Resource allocation for efficient environmental management

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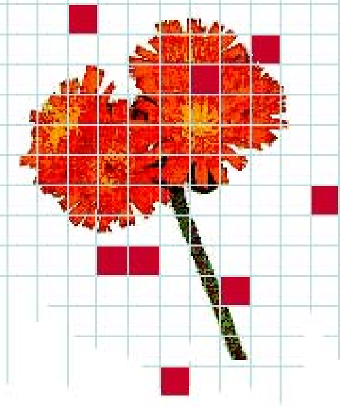
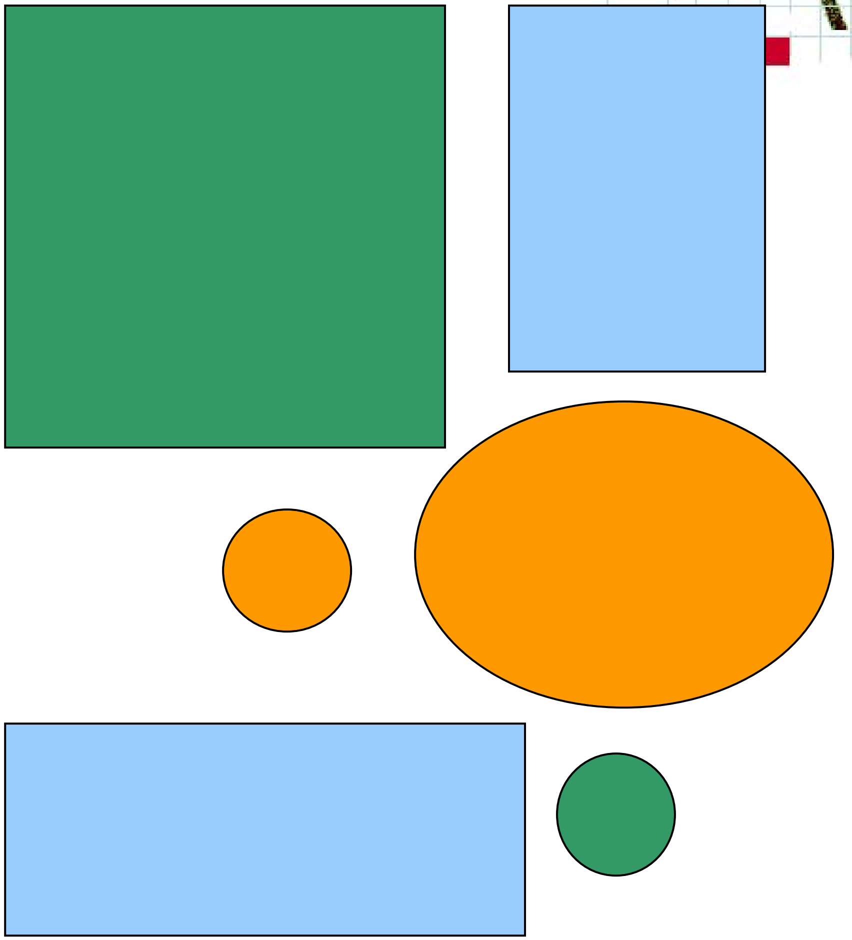
Biosecurity surveillance



- Making the most of surveillance
- Economic framework, room for ecological knowledge
- Explicitly link surveillance effort and accuracy to costs, decisions and outcomes
- Model imperfect detectability
- Surveillance for a pest or disease – where and how hard should we look?

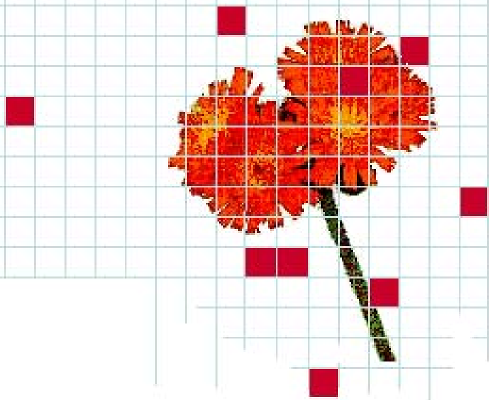
Spatial variation

- We usually have a heterogeneous landscape
- Varying…
    - probability of pest presence
    - ability to detect the pest
    - ability to control the pest
    - value of pest freedom
- *How should we allocate surveillance over space?*



Hauser C.E. & McCarthy M.A. 2009. Streamlining ‘search and destroy’: cost effective surveillance for invasive species management. Ecology Letters *12: 683—692.*

Surveillance impact



Expected costs of undetected pests

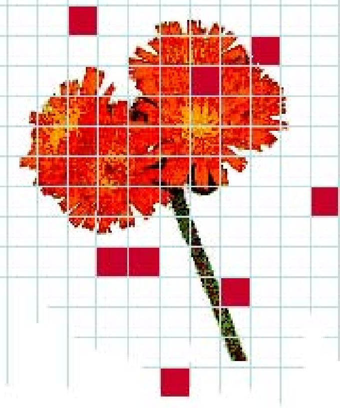
$$L(\mathbf{x}) = \sum_{i=1}^{n} p_i \left[1 - d_i\left(x_i\right)\right] R_i$$

probability that pest is present at location i

probability of failing to detect the pest using effort x_i

consequences of detection failure at location i

Surveillance impact

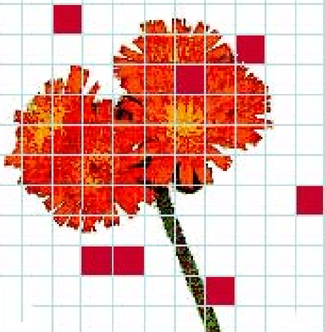


Expected impact of undetected pests

$$L(\mathbf{x}) = \sum_{i=1}^{n} p_i \left[1 - d_i \left(x_i \right) \right] R_i$$

1. **Cost-benefit.** Trade impact of undetected pests against cost of surveillance, $\sum_{i=1}^{n} x_i$
2. **Cost-effectiveness.** Minimise impact of undetected pests subject to surveillance budget $\sum_{i=1}^{n} x_i = B$

The optimal allocation



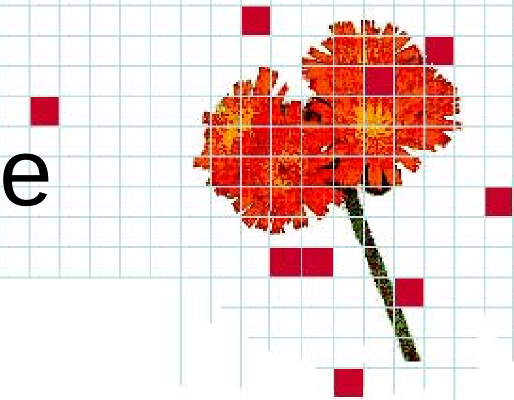
- We can prioritise sites using a score, $p_i \lambda_i R_i$

