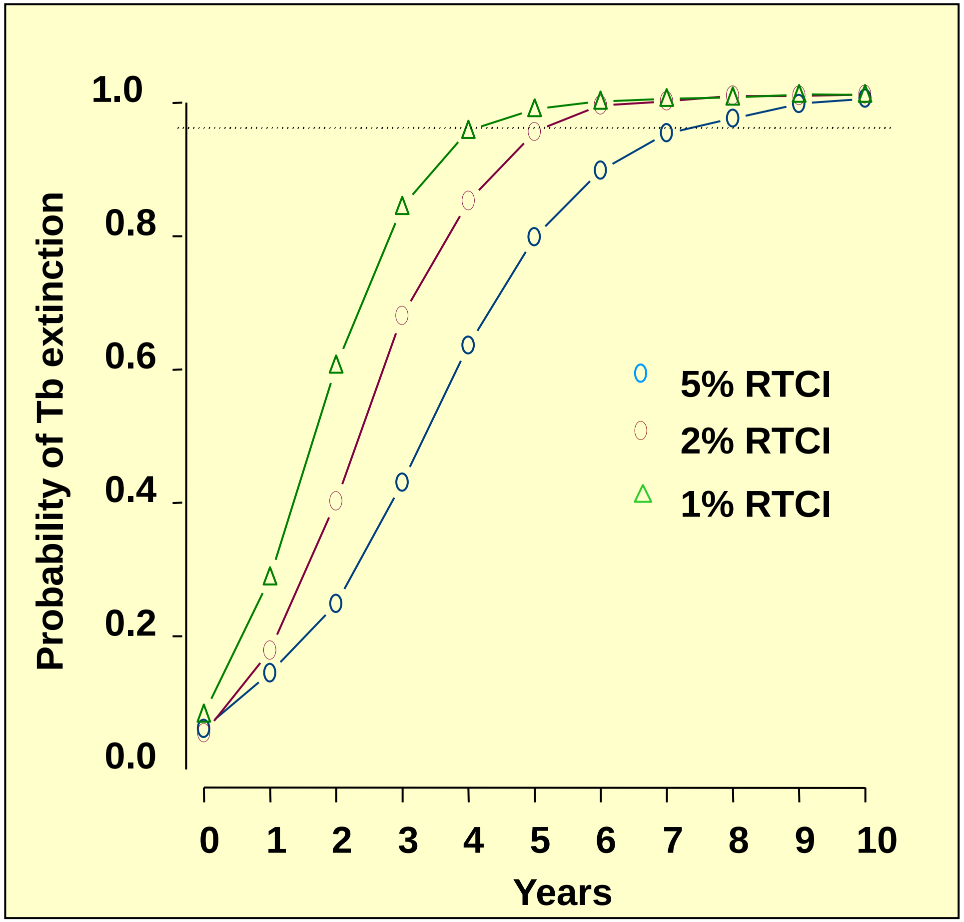
=> Current stopping rule set at POFpost = 0.95

Proving Tb freedom: Two main components

1. Apply possum control for 4-15 years, then assess likelihood of Tb freedom in possums based on control history – **epidemiological modeling to estimate prior**



Calculating prior probability of freedom



Given the history of possum control, what is the probability Tb has been eradicated?

=> The lower the average possum density, the higher the likelihood of TB freedom

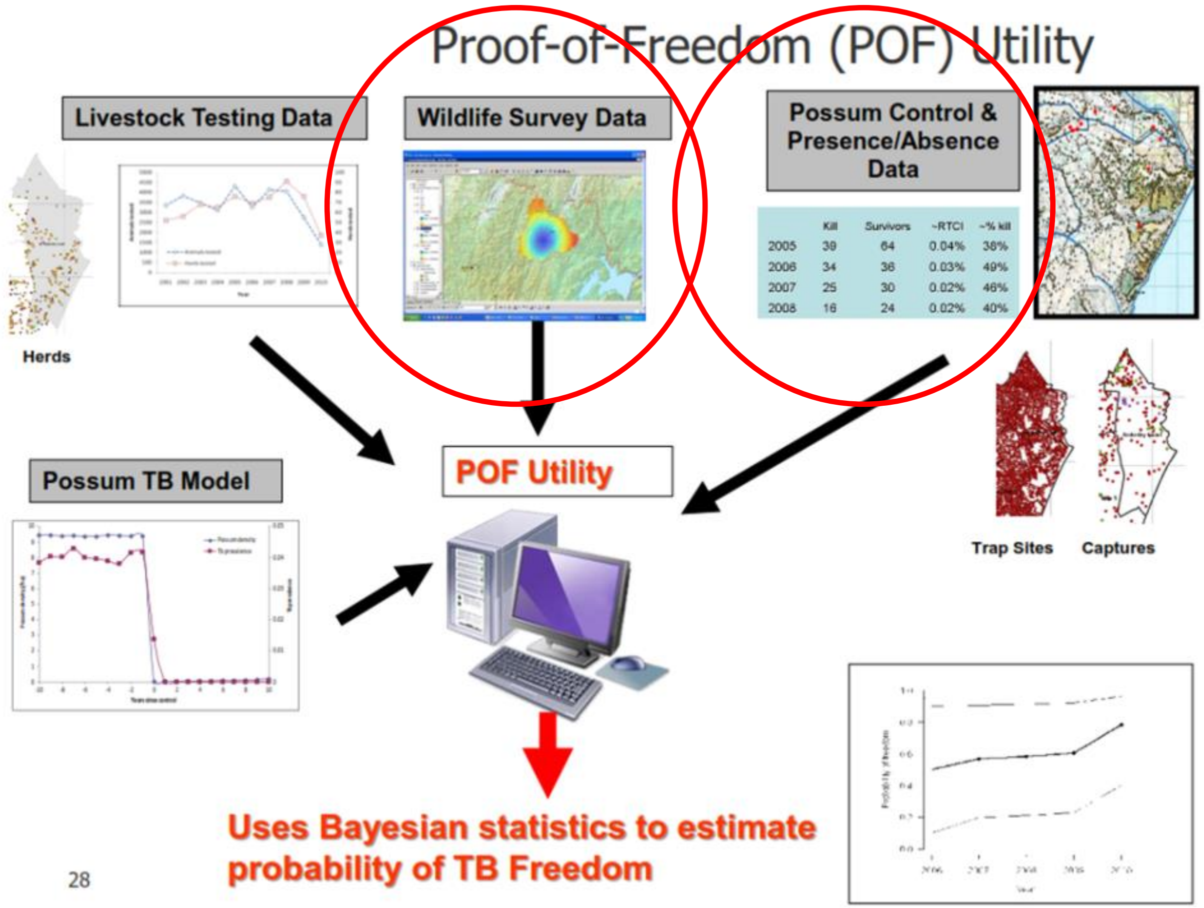
RTCI = Standard trap-catch index of possum abundance

(uncontrolled populations usually 20-50% RTCI)

Ramsey, D.; Efford, M. 2005. Eliminating Tb: Results from a spatially explicit, stochastic model. Landcare Research Contract Report

Proving Tb freedom: Two main components

2. Estimate likelihood of TB freedom in possums based on actual survey – **empirical surveillance, direct and indirect**



	Kill	Survivors	~RTCI	~% kill
2005	39	64	0.04%	38%
2006	34	36	0.03%	49%
2007	25	30	0.02%	46%
2008	16	24	0.02%	40%

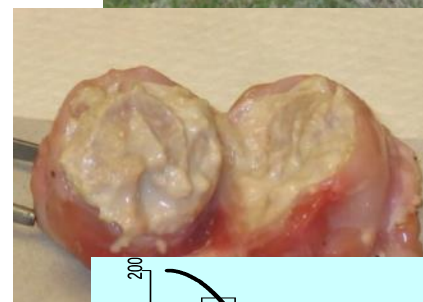
Conventional possum surveillance

- Necropsy survey: proportion of possum population checked for TB
- Conventionally, Surveillance Sensitivity estimate (SSe) calculated from proportion killed
  - the likelihood that 1 (or more) TB possums would have been detected if present
  - depends on proportion killed <u>and</u> test sensitivity
- Major downsides are
  - Possum now rare – expensive to catch
  - No spatial inference for areas where no possum caught

Multi-source surveillance

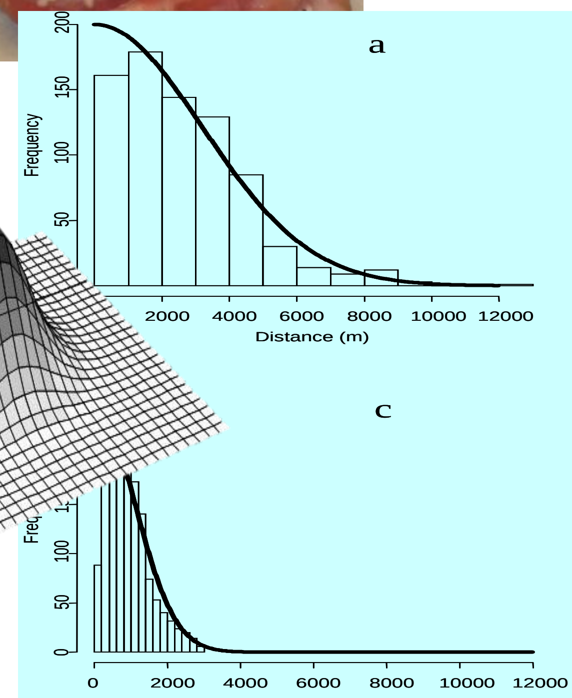
- Spillover hosts (ferrets, deer and pigs) used as **sentinels** of TB in possums
  - SSe = likelihood deer or pig would be infected if TB possum present in its home range
  - Advantage of much bigger ranges than possums
- Trapping effort used where no possum caught
  - If possums are absent, then TB cannot be present in possums
  - Can use trap and detection data for areas where no possum caught