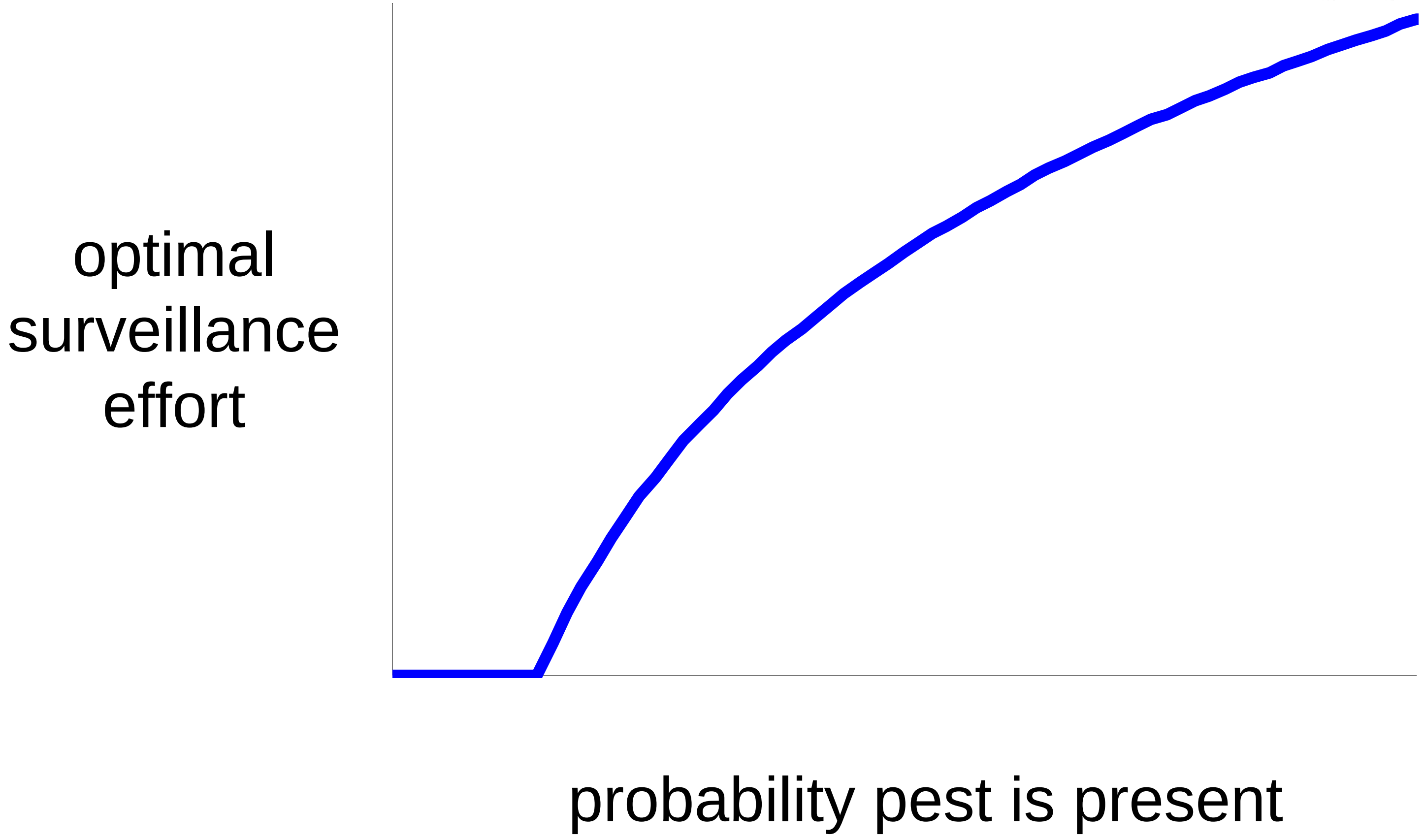
- That is, we target sites where:
  - the pest is most likely to be
  - the surveillance method is most effective
  - successful detection is of most benefit

    (high value of pest freedom, control is cost-effective)

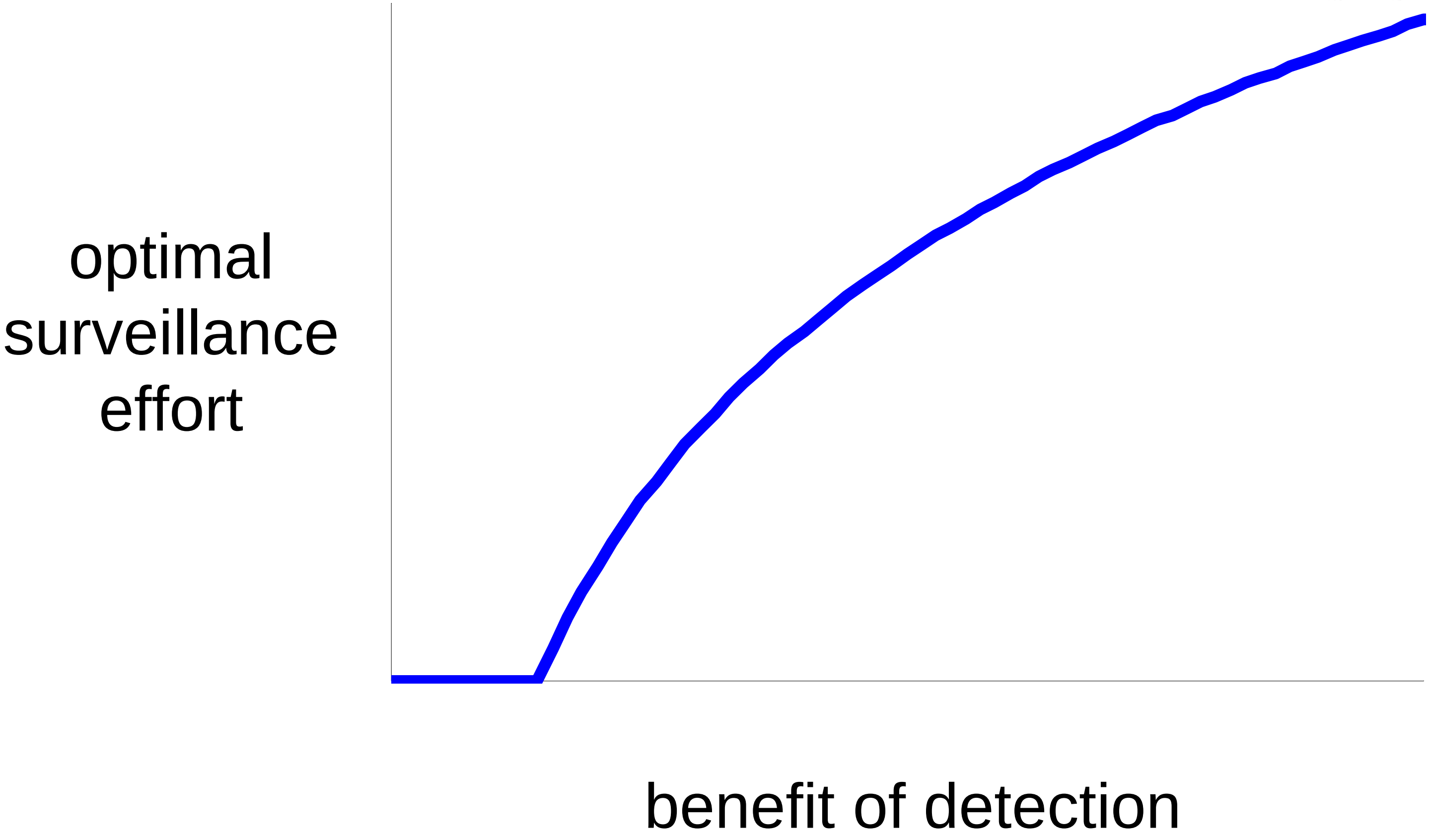
- The solution also tells us *when to stop* searching a site and move down the priority list…