Spatial depiction of SSe

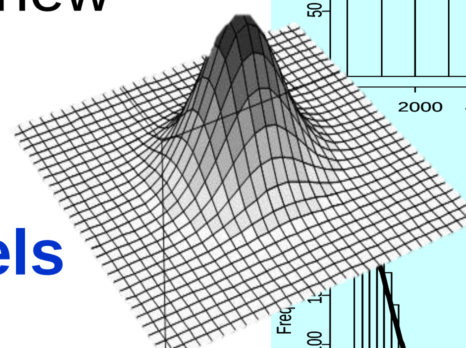


Each animal (or trap or detection device) assigned a average ‘probability of detection’

e.g. Deer: P_d = 0.06 detectable new cases per deer per year per infected possum



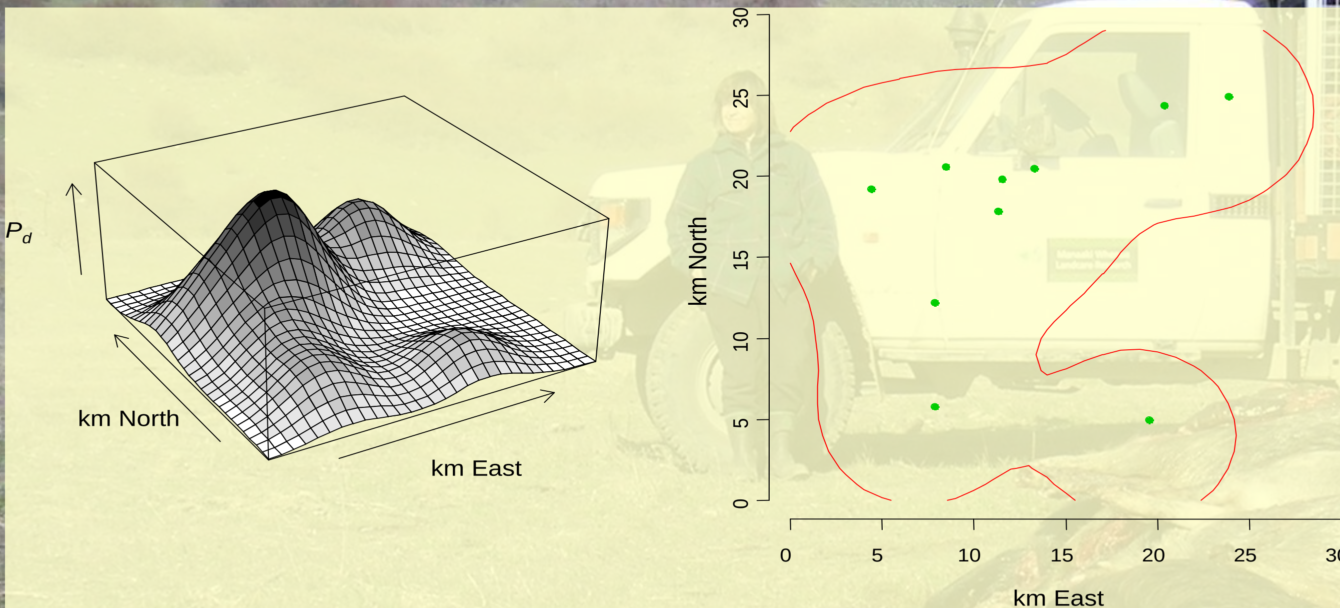
e.g. Pigs: P_d = 0.50 detectable new cases per pig per year per infected possum



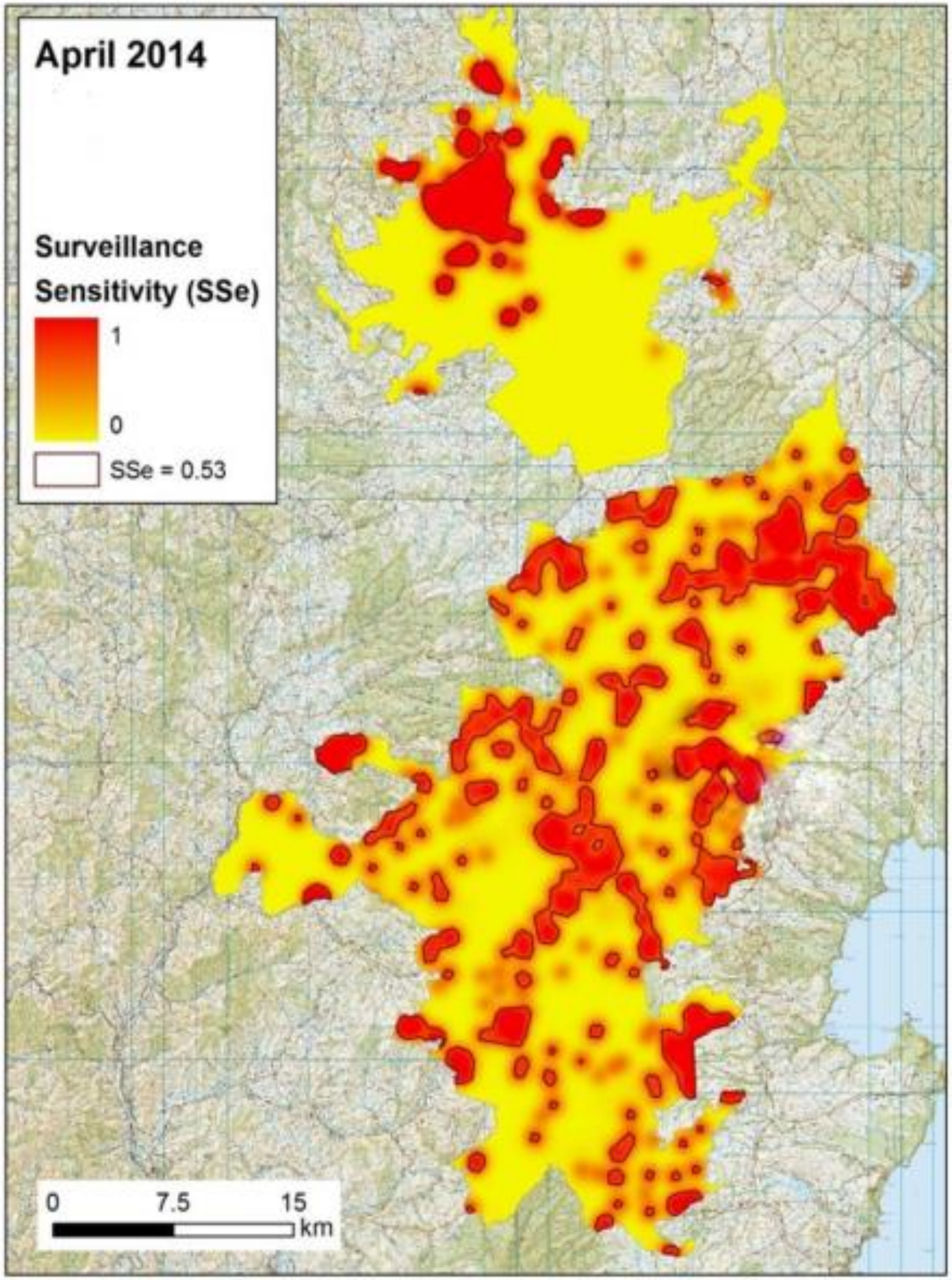
⇒ Pigs by far the best sentinels

P_d expressed spatially as a detection kernel

Creation of a detection surface



- 10 pigs can cover most of a 9000 ha area with >50% chance of detecting TB in possums



Integration across data sources

Hauhungaroa Ranges
2013-2014

- Detection kernels easily combined across species/devices to produce a single surface
- Provides v good depiction of survey coverage
  - Easily identifies where confidence in freedom in lowest
  - Enables targeting of future survey effort

Calculating Posterior Probabilities

- Bayesian approach the used to combine prior and multi-source SSe
  - To calculate POFpost at end of each year post control
  - POFpost year 1 = POFprior year 2

$$P(H_i \mid x) = \frac{P(H_i)\,P(x \mid H_i)}{P(x)}$$

Example: Ruatiti Sth – control stopped 2007,
***POFprior = 0.90 default**, sporadic survey since*

Year	POF Mean	POF Low CI	POF High CI	SSe Mean
2007	0.892	0.836	0.938	0.008

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2007	0.892	0.836	0.938	0.008
2008	0.921	0.882	0.955	0.405
2009	0.907	0.861	0.944	0.021
2010	0.891	0.84	0.934	0

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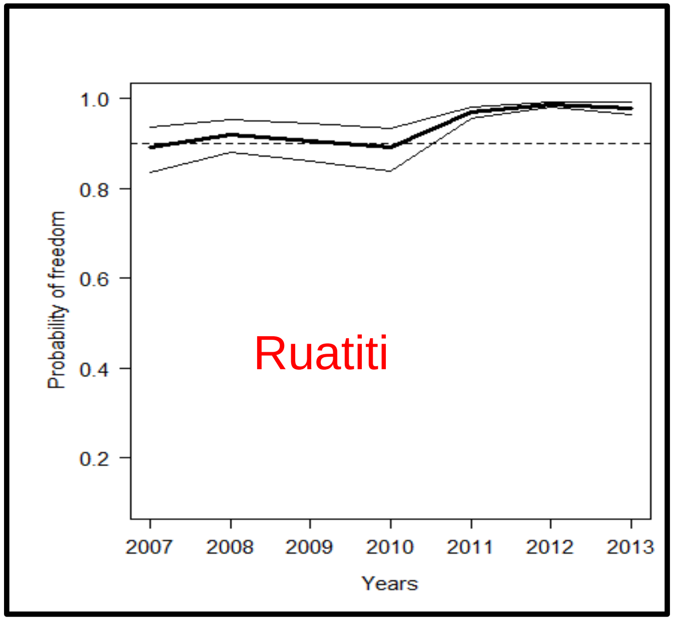
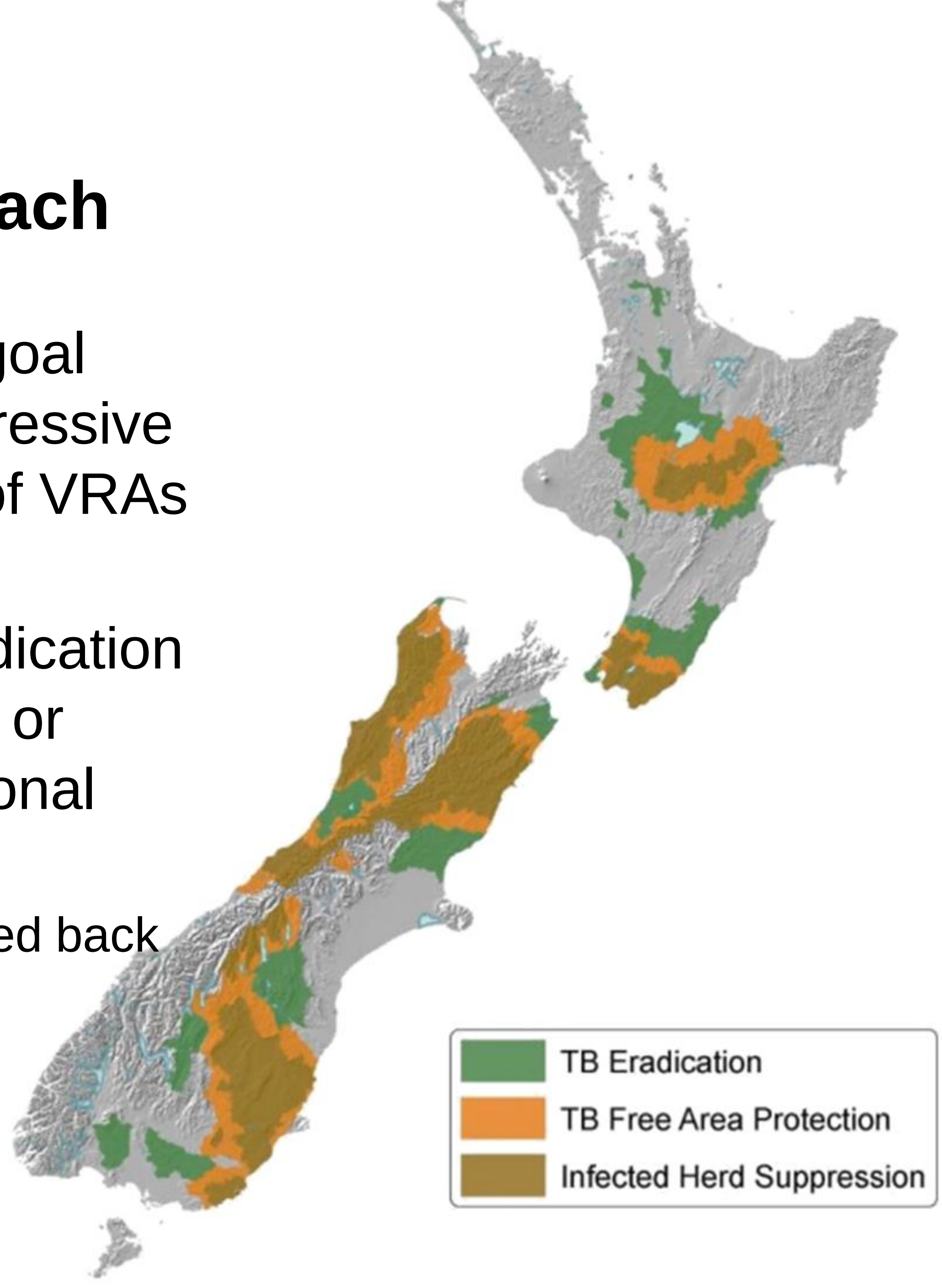
2010	0.891	0.84	0.934	0
2011	**0.971**	**0.956**	**0.983**	**0.79**
2012	0.988	0.981	0.993	0.732
2013	0.98	0.964	0.992	0.267