Effect of probability of presence

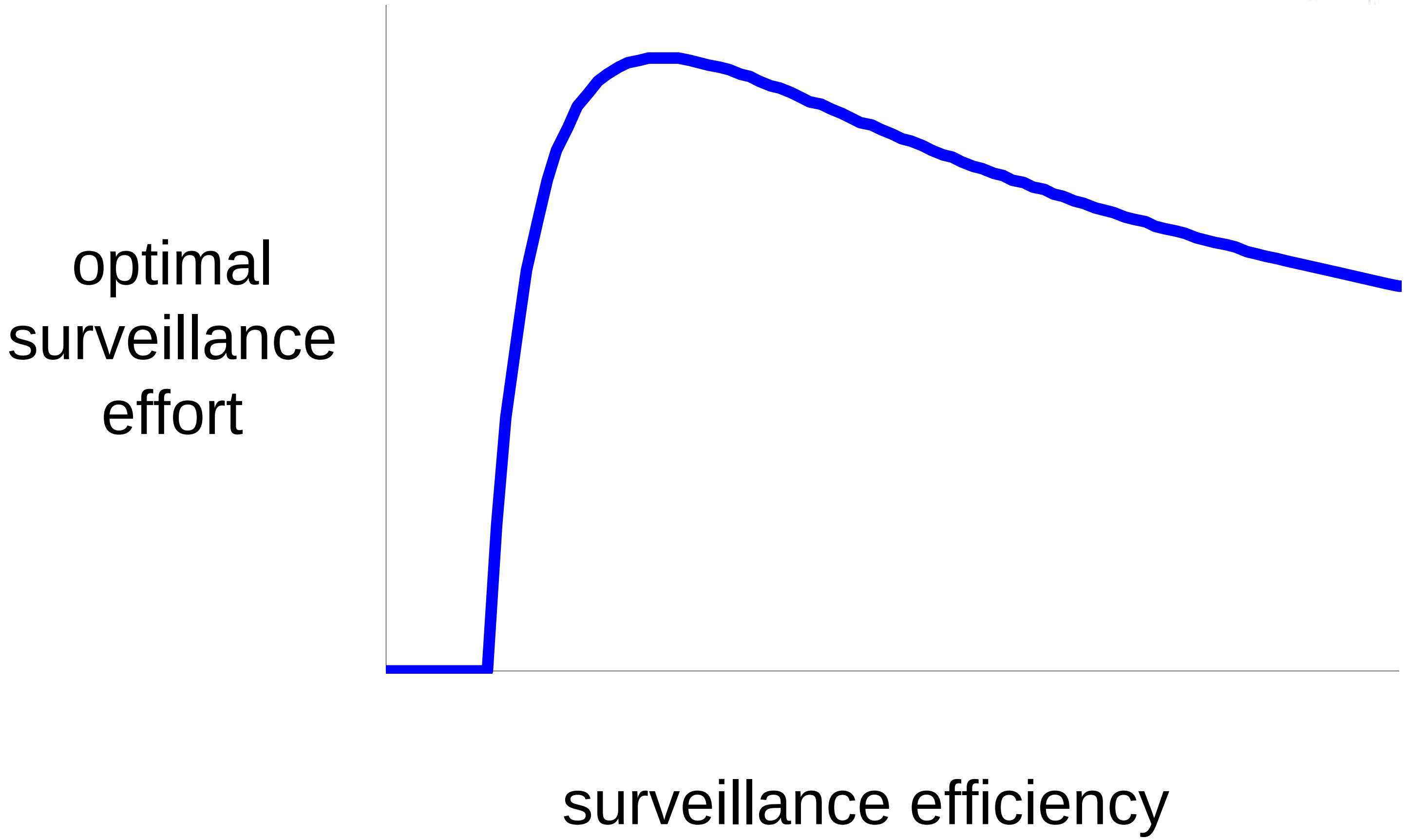




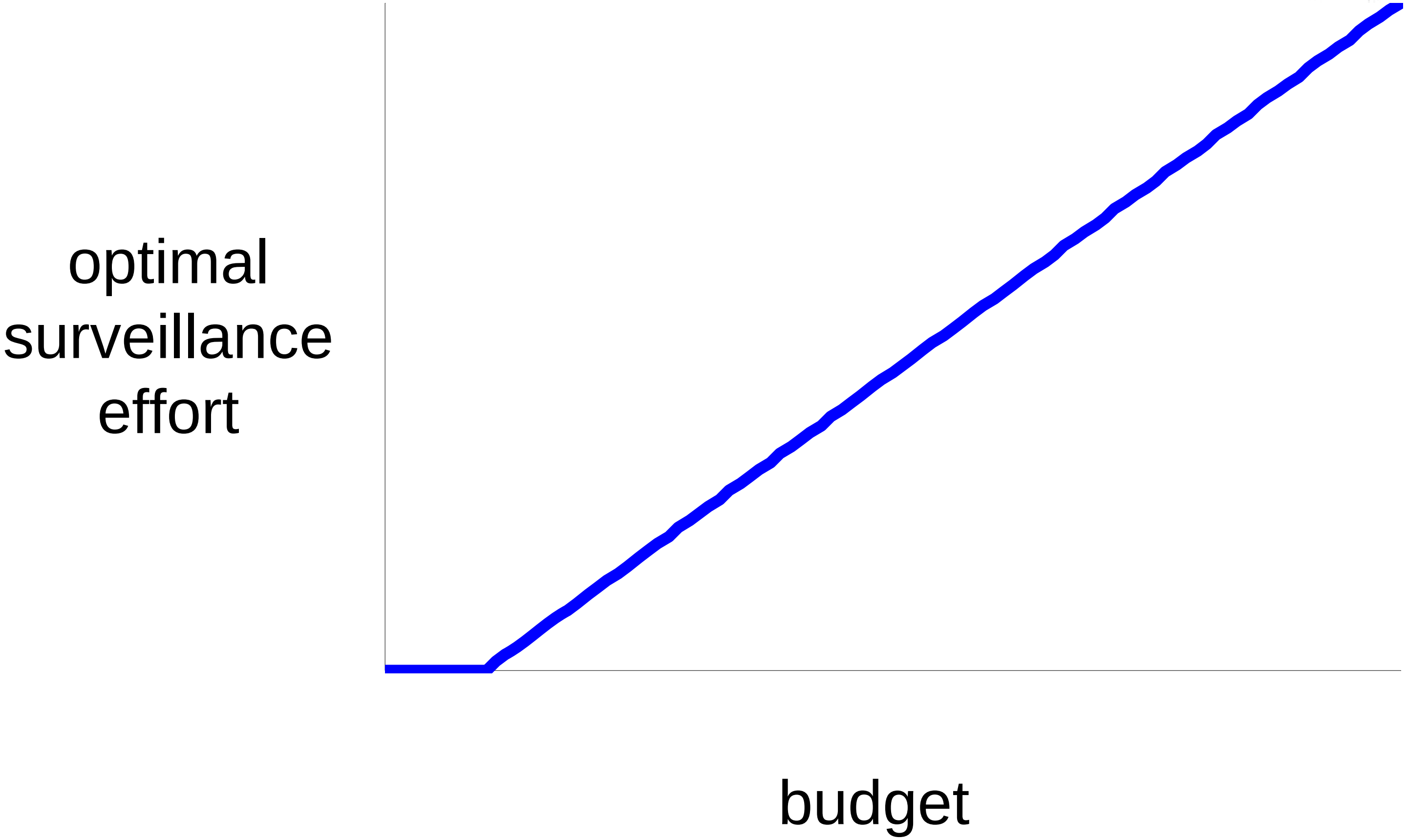
Effect of ‘benefits of detection’



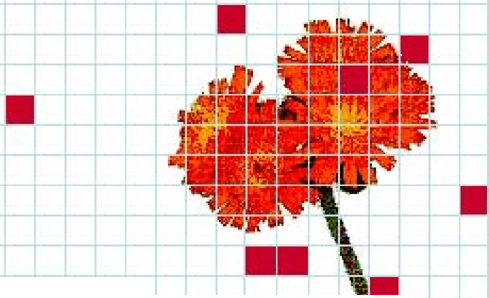
Effect of surveillance efficiency

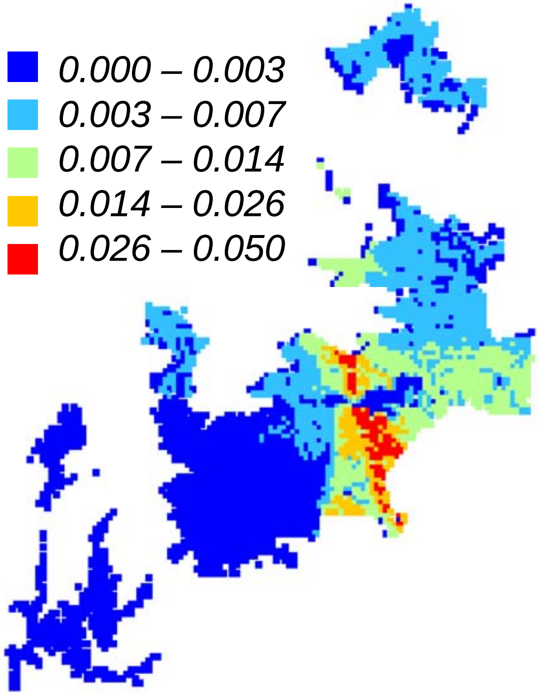


Effect of budget

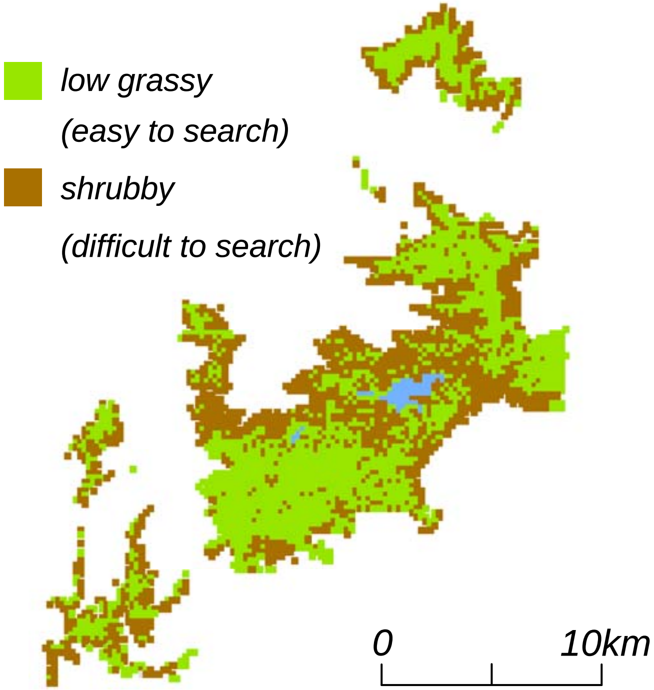


Orange hawkweed on the Bogong High Plains, Victoria

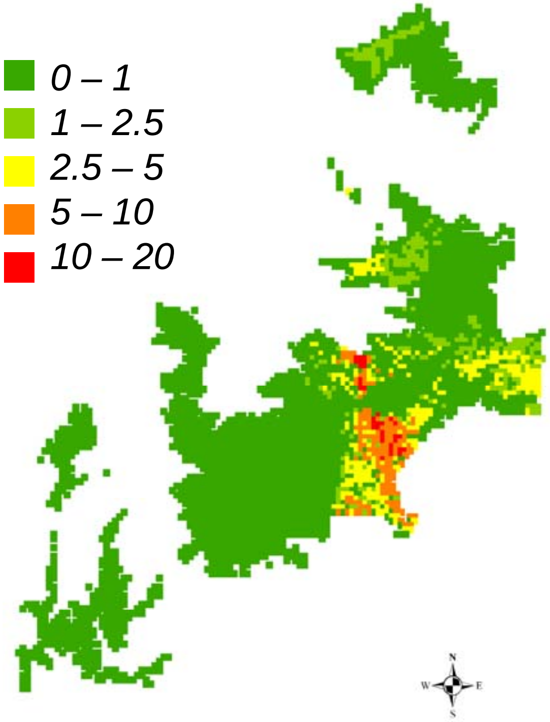




Map 1. *Predicted probability of orange hawkweed occurrence*



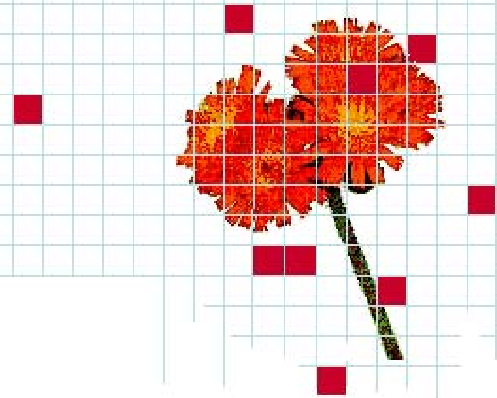