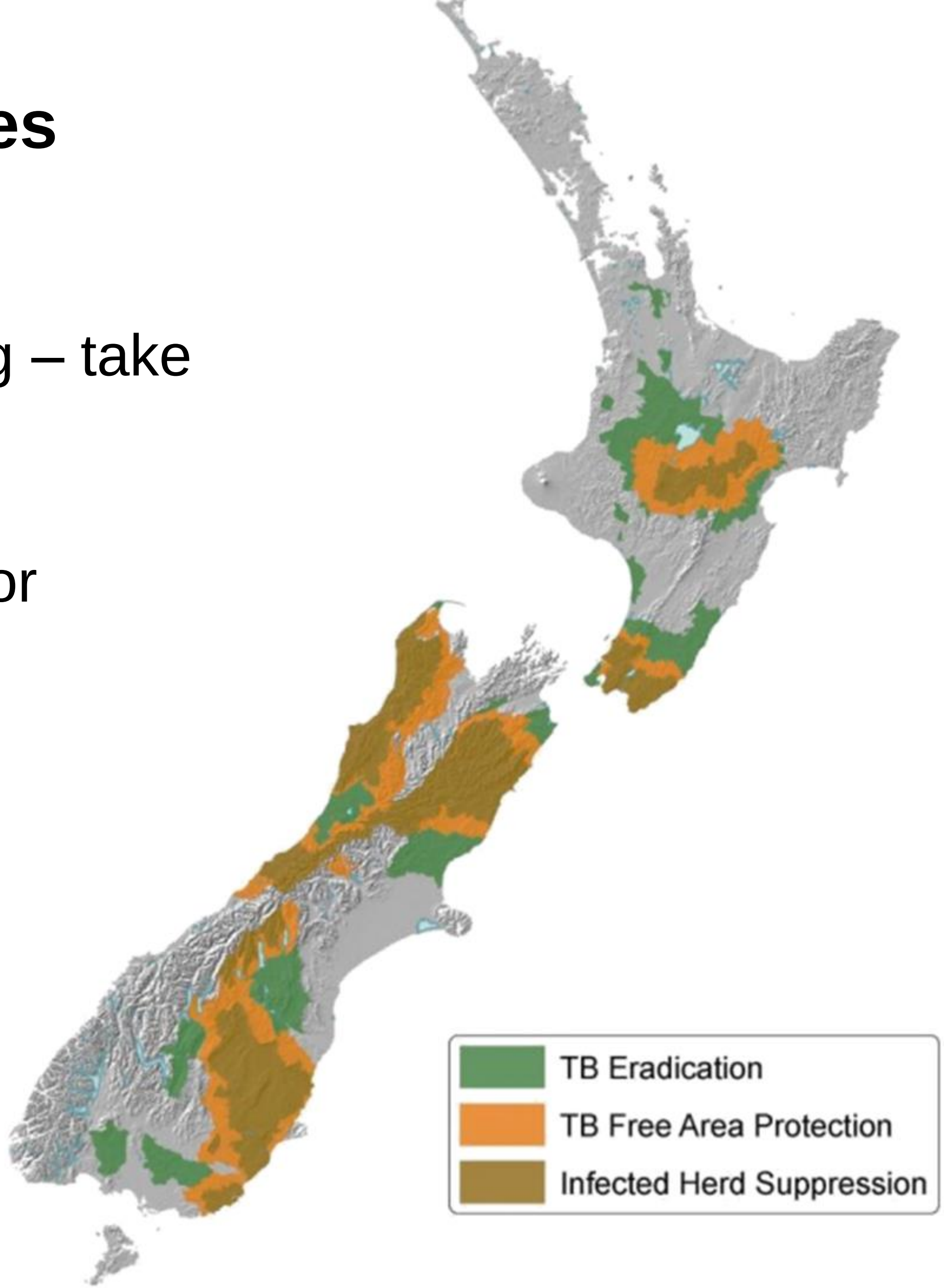
Implementation:
The roll-back approach

- Achievement of 2026 goal (2.5m ha free) by progressive reduction (=roll back) of VRAs from the edges
- Rare approach for eradication in wildlife – typically all or nothing at local or regional scales
  - Although rinderpest rolled back at national scales



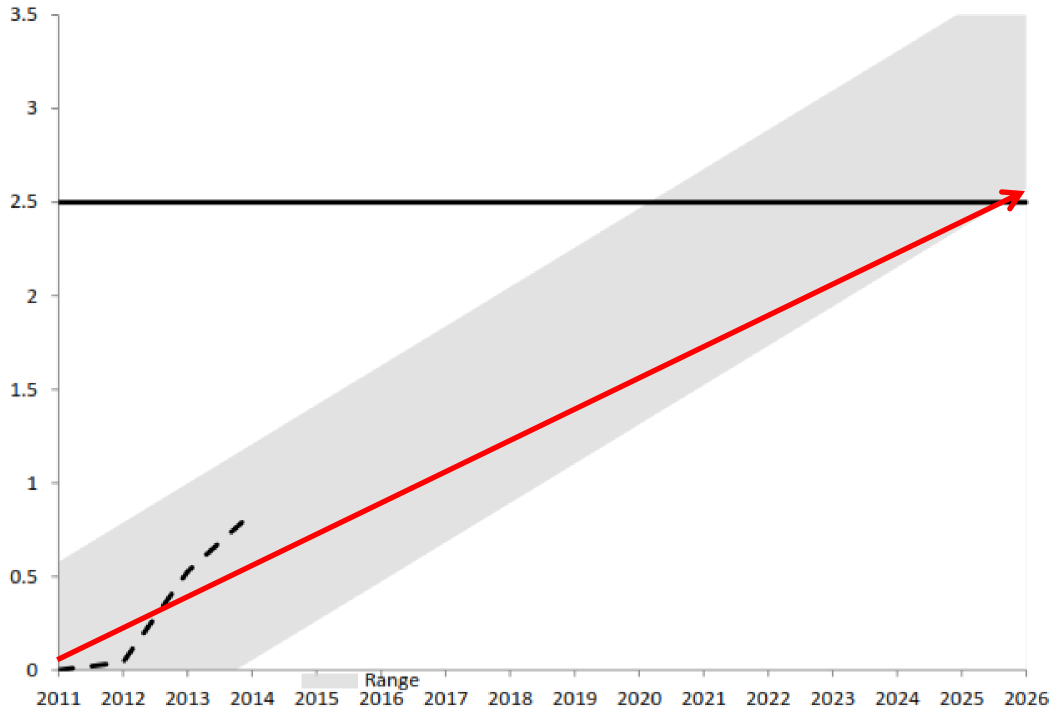
What facilitates roll-back?

- Careful logical planning – take into account status of neighbouring zone
- Include an allowance for reintroduction