Map 2. *Vegetation categories*

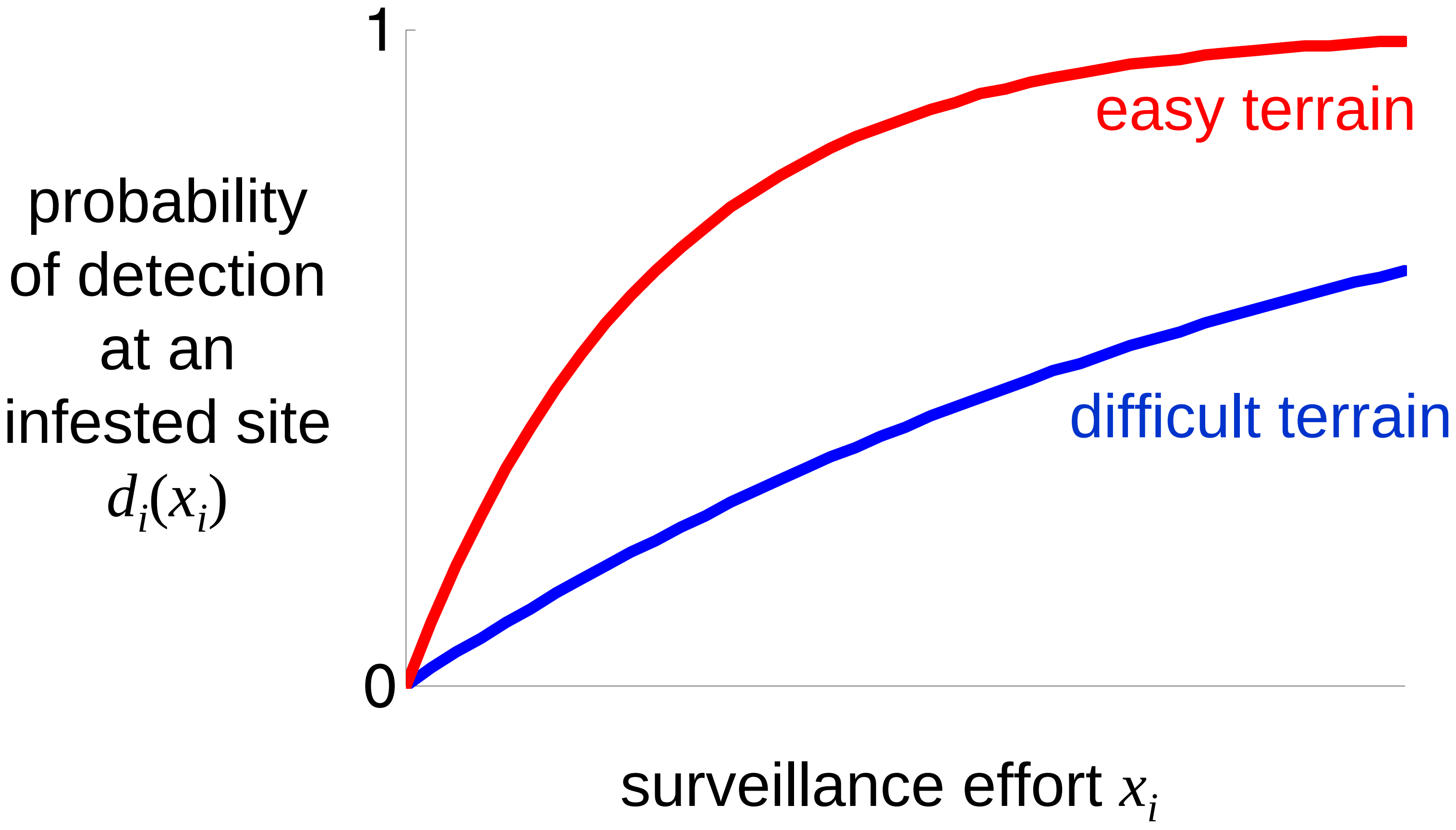


Map 3. *Optimal search time (minutes per 4ha site)*

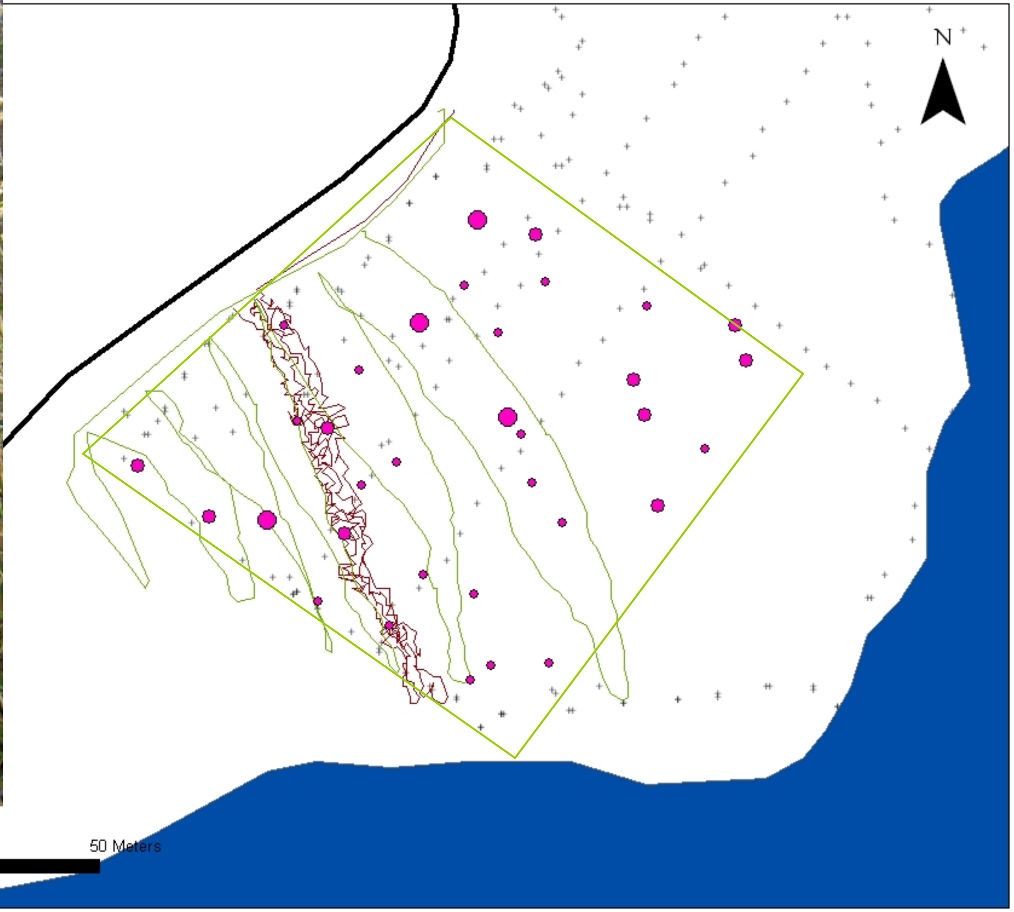
Williams N.S.G., Hahs A.K. & Morgan J.W. 2008. A dispersal-constrained habitat suitability model for predicting invasion of alpine vegetation. Ecological Applications *18:347—359.*