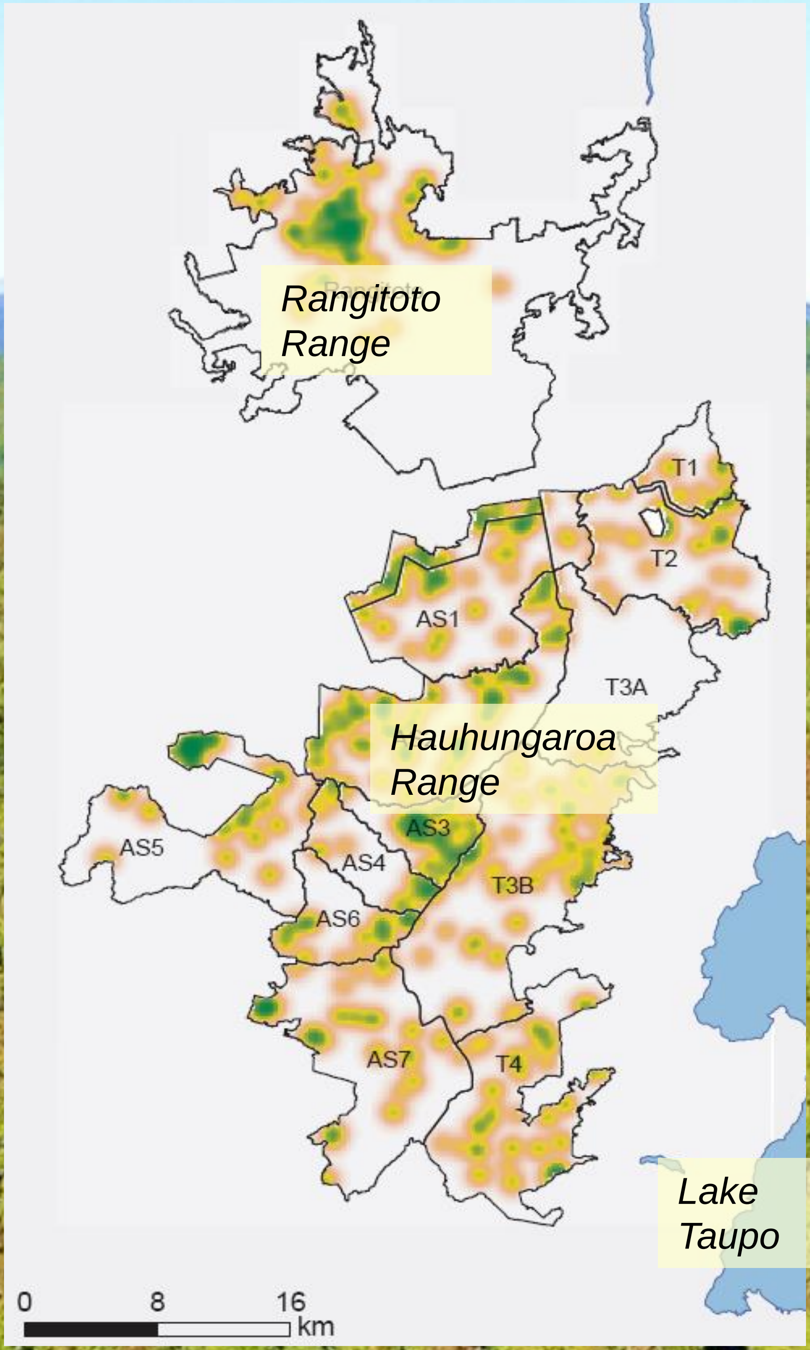


Recent progress

- In May 2014: A total of 28 VCZs, combined area of 309,745 ha, were presented for VRA revocation.
  - all 28 to be declared TB free (with 1 minor variant)
- National total of ~800,000 ha declared free since 2011



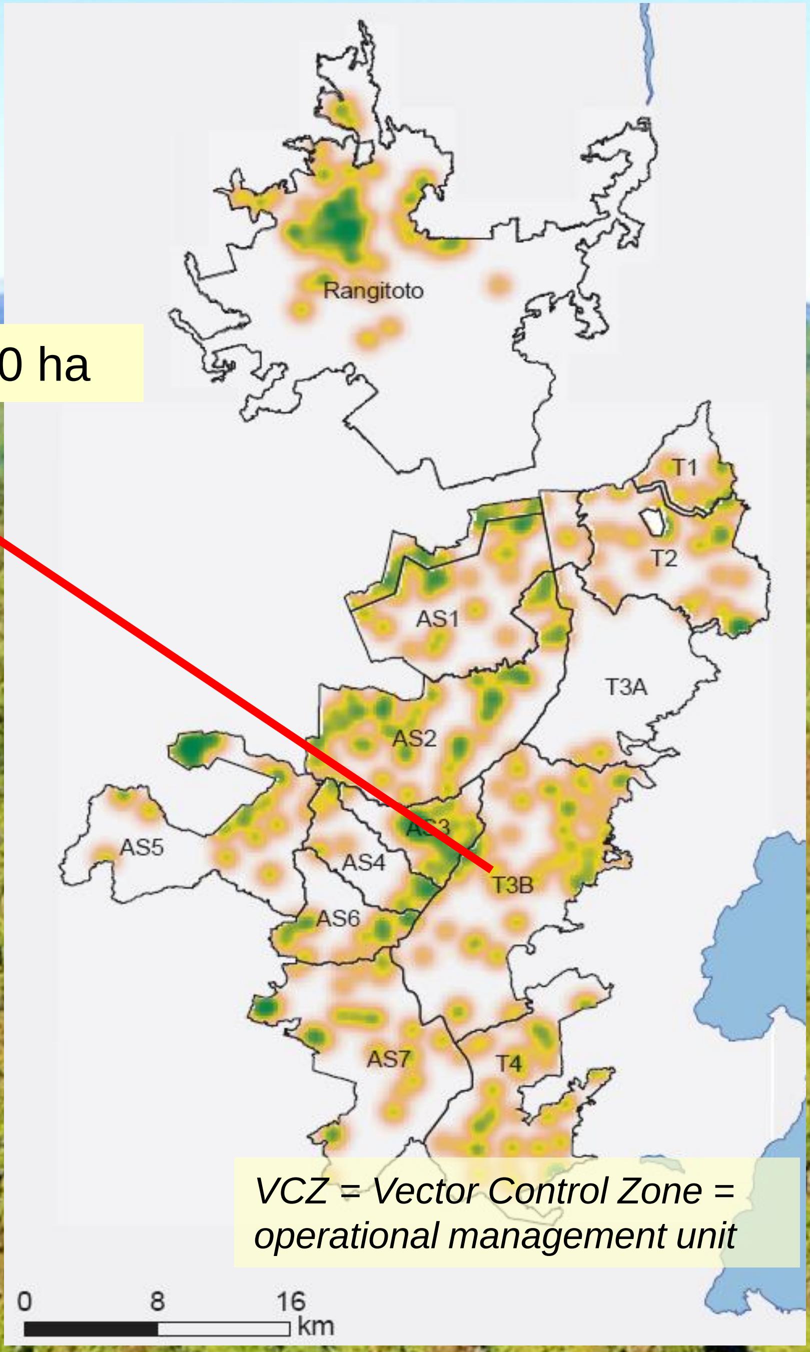
Next challenge: Eradication Feasibility Test



- Key NPMP objective is to show TB can be eradicated from wildlife in two large areas of difficult operational terrain

Hauhungaroa and Rangitoto Ranges

Tihoi 3B VCZ 13800 ha



VCZ = Vector Control Zone = operational management unit

- 122,000 ha
- TB common in possums, pigs, deer since 1970s
- Dense tall rain forest, unroaded, difficult access

=> Possum control mostly by aerial 1080 poisoning

1. Modelling impact of historical population control on TB in possums

- 1981-83: 2-3% of possums infected
  - 4-8 possums/ha
  - total population ~500,000? 10-15,000 w TB?
- Pigs and deer heavily infected, but confirmed spill-over only
  - Possums the only true maintenance host
- Intensive lethal control (80-99% reductions) applied to possums from 1994
  - **But total area not covered fully until 2005**
- Last known TB possum in 2005
  - **But TB+ve deer and pigs found in 2013.**

Control History Examples

(estimated reductions* in possum abundance)

VCZ**	2005	2006	2007	2008	2009	2010	2011	2012	2013
AS2	97%						31%		89%
AS3	95%						91%		
AS4	97%						92%		99%
T3B	**97%**						**92%**		
T1	90%					50%		50%	50%
T3A	97*%					36%		58%	

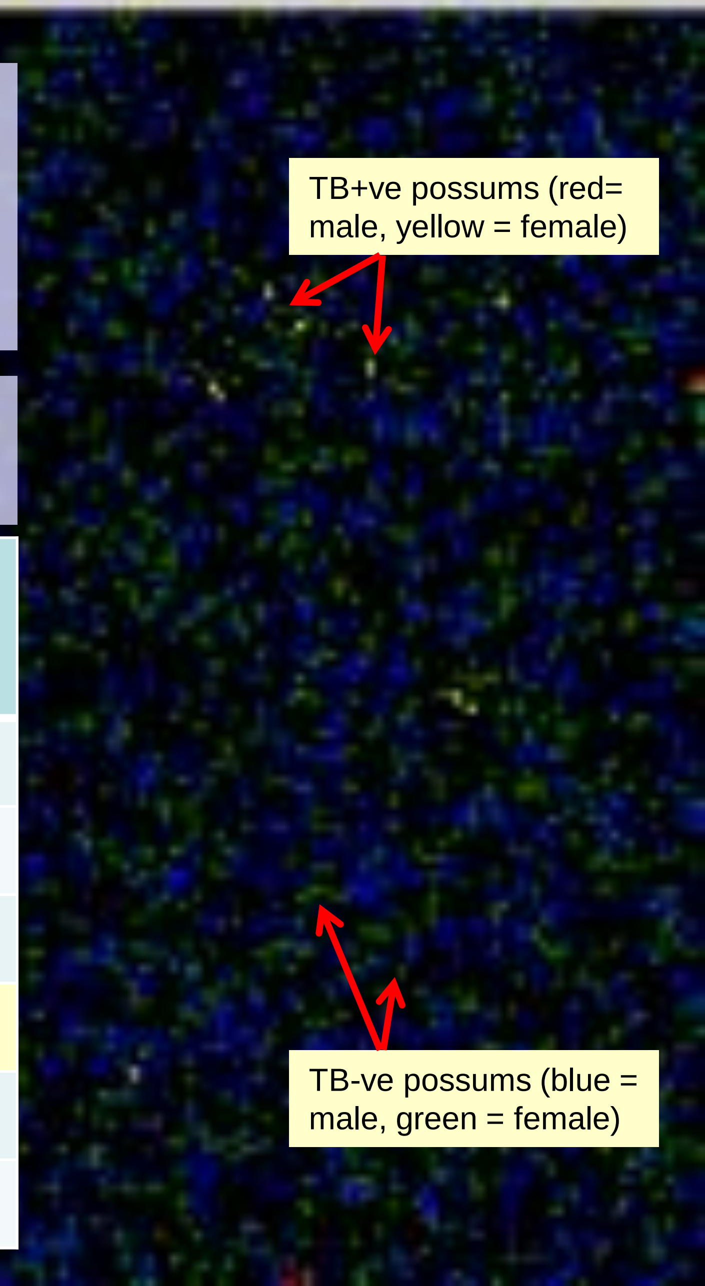
** Reductions = % change in indices of possum abundance before and after lethal control operations (Pre 2005 control not included)*

*** VCZ = Vector Control Zone = operational management unit*

Predicted prior probabilities of TB freedom in possums (PPOF)