Pest detection



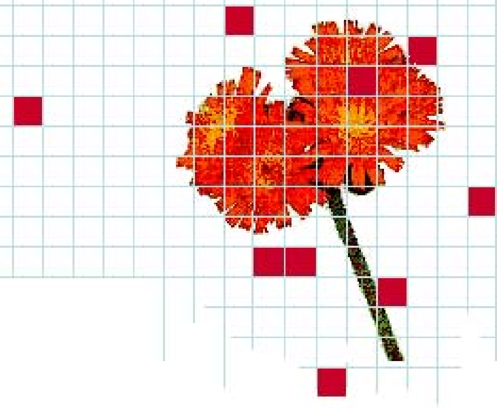


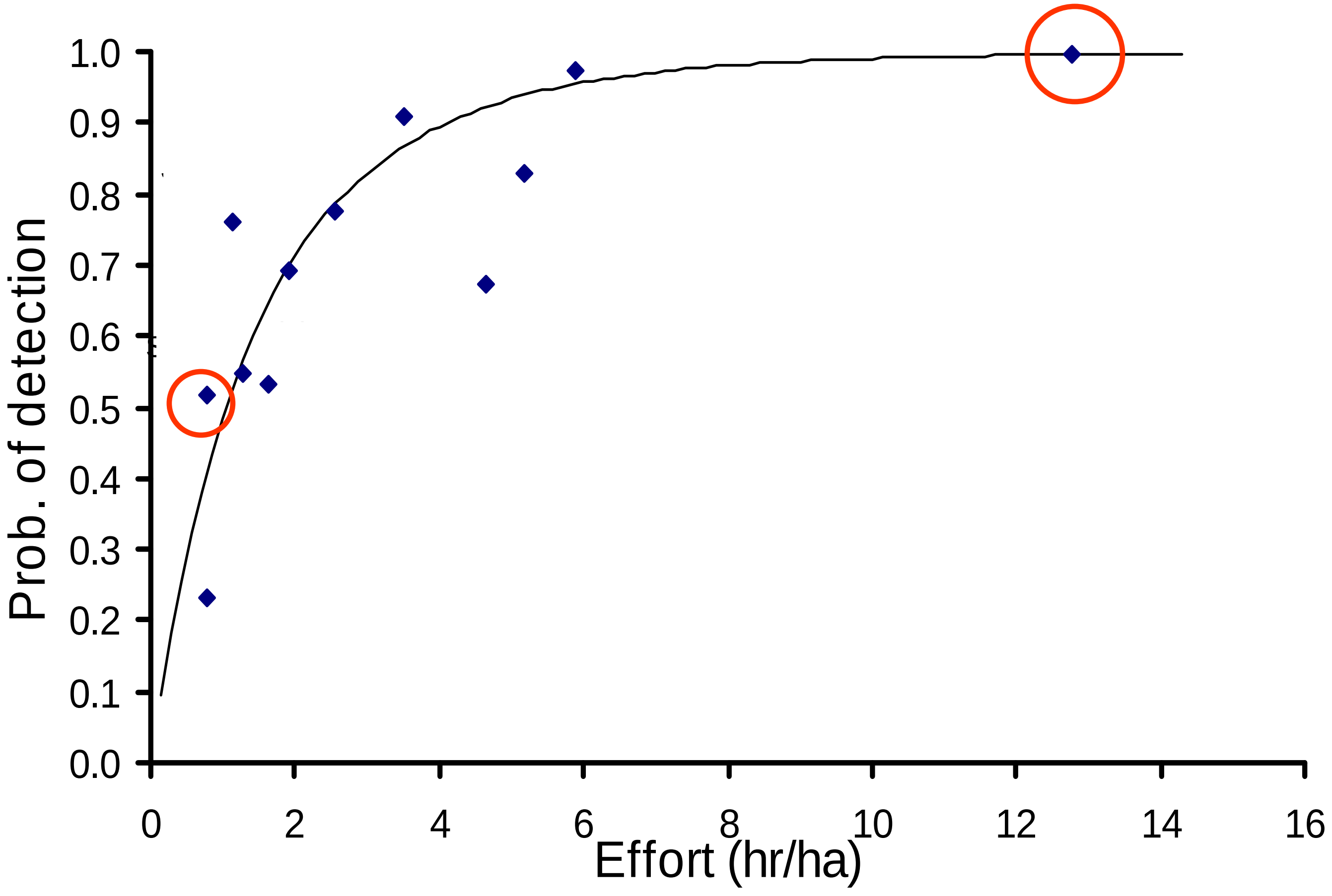
Hawkweed detection

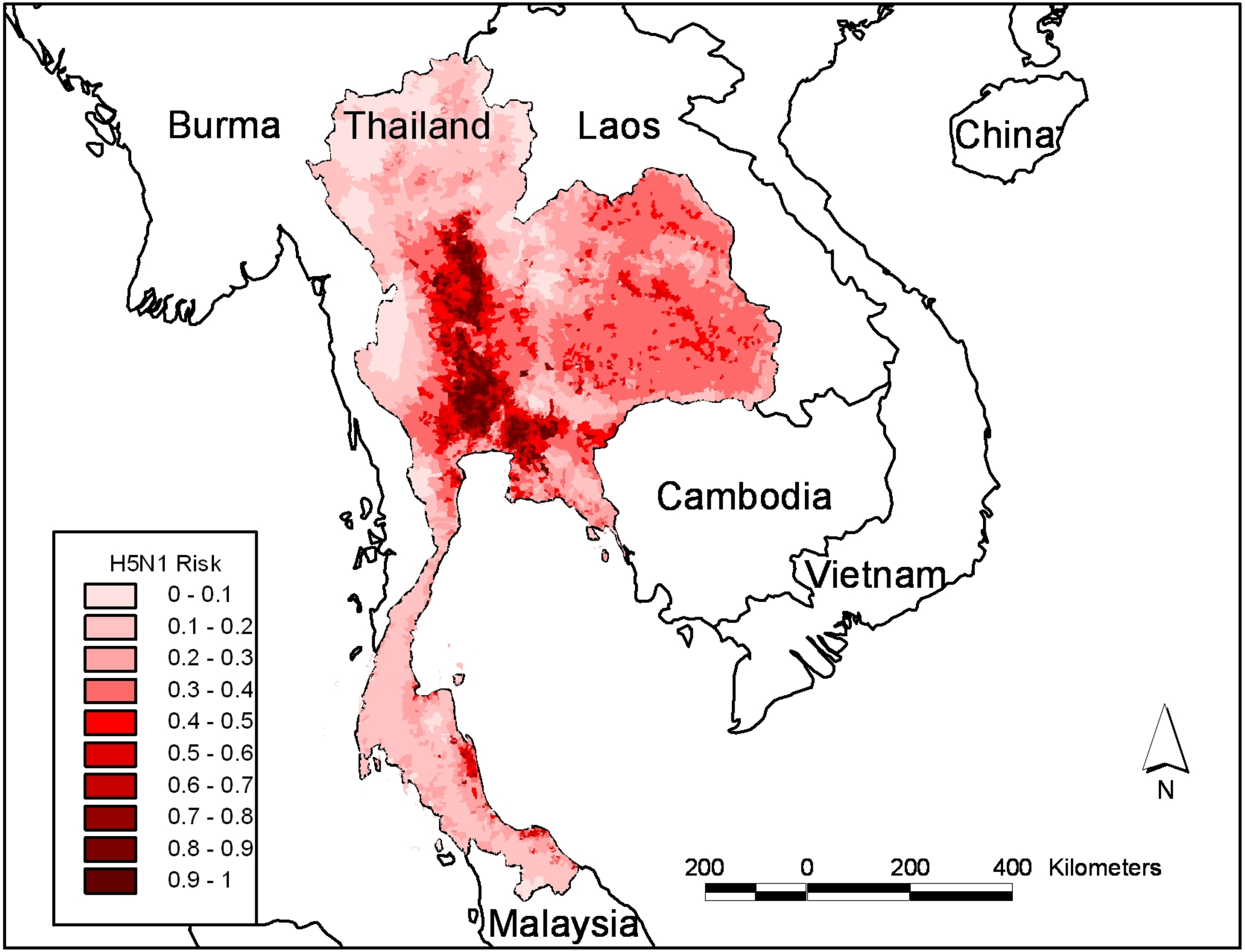


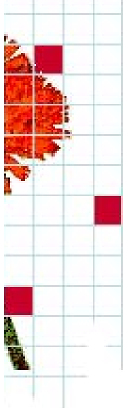
Moore, J., McCarthy, M.A., Hauser, C.E., Bear, J. & Williams, N.S.G. (in prep)