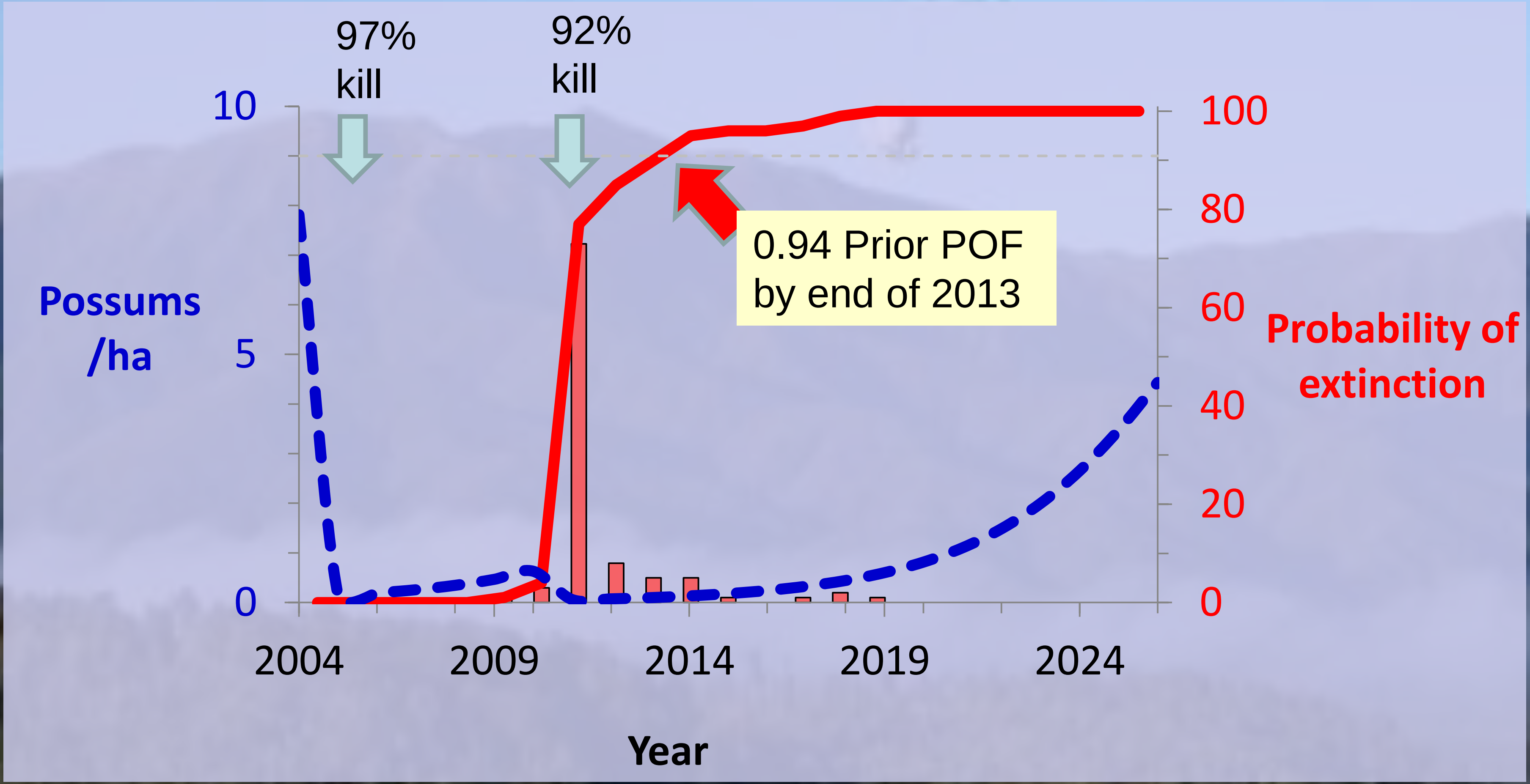
PPOF probabilities predicted by Spatial Possum Model

VCZ	2011	2013
AS2	0.56	0.98
AS3	0.95	0.97
AS4	0.95	1.00
T3B	**0.87**	**0.94**
T1	0.86	0.97
T3A	0.61	0.93



Simulating impact of control on TB persistence

Tihoi 3B (excluding pre 2005)



2. Validation via empirical TB surveillance

Sentinel survey examples

Number (N) and density (N/km^2) pigs and red deer obtained within each VCZ in 2012

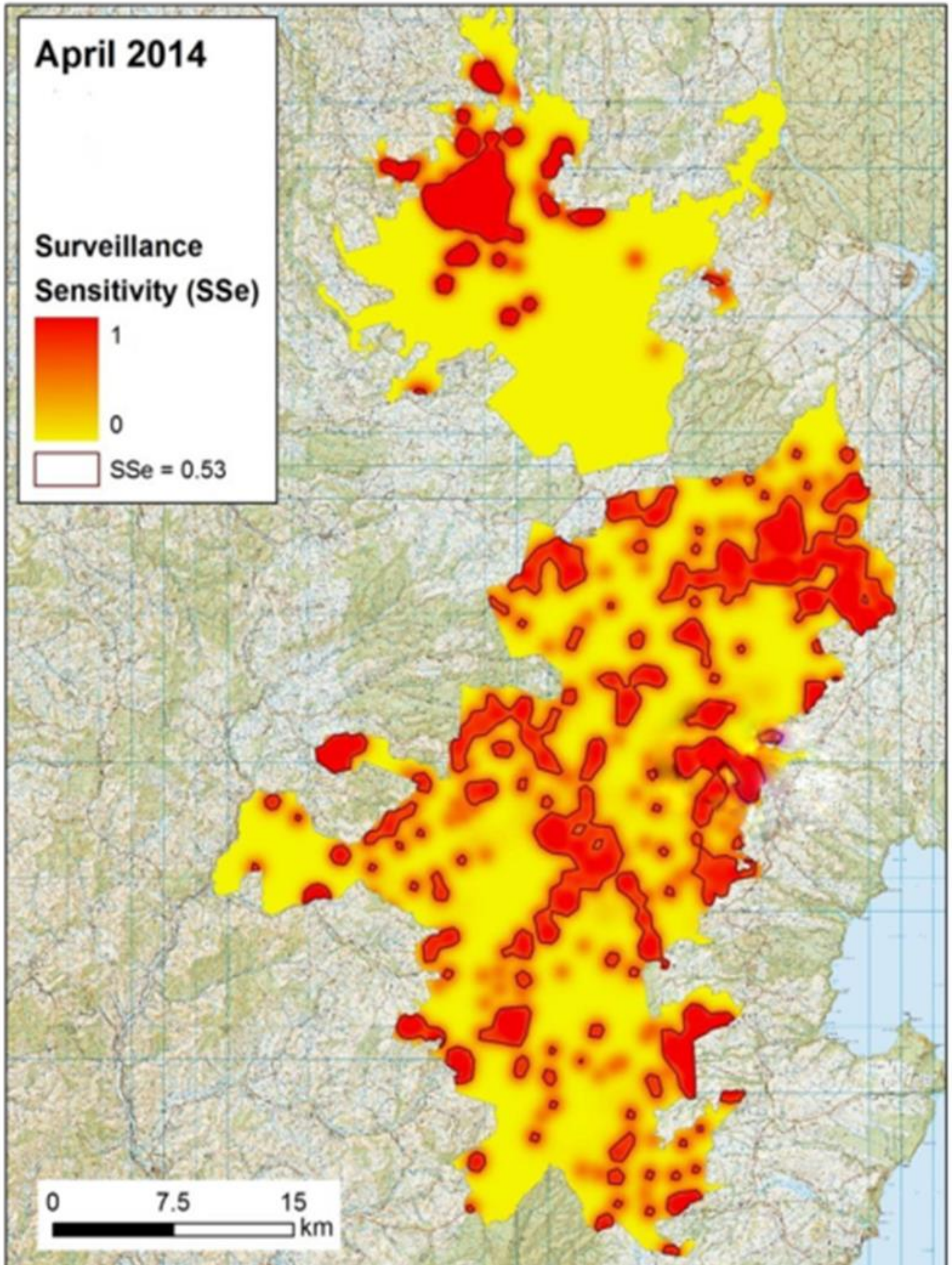
VCZ	Area (km^2)	Pig		Red Deer	
		N	N/km^2	N	N/km^2
AS2	105.3	55	0.52	7	0.07
AS3	29.8	23	0.77	1	0.03
T3B	**138.1**	**61**	**0.44**	**24**	**0.17**
T3A	84.2	3	0.04	4	0.05

3. Quantifying <u>current</u> probabilities of TB freedom

Illustrative example with 2011 start, assuming no TB+ves

VCZ		PPOF by 2011	N Pigs	N Deer	All sentinels
AS2		0.56	55	7	0.642
AS3		0.90	23	1	0.952
AS4		0.90	15		0.909
AS5		0.90	33		0.910
Tihoi 3B		**0.77***	**61**	**24**	**0.799**
Tihoi 3A		0.61	3	4	0.609

**Tihoi 3B*		*PPOF increased to 0.94 after 2011 control*



2013-2014 Sentinel Surveillance efficacy

- Low-intensity sentinel surveys producing worthwhile data at low cost ($1/ha/yr)
- Nominally already sufficient to confirm freedom over ~40% of HRR
- **But only if no TB+ves found**

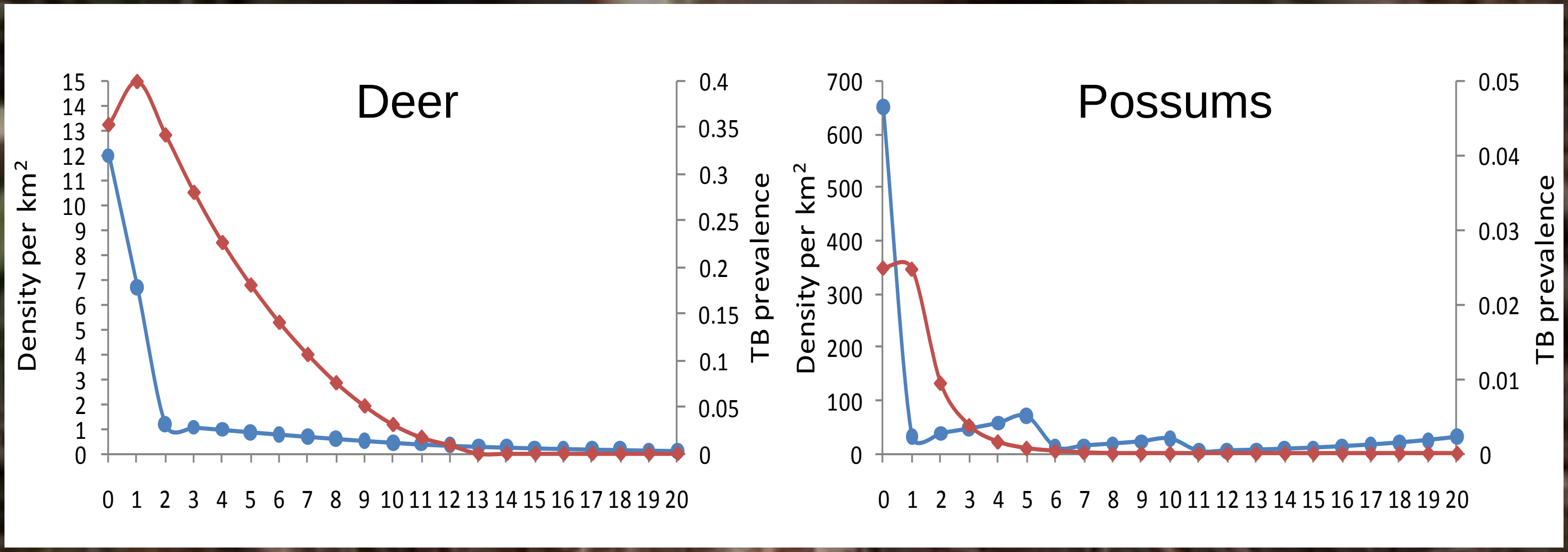
Issue: Continued TB detection in sentinel species

- No TB+ves in July 2012 – June 2013 samples
- But: Spring 2013 TB+ve pig
- Dec 2013 lesioned deer (5 y old)
- Dec 2013 culture +ve deer (1 y old)

Modelling spillback risk

- Rate of spillback not known
- Simulated ‘probable-extreme’ parameters
- TB eradicated from possums within 7 years
- Spillback risk persists for 14 years

=> Possum density must be kept low for 15 years if deer population heavily infected



Consequences II

- Further possum control still needed
  - despite SPM predictions of >90% chance TB will have been eradicated from possums in all VCZs by 2015
  - Such control already long planned – ‘final’ operations in 2015-2018 period.

- **<u>IF</u>** both 2013 TB deer remain confirmed, spill back risk until 2030 in those vicinities? (albeit negligibly small by then)

=> Refined surveillance strategy required?

Hauhungaroa Eradication Feasibility Summary

- Eradication of TB from a large forested area is within reach
- High probability TB already gone from possums (or will be very soon)
- But declaration of freedom may be delayed by ‘ghost hosts’
- Unresolved strategic choice to be made;
  - Either: Wait it out till 2025
  - Or: Declare TB freedom in possums before 2020, but keep possum density too low for re-establishment for at least 5 years after

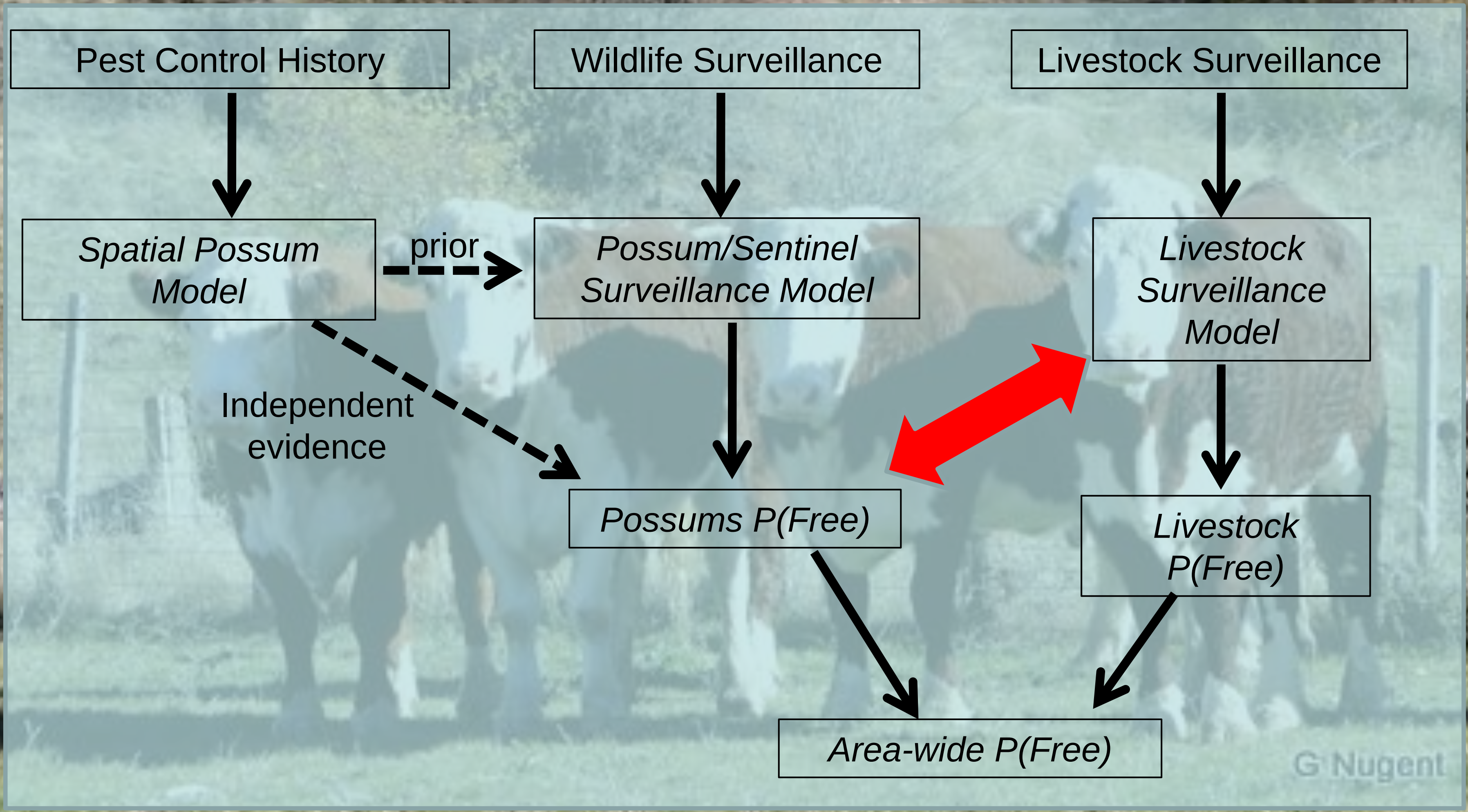
New directions and applications

- Refining/extending POF
- Beyond TB

Current R&D 1:

Inclusion of livestock testing

- For declaration of TB freedom, parallel calculations for livestock – separately at present, but aiming to integrate

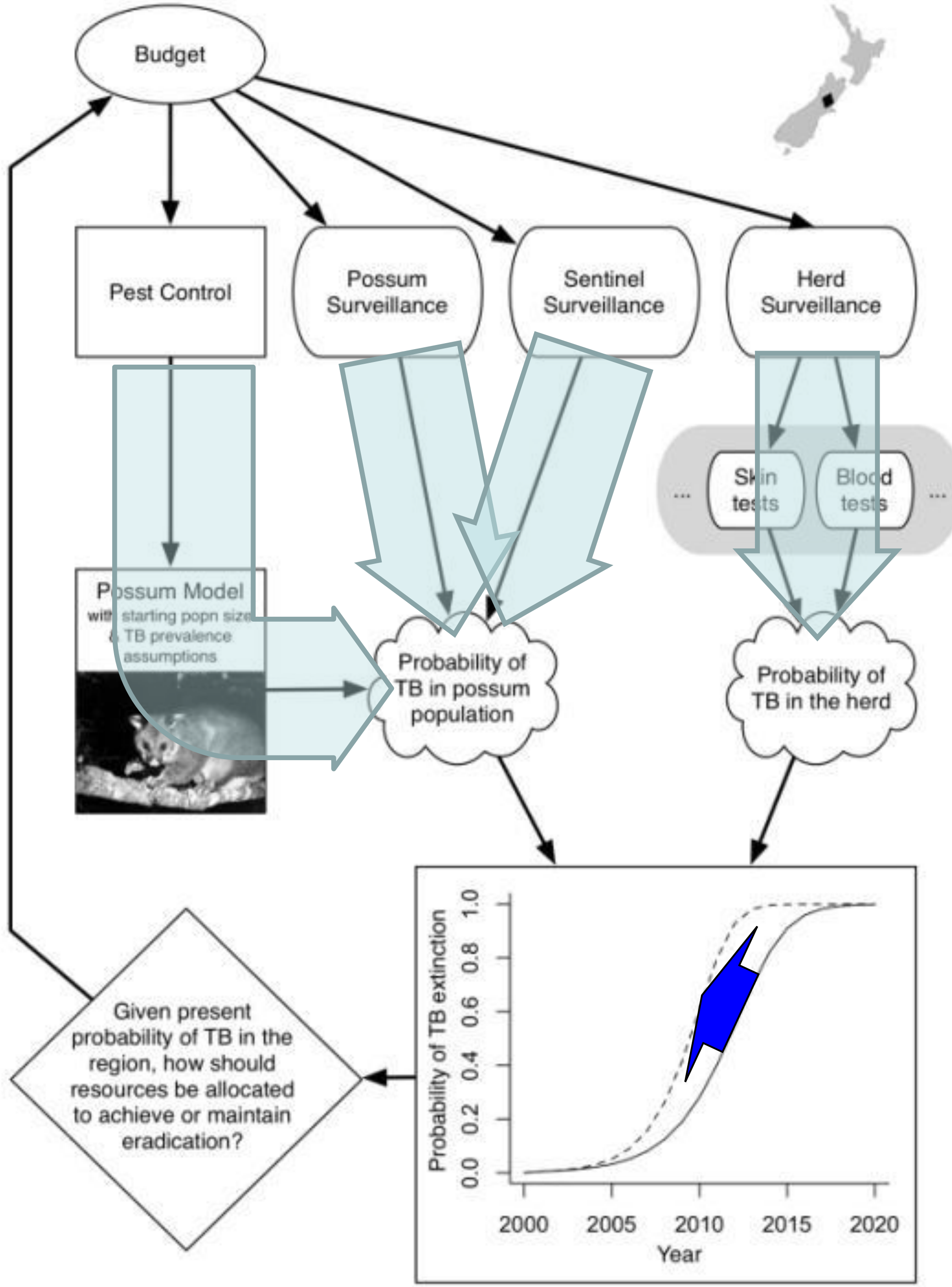


Current R&D 2:

Refining resource allocation

- POF framework uses multiple information sources
  - History of possum control
  - TB survey of possums
  - Tb survey of sentinels
  - Herd testing

Current research Q: Where is funding best spent?