Hawkweed detection

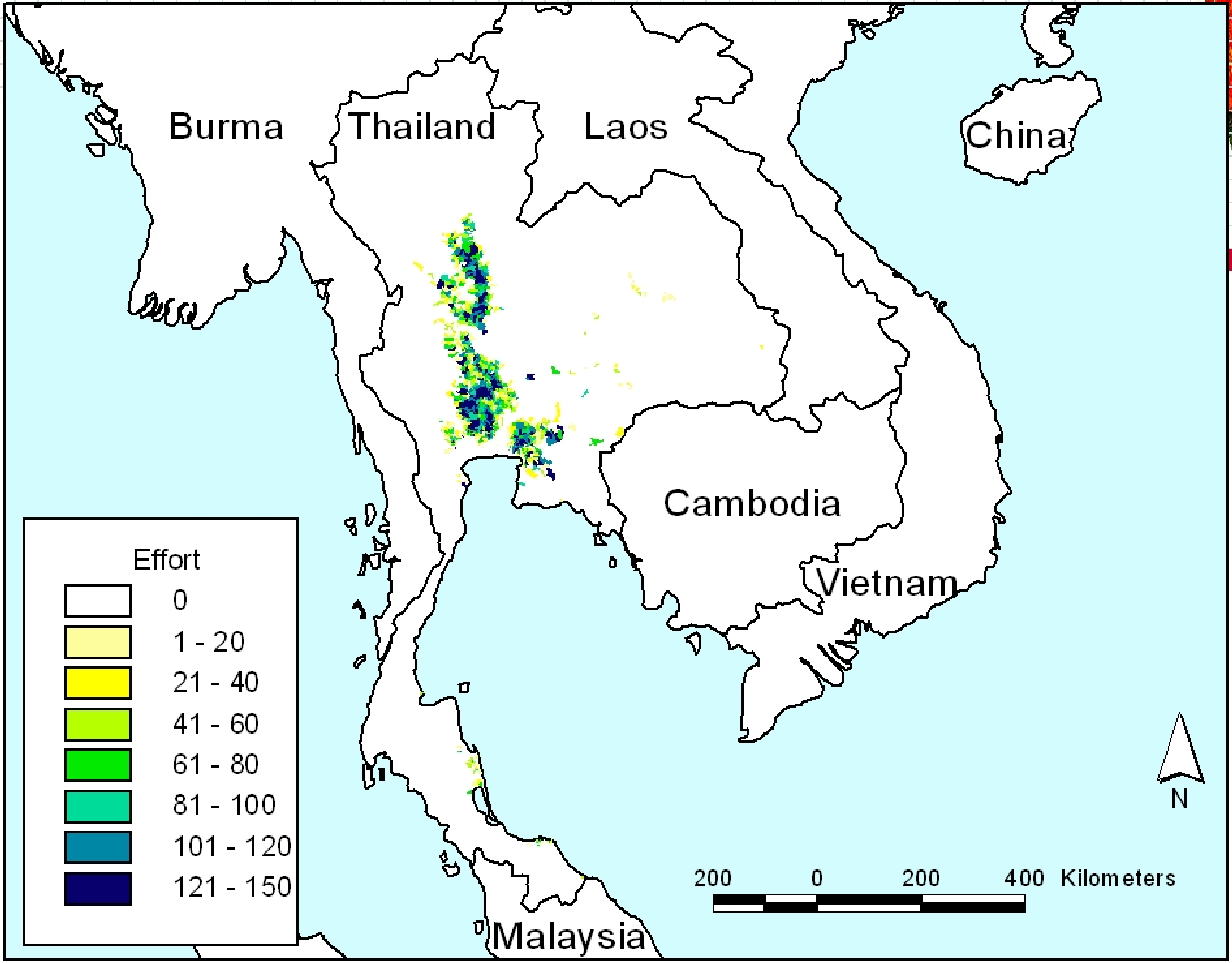




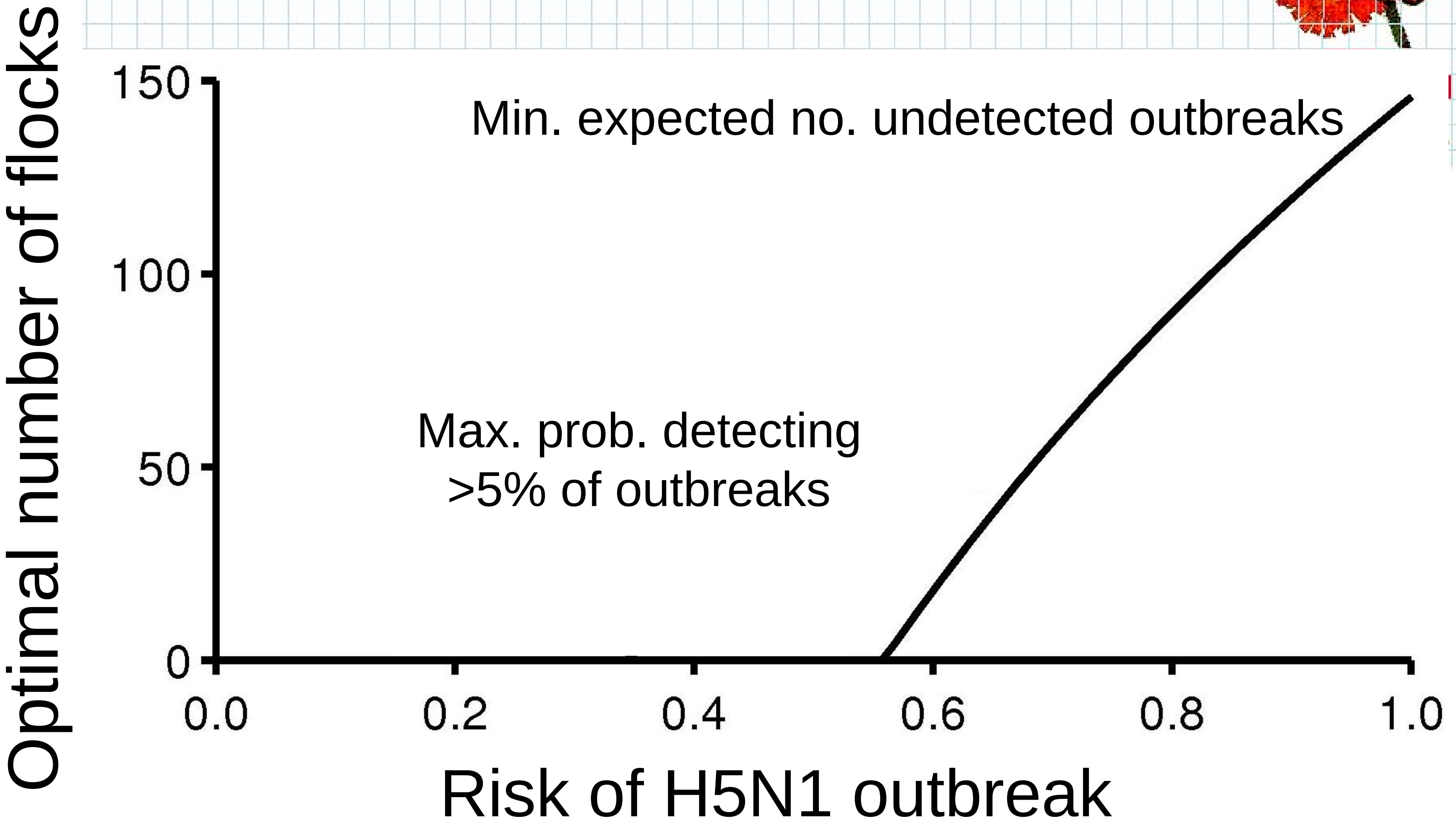




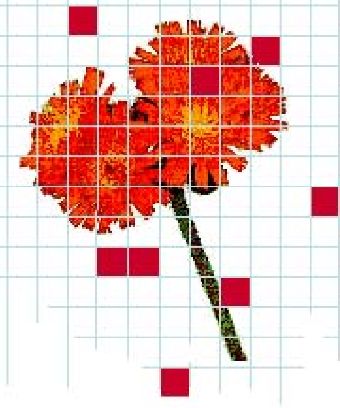
Gilbert et al. (2008) Mapping H5N1 highly pathogenic avian influenza risk in Southeast Asia. Proc. Natl. Acad. Sci. USA *105, 4769-4774*



McCarthy, M.A., Thompson, C.J., Hauser, C.E., Burgman, M.A., Possingham, H.P., Moir, M.L., Tiensin, T., Gilbert, M. (in review)

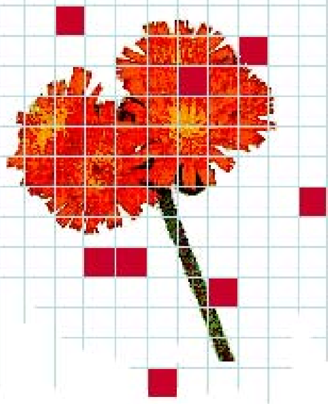

Min. expected no. undetected outbreaks
Max. prob. detecting
>5% of outbreaks
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
Optimal number of flocks
Risk of H5N1 outbreak

Conclusions



- Economic framework accommodating ecological knowledge
- We prioritise options with high impact, high probability of pest presence, high detectability
- Application in portfolio theory, prioritising biodiversity hotspots, choosing amongst survey methods, greenhouse gas mitigation, vegetation management, project prioritisation
- Methods exist for estimating detectability
- Parameter uncertainty leads to diversification of resources

1.Impact/effort trade-off

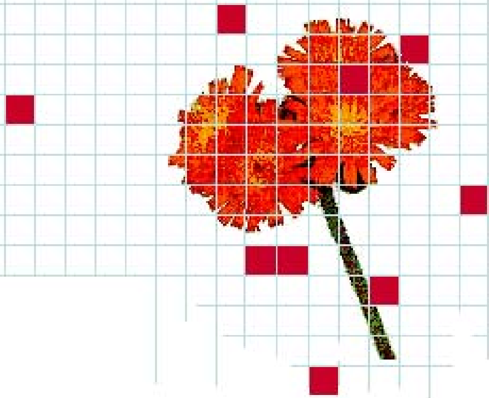


$$x_i^* = \left\{\begin{array}{ll} \dfrac{\ln\left[p_i\lambda_i R_i\right]}{\lambda_i}, & \\ & \\ 0, & \end{array}\right. \boxed{\begin{array}{l} p_iR_i > \dfrac{1}{\lambda_i} \\ \\ p_iR_i \le \dfrac{1}{\lambda_i} \end{array}}$$

p_iR_i is the expected impact of failing to detect the pest at location i

$1/\lambda_i$ is the average cost of detecting the pest if it’s present at location i