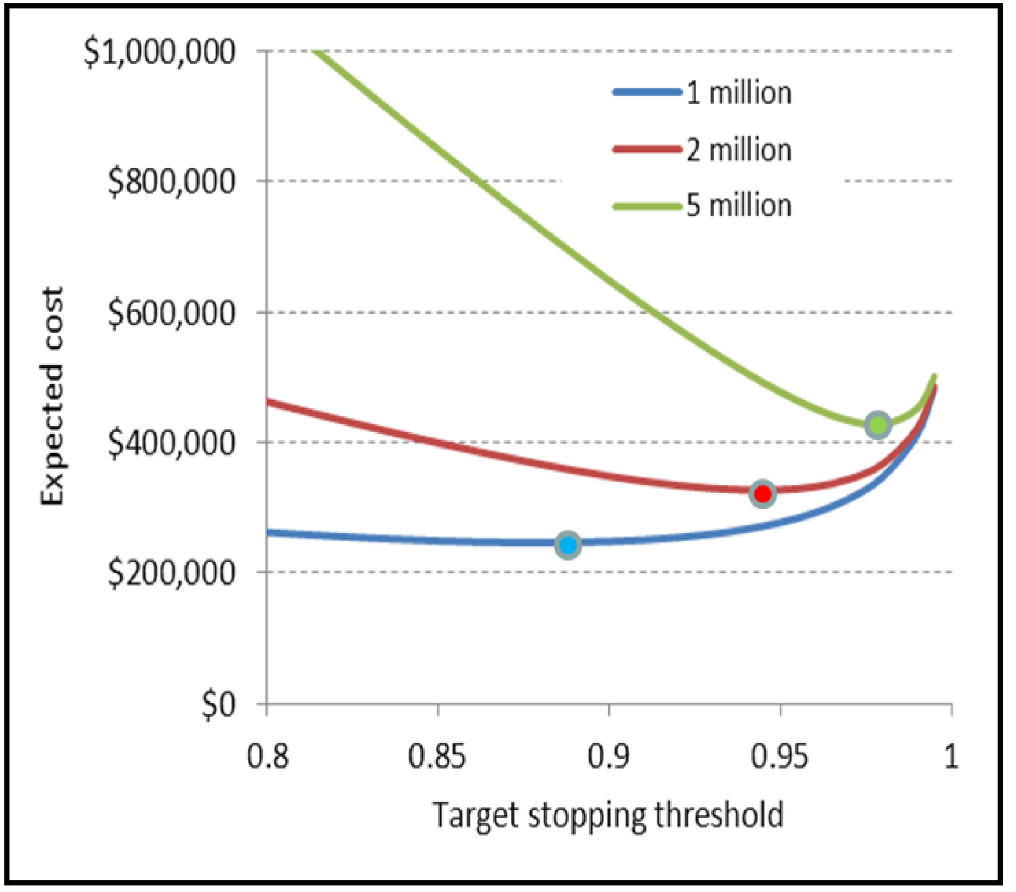


Current R&D 3:

Choosing an optimal stopping rule

- Why do we stop at 0.95?
  - If correct – no consequences
  - If not, expensive re-control required after 5, 10, or 20 years

- Cost of being wrong is key
  - If re-control cost is **high**: Stop **later**
  - **and vv**



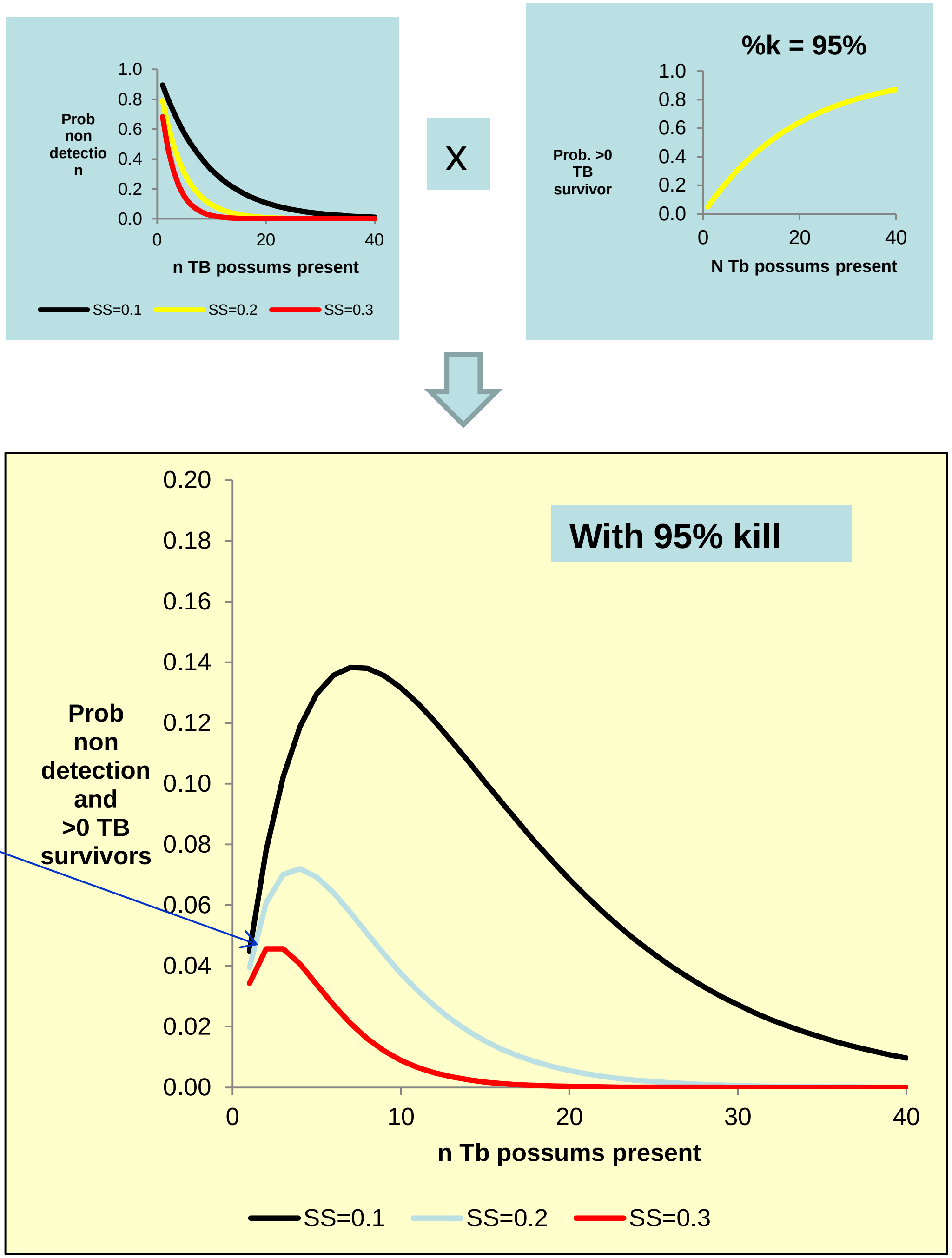
Current R&D 4:

Alternative theoretical approach: Account for removal (by survey then control: StC)

- 4 components envisaged
  i. Prior assessment of Pfree (as currently)
  ii. Survey to be confident that Tb levels are v low
  iii. Apply high intensity control (>95% kill)
     - aim to **eliminate all of the few infected possums present**
  iv. Predict likelihood of TB persistence after control

Survey then control

- Estimate the joint probability that **any possum might have survived undetected**
- With 95% kill, SSe of 0.3 required to achieve worst case 0.05 prob that any possum survived



Removal surveillance

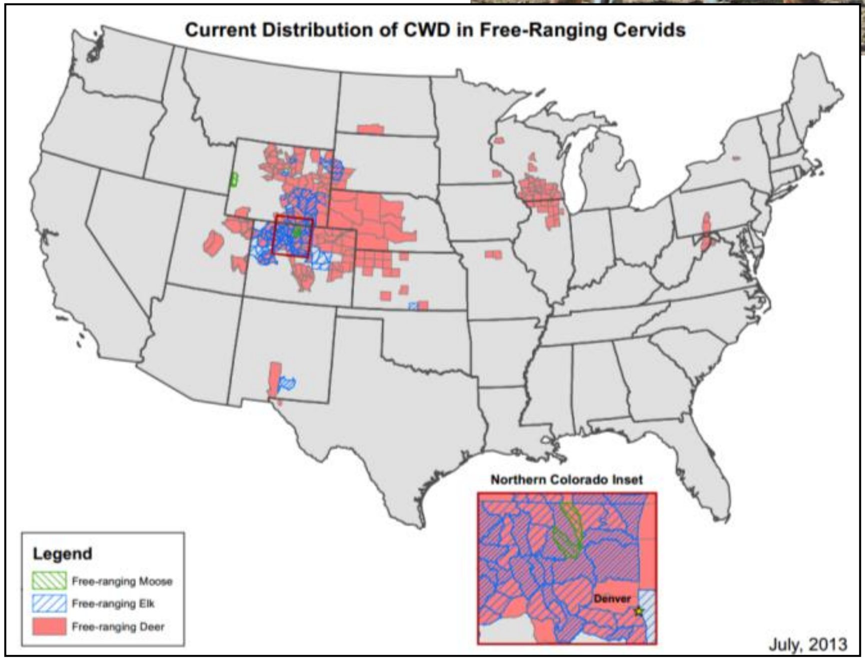
- Enables both surveillance and current control (=removal) outcomes to be included in POF calculations
  - Builds on current POF system
- In principle, could provide a way of fast-tracking Proof of Freedom
  - **Provided the survey phase is –ve**
  - Provided SS and % kill can be estimated accurately
- Being trialled in Hokonui Ranges

Proving Freedom: NZ TB refinements and innovations

- Objective modelling priors, based on control effort/assumed efficacy
- Behaviorally based spatial depiction of surveillance effort (detection kernels)
- Integration of surveillance information from multiple sources
  - Akin to scenario tree modelling for Tb freedom in livestock, but made simple through common denominator (detection kernels)
- Extension to classical ‘surveillance for freedom’ theory accounting for removal

Application to other disease contexts: Confirming continued freedom (wildlife)

- In principle, TB POF could be applied to any other slow-moving wildlife disease
  - Not suited for fast moving diseases such as FMD, bird flu?
  - But appears well suited to CWD in the US where states survey to assess whether or not they are infected



Application to other disease contexts: Confirming continued national or regional TB freedom (livestock)

- Elements wildlife POF could add to existing frameworks for monitoring TB freedom in livestock
- e.g.: could removal surveillance increase sensitivity of TB slaughterhouse surveillance?
    - If so, relevant to TB-monitoring in ‘Tb free’ countries

Epidemiol. Infect. (2013), **141**, 314–323.
doi:10.1017/S0950268812000635

Developing a framework for risk-based surveillance of tuberculosis in cattle: a case study of its application in Scotland

P. R. BESSELL*, R. ORTON, A. O’HARE, D. J. MELLOR, D. LOGUE AND R. R. KAO

Confirming continued national or regional freedom (livestock)

- More broadly, probably relevant wherever the aim is to make inference about the animals remaining in the herd after removal testing
- Applicable to any disease monitoring programme with reliance on slaughterhouse testing

Application to biosecurity contexts

- Potentially useful in assessing success of incursion responses, or pest or weed eradication
  - Underlying Bayesian principles already applied in pig eradication (Santa Cruz, USA) and stoat eradication (Fiordland NZ) and elsewhere
  - Spatial depiction being used in quantifying weeds and pest freedom, Barrow Island (SSe only, not POF)
  - Insect eradications e.g.; Argentine Ants

Conservation Biology

Contributed Paper

Quantifying Eradication Success: the Removal of Feral Pigs from Santa Cruz Island, California

DAVID S. L. RAMSEY,*§ JOHN PARKES,† AND SCOTT A. MORRISON‡

Eradicating stoats (*Mustela erminea*) and red deer (*Cervus elaphus*) off islands in Fiordland

K-A. Edge[1], D. Crouchley[1], P. McMurtrie[1], M.J. Willans[2], and A. Byrom[3]

132 Available on-line at: http://www.newzealandecology.org/nzje/

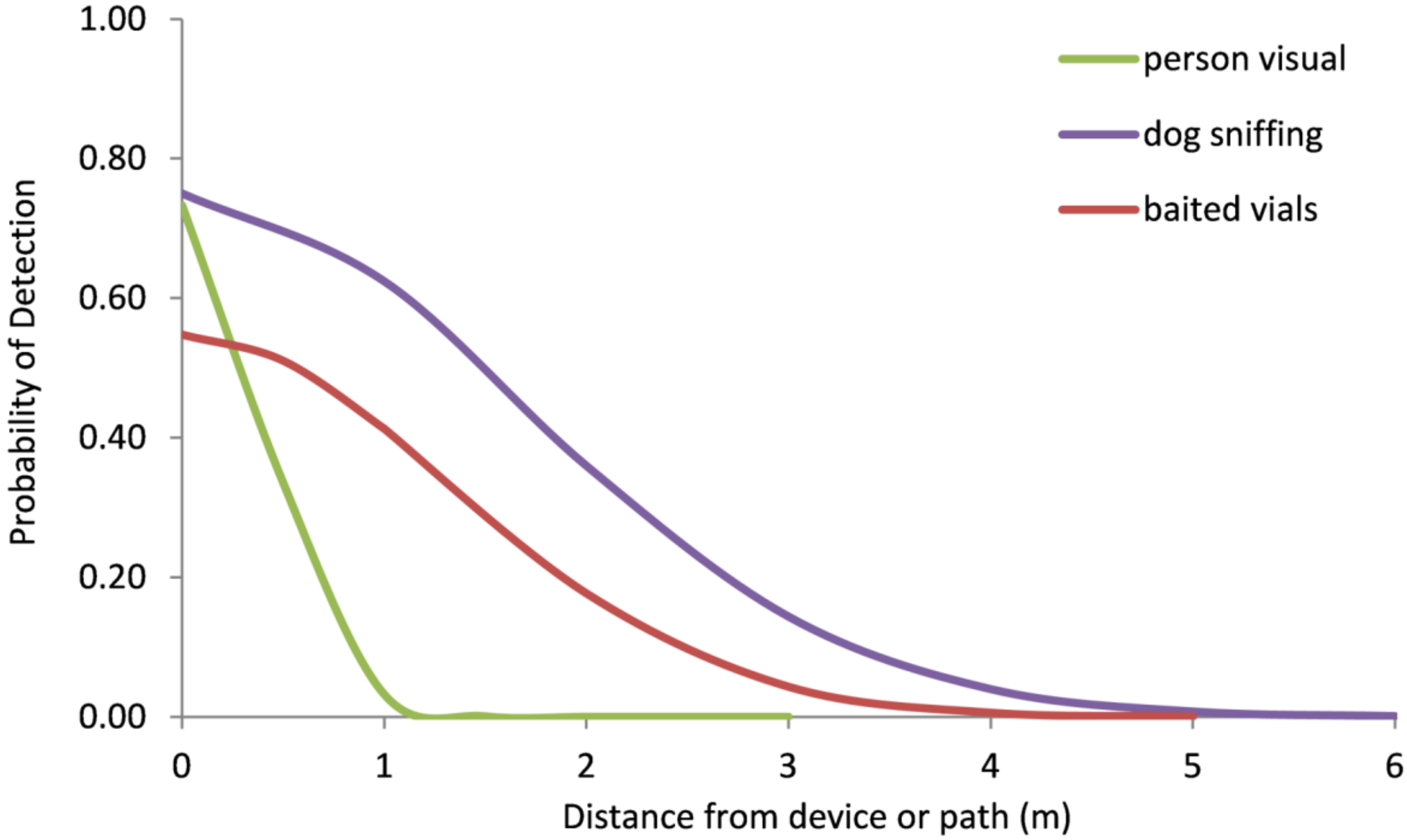
Improved design method for biosecurity surveillance and early detection of non-indigenous rats

Frith C. Jarrad[1,2,*], Susan Barrett[1,2], Justine Murray[1,2], John Parkes[3,4], Richard Stoklosa[5], Kerrie Mengersen[1,2] and Peter Whittle[1,2]

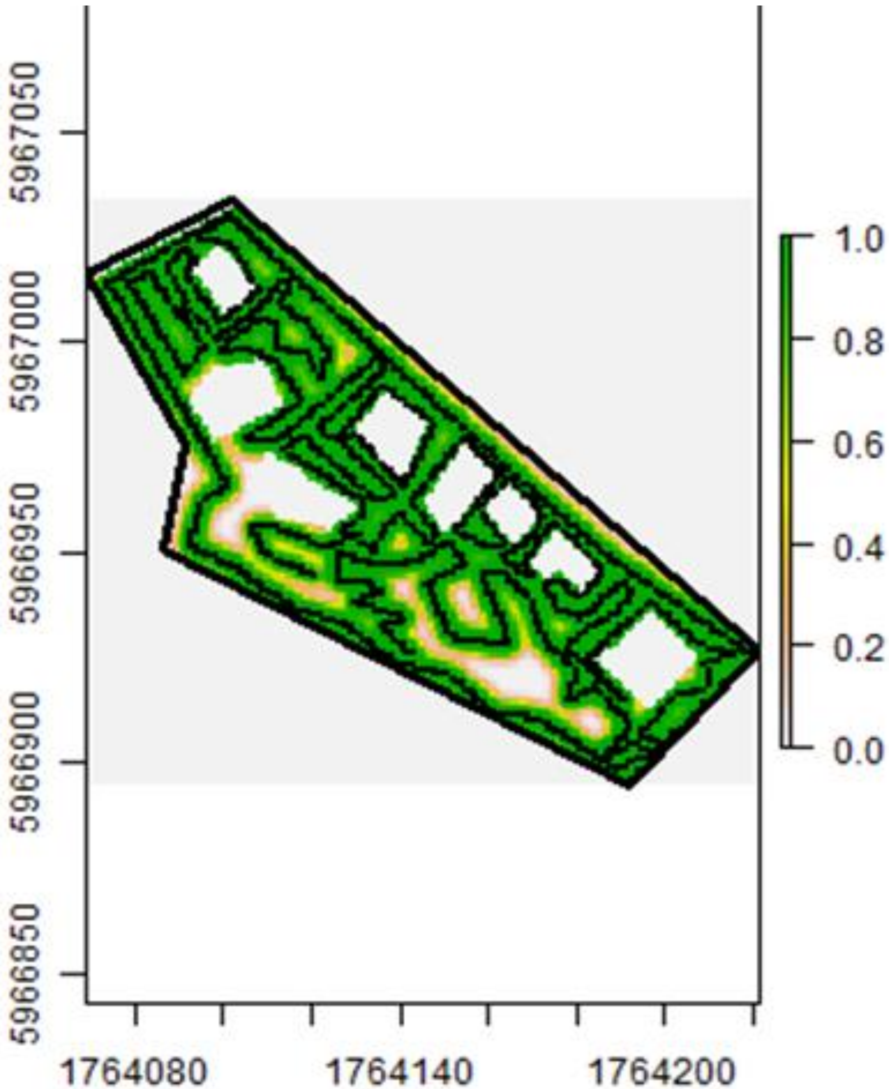
Argentine ant eradication

100 metres

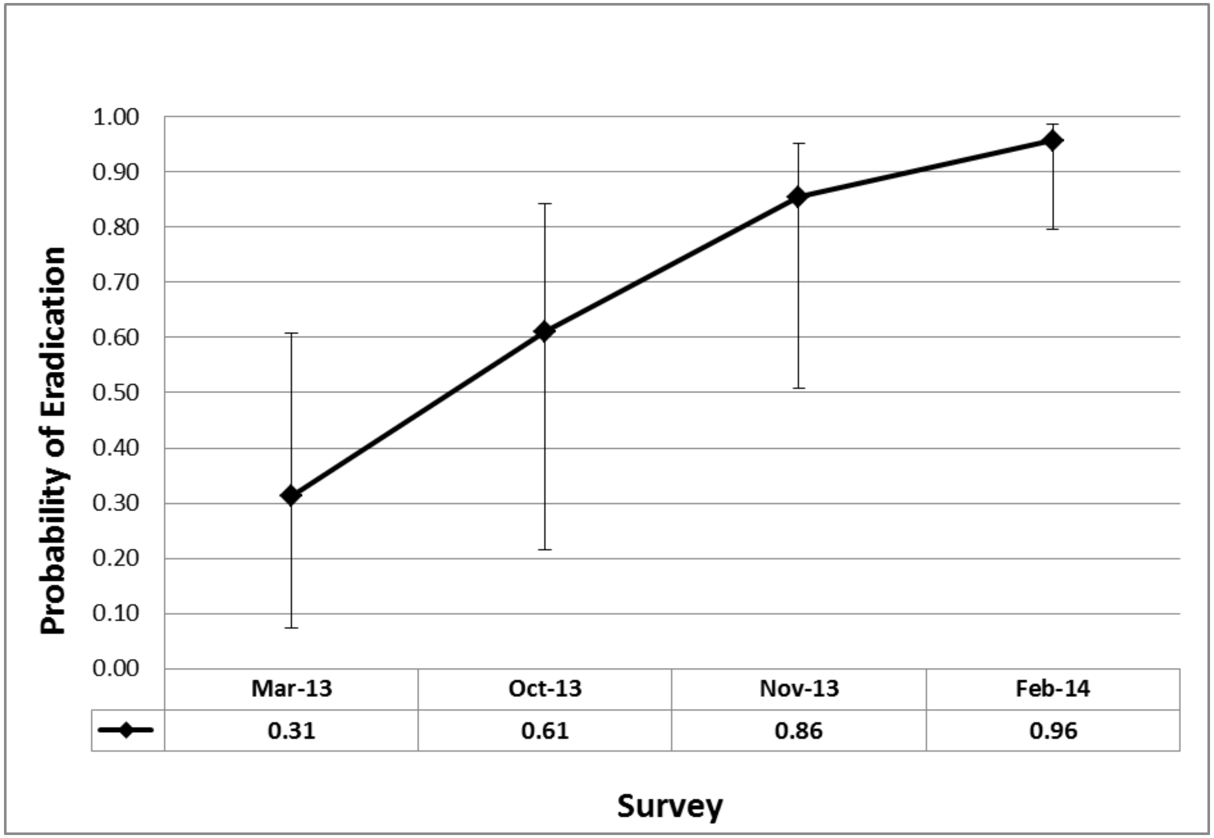
Spatial probability of detection



Spatial sensitivities



Probability of eradication



Endnote

- New Zealand leads the world in managing TB in wildlife
- Globally, first large scale attempt to quantitatively assess wildlife disease freedom with fine-scale multi-source spatial depiction
- A core component of TB POF is inclusion of an objective assessment of management effectiveness into POF calculations – can the same be done for responses to weed and pest incursions?
- Emerging theory around lethal or removal surveillance could have impacts for surveillance theory generally