2.Planning with a budget



$$x_i^* = \begin{cases} \dfrac{\ln\left[p_i \lambda_i R_i\right]}{\lambda_i} + \dfrac{\bar{\lambda}(k)}{\lambda_i}\left[\dfrac{B}{k} - \bar{x}(k)\right], & i = 1, \ldots, k \\ 0, & i = k+1, \ldots, n \end{cases}$$

where

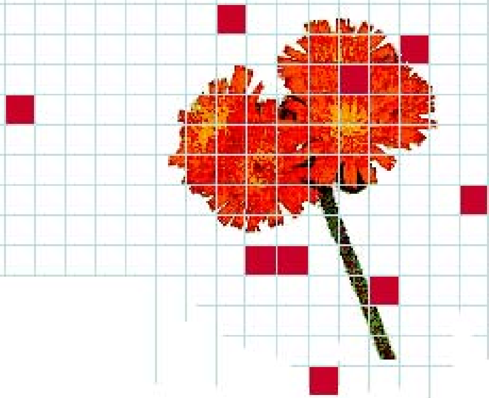
$$\bar{x}(k) = \frac{1}{k}\sum_{i=1}^{k} \frac{\ln\left[p_i \lambda_i R_i\right]}{\lambda_i}$$

mean allocation to each location, without a budget

$$\bar{\lambda}(k) = \frac{k}{\sum_{i=1}^{k} \lambda_i^{-1}}$$

mean surveillance efficacy across landscape

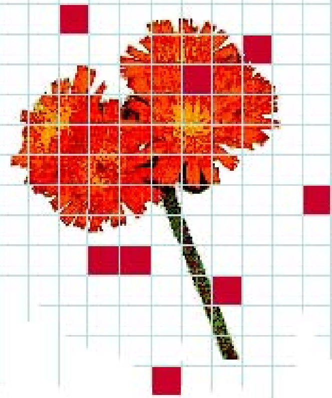
Optimal surveillance with a budget



$$x_i^* = \begin{cases} \boxed{\dfrac{\ln\left[p_i \lambda_i R_i\right]}{\lambda_i}} + \dfrac{\overline{\lambda}(k)}{\lambda_i}\left[\dfrac{B}{k} - \overline{x}(k)\right], & i = 1, \ldots, k \\ 0, & i = k+1, \ldots, n \end{cases}$$

what we’d spend
if we didn’t have
a budget

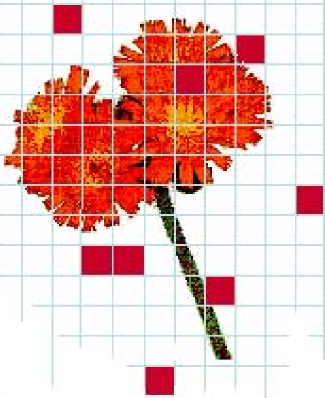
Optimal surveillance with a budget



$$x_i^* = \begin{cases} \dfrac{\ln\left[p_i \lambda_i R_i\right]}{\lambda_i} + \dfrac{\overline{\lambda}(k)}{\lambda_i}\boxed{\left[\dfrac{B}{k} - \overline{x}(k)\right]}, & i = 1,\ldots,k \\ 0, & i = k+1,\ldots,n \end{cases}$$

difference between what we want to spend and what we have to spend on each site

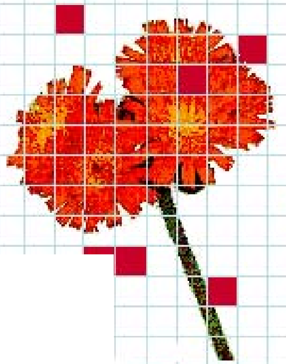
Optimal surveillance with a budget

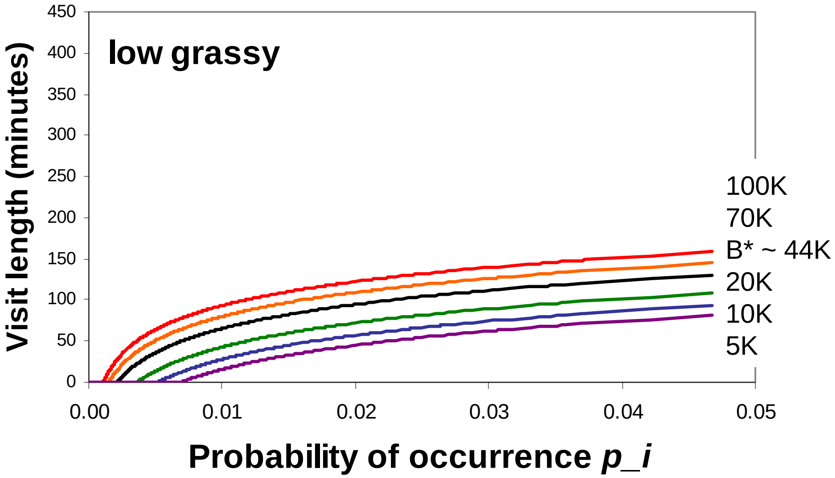


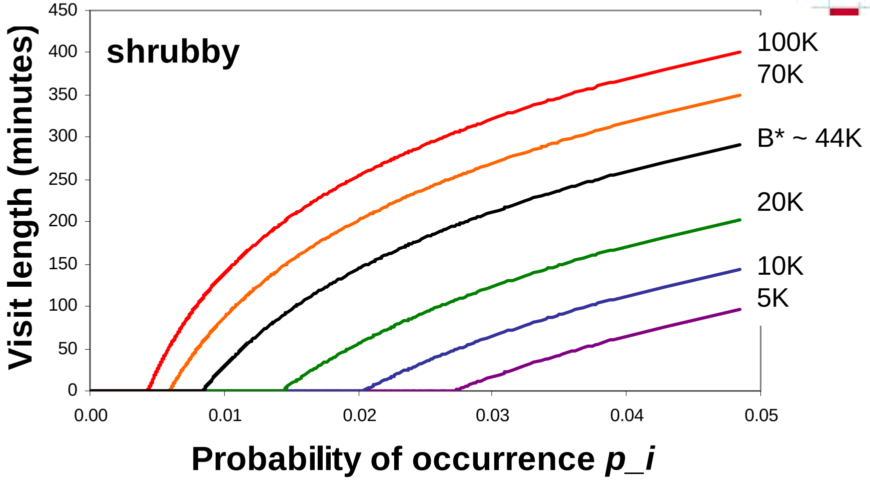
$$x_i^* = \begin{cases} \dfrac{\ln\left[p_i\left(c_i^U - c_i^D\right)\lambda_i\right]}{\lambda_i} + \boxed{\dfrac{\bar{\lambda}(k)}{\lambda_i}}\left[\dfrac{B}{k} - \bar{x}(k)\right], & i = 1, \dots, k \\ 0, & i = k+1, \dots, n \end{cases}$$

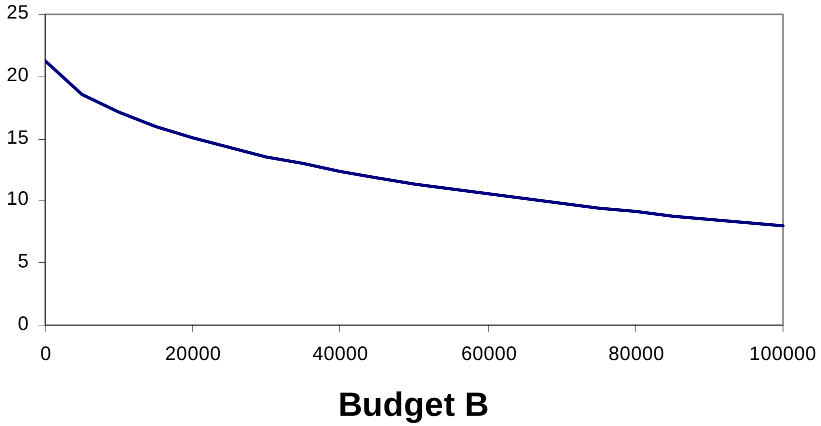
adapt to take surveillance efficacy at this site into account

Orange hawkweed example









Expected number of sites with undetected hawkweed